Organizational Performance Evaluation of Coal-Fired Power Enterprises Using a Hybrid Model

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Abstract: Carbon peaking and carbon neutrality goals have proposed by many countries, including China. Meanwhile, China has also proposed the construction of a new-type electric power system with new energy as the main body, which will have great impacts on coal-fired power generation enterprises. The transformation of coal-fired power enterprises is imperative, and the evaluation of the organizational performance of coal-fired power enterprises is urgent, which can accurately determine the development status and even can find issues related to the transformation of coal-fired power enterprises. In this paper, a hybrid evaluation model is proposed based on the Variational Auto-Encoder algorithm and fuzzy comprehensive evaluation method improved by a vague set to comprehensively evaluate the organizational performance of coal-fired power enterprises. Eight coal-fired power enterprises in North China are selected for empirical analysis. The results show that the YC coal-fired power enterprise has the best organizational performance, while the NK coal-fired power enterprise has the worst organizational performance. Moreover, sensitivity and comparative analyses are carried out to verify the robustness of the evaluation result using the proposed hybrid method in this paper. This paper focuses on the organizational performance evaluation of coal-fired power enterprises, which can provide a reference for the smooth transformation and sustainable development of coal-fired power enterprises in the context of “Dual-Carbon” goals.

Keywords: coal-fired power enterprises; organization performance evaluation; variational autoencoder algorithm; vague set

1. Introduction

In response to climate change, resource depletion and environmental degradation, energy reform has become a common mission of the whole world. More than 130 countries and regions have put forward “Zero Carbon” or carbon neutral goals, and energy giants such as BP have also issued corporate carbon neutral roadmaps [1]. In September 2020, the Chinese president delivered an important speech at the UN General Assembly that China will take strong measures and set “Dual Carbon” goals: carbon dioxide emissions will strive to peak by 2030 and achieve carbon neutrality by 2060 [2]. “Dual Carbon” goals will bring an extensive and profound economic and social systematic change. Recently, the Chinese government have proposed the construction of a new-type electric power system with new energy as the main body. The growth and competitiveness of wind power and photovoltaic power generation will be significantly enhanced, and the development of coal-fired power enterprises is facing great challenges. Affected by the constraints of carbon emission quotas, the proportion of thermal power generation will continue to decline. The dominant position of thermal power generation will be gradually changed to the backing function of peak regulation and frequency regulation in the future.

China is in the late stage of industrialization, and the economy is highly dependent on energy. Due to the congenital defects of new energy, such as seasonality, intermittence, and volatility, the “Wind power optoelectronic + Energy storage” units are not enough to
meet the power demand of the whole society at the present stage. Coal power has made an important contribution to ensuring the economic and social development of China, and coal is still the main choice as the “main force” of power supply for a long time. By 2020, the total installed capacity of power units in China reached 1.095 billion kilowatts, of which, the installed capacity of coal-fired power plants accounts for 50% and power generation accounts for more than 60% [3]. The average investment life of coal-fired power is 14 years, which is currently in the period of “young adults” compared with the technical life of 30 to 60 years. Therefore, to achieve the “Dual Carbon” goals, energy structure adjustment and stable social and economic operation, the transformation of coal-fired power enterprises is imperative [4–8]. The evaluation of the organizational performance of coal-fired power enterprises can accurately determine the development status of coal-fired power enterprises from multiple perspectives, and can even find issues related to their transformation, which is of great significance to the smooth transformation and sustainable development of coal-fired and power enterprises.

In this paper, the organizational performance of coal-fired power enterprises in China is evaluated using a hybrid method including the Variational Auto-Encoder algorithm and improved fuzzy comprehensive evaluation technology based on a vague set. Compared with the existing research, this paper has two main contributions. The first is to propose a comprehensive evaluation method for the organizational performance evaluation of coal-fired power enterprises, which combines the Variational Auto-Encoder algorithm and improved fuzzy comprehensive evaluation technology based on a vague set. Among them, the weights of the comprehensive organizational performance evaluation index of coal-fired power enterprises are determined by the Variational Auto-Encoder intelligent algorithm, and the improved fuzzy comprehensive evaluation technology based on a vague set is used to rank the comprehensive organizational performance of coal-fired power enterprises. Another contribution of this paper is to provide a new research perspective based on management for the comprehensive organizational performance evaluation of coal-fired power enterprises, including the economic operation performance, organization and management performance, environmental performance, and social value performance of coal-fired power enterprises. At present, the research on the organizational performance evaluation of coal-fired power enterprises is mainly focused on economic aspects and resource utilization, so it can be said that this paper expands the research scope of the organizational performance of coal-fired power enterprises, considering not only economic benefits, but also social and environmental benefits. This paper performs a comprehensive evaluation of coal-fired power enterprises from four perspectives: economic operation efficiency, organization and management efficiency, environmental efficiency, and social value efficiency, which enriches the research space in this field. At the same time, the Variational Auto-Encoder algorithm and fuzzy comprehensive evaluation method based on a vague set are applied to the organizational performance evaluation of coal-fired power enterprises for the first time, which expands the application field of the Variational Auto-Encoder algorithm and fuzzy evaluation method.

The following section of this paper is as follows: In Section 2, a literature review is conducted. In Section 3, the index system of organizational performance of coal-fired power enterprises is built. In Section 4, the organizational performance evaluation method of coal-fired power enterprises is introduced. In Section 5, the empirical analysis is carried out, and the organizational performance evaluation results of eight coal-fired power enterprises are analyzed. In Section 6, sensitivity and comparative analyses are conducted; In Section 7, the research conclusions are obtained, and the deficiency and prospect of the research are expounded.

2. Literature Review

The performance evaluation of coal-fired power enterprises mainly includes index system construction, feature importance calculation and evaluation scheme design.
From the perspective of index system construction, in [9], a comprehensive evaluation of coal-fired power enterprises using the two evaluation indexes of the internal value chain and external value chain is conducted. In [9,10], it is proposed that in the period of energy reform, it should not only promote the performance of coal-fired power enterprises, but also improve the environmental efficiency, and design a performance evaluation index system with low-carbon management, the sewage discharge process and environmental protection effectiveness as indicators. However, there is a lack of analysis and research on the interaction between the indicators. Analytic hierarchy process (AHP) and analytic network process (ANP) analyses can be used to analyze the relationships between indicators. However, AHP and ANP are susceptible to qualitative and homogenization problems. Therefore, the fuzzy comprehensive evaluation method was introduced to solve the problems of correlation and feedback relations among indicators [11,12].

In the calculation of feature importance, the subjective weighting method and objective weighting method are usually used. The subjective weighting method judges the importance of each index according to the expert’s experience, including eigenvalue and ranking methods, which can reflect the evaluator’s subjective experience and intuition, and is often used in the study of humanities, but it may have a certain degree of subjectivity and arbitrariness. In [13], the expert method is used to evaluate the operation level of early coal enterprises and determine the order of the importance of the evaluation index. Compared with the subjective weighting method, the objective weighting method is more objective and scientific, which is based on original data and uses mathematical theory to determine the importance of index characteristics, including the entropy method and independent weight. The subjectivity of evaluation results can be avoided. In [8], the entropy method is used to calculate the index weight of coal-fired power enterprises in Northwest China, ignoring the importance calculation of the enterprise efficiency index to a certain extent. To give full play to the advantages and disadvantages of subjective and objective index weighting methods, an intelligent algorithm was introduced to calculate the importance of index features to minimize the deviation of weight coefficients.

From the perspective of evaluation scheme design, different methods have different scopes of application. The comprehensive evaluation and analysis methods of coal-fired power enterprises mainly include the grey clustering method [14,15], analytic hierarchy process [16,17] and expert system method [18,19]. In [20], the DEA method is used to evaluate and analyze business efficiency in terms of total assets, number of employees and economic indicators. In [19], the performance of listed coal-fired power companies is evaluated using the AHP method, and the relationship between performance evaluation results and their growth ability, operation ability and profitability is determined. Due to problems such as information omission or unreasonable index quantitative standard setting in the evaluation process of the above methods, the results of individual evaluation indicators are incompatible, and the accuracy of evaluation results is affected. It is difficult to make an accurate evaluation. To solve this kind of contradiction and index incompatibility problem, the fuzzy comprehensive evaluation method is proposed for the operation evaluation of wind power enterprises in the literature [9]. The above literature designs and studies the evaluation index system of coal-fired power enterprises from different angles, and explores a variety of evaluation methods, most of which aim at achieving economic benefits. However, in the special period of transformation, development and reform, the development applicability of the index system is still not considered, and more accurate model methods are needed in index selection and feature importance measurement [21–24].

From the above literature review, the research related to coal-fired power enterprises mainly focuses on resource utilization, operating profit, technical economy, and market development. However, research focusing on the comprehensive performance of the economy, social responsibility, environmental protection, and the internal management of coal-fired power generation enterprises is scarce, which is insufficient. Therefore, in the context of “Dual-Carbon” goals and energy structure adjustment, this paper comprehensively evaluates the performance of coal-fired power enterprises from four perspectives, namely,
economic performance, social performance, environmental performance, and management performance. Meanwhile, a hybrid method combining the Variational Auto-Encoder intelligent algorithm and improved fuzzy comprehensive evaluation technology based on a vague set is proposed to evaluate the performance of coal-fired power enterprises.

3. Index System for Evaluating the Organizational Performance of Coal-Fired Power Enterprises

The organizational performance index system provides guidance for coal-fired power enterprises to achieve organizational goals, and the objectivity of the performance index system can ensure that coal-fired power enterprises reflect the actual economic environment, industry characteristics and regional development level. The evaluation of coal-fired power enterprises based on economic benefit indicators alone can no longer meet the needs of strategic development. Scholars have defined the factors of the enterprise development level from different perspectives. It is necessary to establish a performance evaluation index system which is in line with the realization of the long-term transformation and development goal of coal-fired power enterprises, which is helpful to promote an overall improvement.

In the process of selecting the organizational performance evaluation index of coal-fired power enterprises, this paper first used the literature statistics method to gather 17 related studies. The following important aspects recognized by experts were extracted: economic factors, environmental factors, resource conditions, technical level, operation and management level and social factors, as listed in Table 1. With different frequencies, researchers discussed 33 secondary indicators that have an important impact on the organizational performance of coal-fired power enterprises.

To enhance the independence and representativeness of indicators and weaken the correlation among indicators, this paper used the research method to refine 36 influencing factors and distribute semi-structured questionnaires in 20 provinces in North, Northwest, Northeast, and Central China. The main targets included 32 employees, 45 middle managers and 12 executives from coal-fired power enterprises, coal enterprises and wind power enterprises. A total of 100 questionnaires were distributed, and 89 questionnaires were collected. The recycling efficiency was 89%. According to the statistical analysis of the results of the questionnaire, the KMO value was 0.868, the observed value of Bartlett’s Sphericity test was 328.375, the degree of freedom was 28 and the corresponding concomitant probability was 0, which is less than the significant level, and the indexes with different opinions were excluded using factor analysis. At the same time, to show the characteristics of generality and particularity and reflect the comprehensive concept of the overall development level and quality in the special period, considering the dual responsibilities of profit maximization and social environmental protection, the organizational performance evaluation index system of coal-fired power enterprises was determined as shown in Table 2.

Table 1. The performance index statistics in the relevant literature.

| Primary Indicators       | Secondary Indicators                                | Number of Literatures |
|--------------------------|-----------------------------------------------------|-----------------------|
| Economic factors         | Return on total assets                              | 15                    |
|                          | Total asset turnover                                | 12                    |
|                          | Total asset growth rate                             | 12                    |
|                          | Assets and liabilities                              | 11                    |
|                          | Return on equity                                    | 10                    |
|                          | Asset Impairment Reserve Rate                       | 6                     |
| Environmental factors    | Plant greening degree                               | 10                    |
|                          | Special funds for environmental protection          | 9                     |
|                          | Special funds for energy conservation               | 8                     |
|                          | Ecological construction restoration investment      | 8                     |
|                          | Environmental governance status                     | 7                     |
|                          | Enforcement of environmental laws and regulations   | 4                     |
Table 1. Cont.

| Primary Indicators     | Secondary Indicators                                    | Number of Literatures |
|------------------------|---------------------------------------------------------|-----------------------|
| **Resource conditions**| Comprehensive utilization of resources                 | 14                    |
|                        | Comprehensive energy consumption per CNY ten thousand of |                      |
|                        |   output value                                          |                      |
|                        | Standard coal consumption for power generation         | 12                    |
|                        | Water consumption per CNY ten thousand of output value  | 11                    |
|                        | Large machinery equipment rate                         | 10                    |
|                        | Large machinery utilization                            | 8                     |
| **Technique level**    | Technology project success rate                         | 12                    |
|                        | R&D expense ratio                                       | 12                    |
|                        | Proportion of scientific and technological talents      | 9                     |
| **Operation management level** | Employee training                                   | 13                    |
|                        | Labor productivity                                     | 13                    |
|                        | Employee salary and benefits                            | 12                    |
|                        | Employee satisfaction                                  | 9                     |
|                        | Management rules and regulations                        | 7                     |
|                        | Talent introduction index                              | 7                     |
|                        | Talent equivalent density                              | 3                     |
| **Social factors**     | Unit asset tax amount                                  | 12                    |
|                        | Employment contribution                                | 11                    |
|                        | Social donation                                        | 10                    |
|                        | Accidents per ten thousand people                      | 9                     |
|                        | Government satisfaction                                | 5                     |
|                        | Satisfaction of surrounding residents                  | 4                     |

Table 2. The organizational performance evaluation index system of coal-fired power enterprises.

| Indicator Order | Primary Indicators          | Indicator Order | Secondary Indicators                                      |
|-----------------|-----------------------------|-----------------|-----------------------------------------------------------|
| Q₁               | Economic Operational       | Q₁₁             | Total assets                                              |
|                  | Performance                 | Q₁₂             | Return on total assets                                    |
|                  |                             | Q₁₃             | Return on equity                                          |
|                  |                             | Q₁₄             | Net asset growth rate                                     |
|                  |                             | Q₁₅             | Total installed capacity                                  |
|                  |                             | Q₁₆             | Generating capacity                                       |
| Q₂               | Organizational Management  | Q₂₁             | Organization management                                   |
|                  | Performance                 | Q₂₂             | Labor productivity per capita                             |
|                  |                             | Q₂₃             | Post turnover rate                                        |
|                  |                             | Q₂₄             | Highly skilled talent ratio                               |
|                  |                             | Q₂₅             | Technological innovation project success rate             |
|                  |                             | Q₂₆             | R&D expense ratio                                         |
| Q₃               | Environmental Performance   | Q₃₁             | Eco-friendly input                                        |
|                  |                             | Q₃₂             | Environmental load rate                                   |
|                  |                             | Q₃₃             | Industrial solid waste recycling rate                     |
|                  |                             | Q₃₄             | Technical level of intelligent environment protection     |
| Q₄               | Social Value Performance    | Q₄₁             | Application of carbon capture technology                  |
|                  |                             | Q₄₂             | Social contribution rate                                  |
|                  |                             | Q₄₃             | Guaranteed power supply level                             |
|                  |                             | Q₄₄             | Emergency handling                                        |

3.1. Economic Operational Performance

For economic operation performance, the realization of economic benefits is still the core performance goal of coal-fired power enterprises. From the two perspectives of the asset scale and capital operation, the indicator measures the current economic benefits and scale development of coal-fired power enterprises and reflects the contribution of asset scale,
resource reserves and capital operation to the economic growth of the organization. The economic operation emphasizes core production and business development capabilities.

- Total assets

All assets owned or controlled by the coal-fired power enterprise, to reflect the scale and development level of the enterprise. According to different situations, this can be classified according to the period of holding the assets; the turnover characteristics of the assets; and the different forms of the assets, including current assets, long-term investment, fixed assets, intangible and deferred assets and other long-term assets.

- Return on total assets

A measure of a company’s earnings before interest and taxes relative to its total net asset value. It is defined as the ratio between net income and total average assets and reflects the efficiency of coal-fired power enterprises’ utilization of assets, that is, how effectively coal-fired power enterprises use their asset conditions to generate revenue, thereby affecting organizational performance.

- Return on equity

\[ \text{ROE} = \frac{\text{Net Profit}}{\text{Equity}} \]

This is defined as a measure of financial performance by dividing net income by shareholders’ equity. ROE is the return on equity, a measure of a company’s profitability and profitability and explains the effectiveness of the management with an owner’s assets.

- Net asset growth rate

Refers to the ratio of the increase in the net assets of the enterprise in the current period to the total net assets of the previous period, reflecting the expansion speed of the enterprise’s capital scale. It reflects the expansion speed of the capital scale of the enterprise and is an important indicator to measure the change and growth of the total scale of the enterprise.

- Total installed capacity

Additionally, known as power station capacity, this refers to the sum of the rated power of all steam turbine units installed in a thermal power plant and is one of the main indicators to characterize the construction scale and power production capacity of a thermal power plant. It reflects the power station scale and production capacity.

- Generating capacity

Refers to the amount of electrical energy produced by the generator for energy conversion during a specific period. It is used to measure the scale and power supply capacity of coal-fired power enterprises.

### 3.2. Organizational Management Performance

For organizational management performance, this mainly measures the management level and future development potential of coal-fired power enterprises. Employees, research and management guarantee the development of the organization, accomplishing technical support, talent pillar and mechanical support. Enterprises invest in research and development through coal power technology, constantly improve the management innovation mechanism, promote the integration of modern management concepts, and enhance the comprehensive competitive strength of coal-fired power enterprises. Organizational management focuses on internal operations and resource allocation.

- Organization management

This refers to the process of effectively achieving organizational goals by establishing organizational structure design, specifying positions or positions, and clarifying the relationship between responsibilities and rights. It is mainly divided into three parts: organizational design, operation, and maintenance; organizational adjustment; and optimization. It is used to measure the management concept and overall management and control mode and level of coal-fired power enterprises.
• Labor productivity per capita
This refers to the ratio of labor results created by laborers in an enterprise to their corresponding labor consumption within a certain period. The more work done per unit of time, the higher the labor productivity. In this article, it refers to the ratio of labor consumption corresponding to the power generation of coal-fired power enterprises in a specified period. It is an important indicator for evaluating the economic activities of coal-fired power enterprises and is a comprehensive performance indicator of production technology level, management level, staff technical level and labor enthusiasm.

• Post turnover rate
This refers to the ratio of the number of employees who have set up positions in the enterprise to leave or change within a certain period. It measures the stability and development of coal-fired power enterprises and reflects the rationality of the organizational structure and post setting of coal-fired power enterprises during the transformation and reform periods.

• Highly skilled talent ratio
This refers to the proportion of the total number of employees in the fields of production, transportation and service who are proficient in specialized knowledge and technology, have superb operational capabilities and can solve operational problems of key technologies and processes in work practice. It can reflect the technical level and R&D capability of the enterprise, especially the importance attached to science and technology by coal-fired power enterprises in the period of transformation and reform.

• Technological innovation project success rate
Measuring the degree of completion of technological reform projects by coal-fired power companies is conducive to drawing the attention of coal-fired power enterprises to R&D projects, and at the same time improving R&D ideas, means and technologies.

• R&D expense ratio
This refers to the ratio of the cost paid by a coal-fired power enterprise to the total expenditure of the company for technical research and development in the process of transformation and reform. It reflects the cost of technology input and the determination to reform technology.

3.3. Environmental Performance
For environmental performance, the performance of coal-fired power enterprises in energy conservation, emission reduction and environmental governance was evaluated from two perspectives: environmental protection investment and environmental protection effectiveness. Four indexes of ecological environmental protection input, green area ratio of mining area, equivalent availability coefficient and recovery and utilization rate of industrial solid waste were selected to support the environmental protection decision-making and strategic planning of coal-fired power enterprises. The realization of environmental performance focused on the ability to maintain the external natural environment.

• Eco-friendly input
This refers to the proportion of investment in environmental pollution prevention, ecological protection and construction in the current year’s corporate asset investment. It is the material basis for the development of environmental protection. To measure the transformation and development of coal-fired power enterprises, the strategic goals have changed from resource consumption to environmental protection technology, and the determination and strategy to implement the “Dual carbon goal”.

• Environmental load rate
This refers to the ratio of the total amount of non-renewable energy input energy to the total renewable energy input energy. Measuring the utilization of non-renewable energy by coal-fired power companies during the period of transformation, reform and development is one of the important indicators of environmental protection efficiency.

• Industrial solid waste recycling rate
This refers to the recycling of solid waste generated in the process of coal-fired power generation. Through the collection, storage, transportation, utilization and disposal of solid waste, it reflects the environmental protection measures and degree of coal-fired power enterprises.

- **Technical level of intelligent environment protection**
  This is an extension and expansion of the concept of “digital environmental protection”. It uses Internet of Things technology to embed sensors and equipment into various environmental monitoring objects and integrates the Internet of Things in the field of environmental protection through supercomputers and cloud computing. The integration with the environmental business system will help coal-fired power enterprises realize the wisdom of environmental management and decision making in a more refined and dynamic way during the period of transformation, reform and development.

### 3.4 Social Value Performance

Social value performance refers to the dimension of social value performance, which specifically refers to the value contribution of coal-fired power enterprises to society under the guidance of dual-carbon goals and the theory of sustainable development. Social value emphasizes the corresponding ability to external policies and social environment.

- **Application of carbon capture technology**
  Carbon capture technology is a key measure to achieve the “Dual carbon Goals”. Setting this indicator refers to the application of technology to capture carbon dioxide released into the atmosphere, compress it and press it back into depleted oil and gas fields or other safe underground locations, which focus on the application and promotion of social science and technology.

- **Social contribution rate**
  Social responsibility indicators focus on people’s livelihood and economic contribution and effectiveness, which is the evaluation of the ability of enterprises to fulfill social responsibilities. In this article, it specifically refers to the contribution of coal-fired power enterprises to people’s livelihood and social life security.

- **Guaranteed power supply level**
  This refers to the ability of coal-fired power generation enterprises to ensure power generation and power supply and measures their measures and contributions to ensuring basic people’s livelihood and social stability, especially in the past two years.

- **Emergency Handling**
  This refers to emergency management, command and safeguarding measures in the face of emergencies, such as natural disasters, major accidents, environmental hazards and man-made damage. This specifically refers to the guaranteed function of coal-fired power enterprises in handling power emergencies.

### 4. Construction of Organizational Performance Evaluation Model for Coal-Fired Power Enterprises

#### 4.1 Index Weighting Method Based on VAE

This paper used VAE to determine the interaction among indicators and the degree of interaction. The unsupervised learning intelligent algorithm Autoencoder, which consists of an encoder, a decoder, and a hidden layer, can realize feature reduction and reconstruction. When there was no prior information on index weight, this paper used one of the branches of self-encoder research, Variational Autoencoder. The VAE encodes input variables into the distribution of hidden variables, samples and trains the data according to the distribution and then outputs the distribution of hidden variables. The specific calculation process is shown in Figure 1.
When using VAE to generate the scene, the generation network is defined as \( p_{\theta}(x|z) \), and the network is identified as \( q_{\phi}(z|x) \). As it is difficult to optimize the maximum likelihood estimation directly, variational inference is used to optimize the lower bound of the maximum likelihood function \( \log p_{\phi}(x) \).

\[
\log p_{\phi}(x) \geq E_{q_{\phi}(z|x)} \left[ \log \frac{p_{\theta}(x,z)}{q_{\phi}(z|x)} \right] = E_{q_{\phi}(z|x)} \left[ \log p_{\theta}(x,z) \right] - D_{KL}(q_{\phi}(z|x) \parallel p(z))
\]

where \( D_{KL} \) represents KL divergence.

The VAE has a good effect in generating scenarios under certain conditions, and the performance would be further improved by mining its inherent statistical rules and obtaining the a posteriori distribution of samples from historical data with complex coupling relationships.

4.2. Fuzzy Comprehensive Evaluation Based on Vague Sets

A fuzzy comprehensive evaluation can effectively analyze the non-sequential relationship between the levels of the target criterion system, and effectively synthesize the judgment and comparison of decision makers. The fuzzy analytic hierarchy method improves the difference between the consistency and matrix consistency in the analytic hierarchy method, the difficulty of consistency testing and the lack of scientific research, to determine the size of the scheme weight. In this paper, the organizational performance index system of coal-fired power enterprises contained some qualitative indicators. As the membership in the classical fuzzy evaluation theory cannot be added, and the direct use of the maximum or minimum value can easily lead to the distortion of the evaluation results, this paper adopted the vague set fuzzy comprehensive evaluation method and used it to evaluate the organizational performance of coal-fired power enterprises.

The fuzzy set expands the membership to the range \([0, 1]\), which is an extension of the fuzzy set. Assuming \( x \) is any element in the element space \( Z \), a vague set in the vague can
be represented by membership \( t_A \) and \( f_A \) functions, in which \( t_A(x) \) is the true membership function, indicating the degree of support for \( x \), and \( f_A(x) \) is the false membership function, indicating the degree of opposition to \( x \).

This paper recorded \( t_A(x) \) as \( t_x \), recorded \( f_A(x) \) as \( f_x \), where \( t_x \in [0, 1] \), \( 1 - f_x \in [0, 1] \). If \( t_x = 1 - f_x \), the vague set degenerates into a Fuzzy set. If \( t_x = 1 - f_x = 0 \) or \( t_x = 1 - f_x = 1 \), the vague set degenerates into a normal set. The steps to evaluate the organizational performance of coal-fired power enterprises using the fuzzy comprehensive evaluation method based on the vague set are as follows:

1. Evaluate statements that set the corresponding level of the evaluation indicators. Referring to the actual situation of coal-fired power enterprises, this paper is related to the improvement of enterprise performance, setting the \( V = (V_1, V_2, V_3, V_4, V_5) \) corresponding comment set = (fully compliant, more consistent, barely compliant, not very compliant, completely inconsistent) as five levels.

2. Construct a vague set evaluation matrix.

   Comment set \( V_j = (j = 1, 2, 3, 4, 5) \). Ask several experts to judge the evaluation of the indicators one by one, and then construct the vague set evaluation relationship matrix \( R \):

   \[
   R = \begin{bmatrix}
   r_{11} & r_{12} & \cdots & r_{15} \\
   r_{21} & r_{22} & \cdots & r_{25} \\
   \vdots & \vdots & \ddots & \vdots \\
   r_{n1} & r_{n2} & \cdots & r_{n5}
   \end{bmatrix}
   \]

   (3)

   where \( r_{ij} \) represents the corresponding comment \( V_j \) level of the indicator \( U_i \).

   There are \( r_{ij} = [t_A, 1 - f_A] \) experts who are asked to provide the corresponding evaluation results of each indicator according to the set of comments, and to reflect the degree of hesitation of the experts.

3. Based on the weights \( W \) and matrices \( R \), a comprehensive evaluation is carried out

   \[
   F = W \otimes R = (F_1, F_2, F_3, F_4, F_5)
   \]

   (4)

   \[
   F_j = (w_1 \otimes r_{1j}) \oplus (w_2 \otimes r_{2j}) \oplus \cdots \oplus (w_n \otimes r_{nj}), j = (1, 2, 3, 4, 5)
   \]

   (5)

   where \( F \) is the comprehensive evaluation results based on the vague set.

   The vague value of the comment level \( F_j \) is commented on by the object \( V_j \) to be evaluated. Set \( l \) to \([0, 1]\) a real number on an interval, the \( P \) and \( Q \) are the elements on a vague set, then \( P = [t_P, 1 - f_P], Q = [t_Q, 1 - f_Q]\).

   \[
   k \otimes P = [lt_P, l(1 - f_P)]
   \]

   (6)

   \[
   P \oplus Q = \left[ \min \{1, t_P + t_Q\}, \min \{1, (1 - f_P) + (1 - f_Q)\} \right]
   \]

   (7)

   For intervals such as vague values, it can choose the relative scoring function as the collation for the membership of the vague set. Finally, the evaluation results are determined according to the criteria for maximum membership. The formula is as follows:

   \[
   J(x) = \frac{t_x}{t_x + f_x}
   \]

   (8)

   where \( J(x) \) is the maximum membership of the evaluated object.

   The greater the proportion of the evaluated object that belongs to a certain evaluation \( t_x \) level, the greater the probability that the \( t_x + f_x \) evaluated object belongs to the evaluation level. If there is an impact of partial waivers, the above equation indicates that the abstained parts are subdivided infinitely proportionally until the uncertainties no longer affect the evaluation level membership of the evaluation object.
5. Empirical Analysis

5.1. Overview

This paper took eight coal-fired power enterprises in North China as cases, namely, YC, DA, NK, ZJM, JN, KL, PM and DY, which are all in a critical period of transformation and development. The research objects were all demonstration projects of energy conservation and emission reduction and ecological environmental protection. Among them, the YC coal-fired enterprise was the largest one in the selected sample, with an approved production capacity of 2.1 million tons/year, and the installed capacity of the gangue comprehensive utilization power plant was $2 \times 150,000$ kilowatts. The sources of the evaluation index data in the empirical analysis are as follows: the economic-related index data were all obtained from the annual major financial information bulletins issued by the group website; based on the cooperative research relationship and communication consensus between the research team and the enterprises, the index data related to organization and management were provided by enterprises. The data on environmental data- and social responsibility-related indicators were obtained from the China Statistical Yearbook, China Energy Statistical Yearbook, China Environmental Statistical Yearbook, provincial Statistical Yearbooks, and references and combined with the subject research practice.

5.2. VAE Feature Input

The performance evaluation index system proposed in this paper is based on Variational Autoencoder preprocessing deep learning. The basic steps are as follows:

1. Obtain the original performance data of eight coal-fired power companies as the original training samples.
2. Build the training sample composition, set the maximum number of iterations of VAE, and expand the minority class training samples.
3. Build the training sample set based on the original training samples of the minority class expanded sample set.
4. Use the training sample set and build it based on the pre-training and fine-tuning process performance index feature importance model.

5.3. Index Weighting Results

Using the random gradient descent algorithm, the batch size was set to 100 during training. In contrast to the traditional calculation scheme of the effectiveness evaluation index weight, the range of the effectiveness evaluation index in this paper was set to 0–1, and the step size was 0.5. The higher the index, the higher the correlation. The algorithm builds a model on Pytorch, trains 20 s-level indicators and obtains the corresponding results. The correlation and weight results after dimension reduction from the encoder are shown in Table 3.

5.4. Fuzzy Evaluation Results Based on Vague Set

Enterprise managers and relevant leaders were invited to form an expert group to evaluate the enterprise performance of eight coal-fired power enterprises. The applicability of enterprise performance to enterprise development can be divided into five levels: fully meets the requirements of enterprise development ($V_1$), more in line with the requirements of enterprise development ($V_2$), barely meets the requirements of enterprise development ($V_3$), does not meet the requirements of enterprise development ($V_4$) and completely does not meet the requirements of enterprise development ($V_5$). The vague value evaluation matrix of each index of eight coal-fired power enterprises was obtained, and then according to Formulas (11)–(14), the vague set evaluation matrix of each coal-fired power enterprise was multiplied by the weight of the index system, and the index weighted vague value evaluation of each coal-fired power enterprise was obtained. YC coal-fired power enterprises were used as an example to show the vague set evaluation matrix and performance evaluation process of the evaluation index system, as shown in Tables 4 and 5. Then, the
performance evaluation results of eight coal-fired power enterprises were obtained through finite sum operation, as shown in Table 6.

Table 3. Correlation degree and weight result of self-encoder index.

| Indicators       | Correlation Degree | Weight |
|------------------|--------------------|--------|
| Q1 Economic       |                    |        |
| Q11              | 0.0509             | 0.0547 |
| Q12              | 0.0518             | 0.0595 |
| Q13              | 0.0542             | 0.0727 |
| Q14              | 0.0487             | 0.0428 |
| Q15              | 0.0458             | 0.0274 |
| Q16              | 0.0510             | 0.0555 |
| Q1 Operational    |                    |        |
| Q21              | 0.0520             | 0.0610 |
| Q22              | 0.0492             | 0.0456 |
| Q23              | 0.0444             | 0.0195 |
| Q24              | 0.0483             | 0.0409 |
| Q25              | 0.0512             | 0.0566 |
| Q26              | 0.0495             | 0.0471 |
| Q1 Performance    |                    |        |
| Q31              | 0.0504             | 0.0523 |
| Q32              | 0.0512             | 0.0567 |
| Q33              | 0.0458             | 0.0273 |
| Q34              | 0.0450             | 0.0231 |
| Q2 Organizational |                    |        |
| Q41              | 0.0524             | 0.0629 |
| Q42              | 0.0535             | 0.0690 |
| Q43              | 0.0529             | 0.0655 |
| Q44              | 0.0518             | 0.0600 |

Table 4. Vague set evaluation matrix of YC evaluation index by expert group.

| Primary Indicators | Secondary Indicators | V1   | V2   | V3   | V4   | V5   |
|--------------------|----------------------|------|------|------|------|------|
| Q1                 | Q11                  | [0.15,0.25] | [0.3,0.4] | [0.25,0.35] | [0.125,0.225] | [0.075,0.175] |
|                    | Q12                  | [0.1,0.2] | [0.35,0.45] | [0.275,0.375] | [0.1,0.2] | [0.075,0.175] |
|                    | Q13                  | [0.15,0.25] | [0.325,0.425] | [0.275,0.375] | [0.125,0.225] | [0.025,0.125] |
|                    | Q14                  | [0.125,0.225] | [0.25,0.35] | [0.3,0.4] | [0.15,0.25] | [0.075,0.175] |
|                    | Q15                  | [0.125,0.225] | [0.275,0.375] | [0.3,0.4] | [0.15,0.25] | [0.05,0.15] |
|                    | Q16                  | [0.1,0.2] | [0.25,0.35] | [0.275,0.375] | [0.2,0.3] | [0.075,0.175] |
|                    | Q21                  | [0.075,0.275] | [0.125,0.325] | [0.15,0.35] | [0.25,0.45] | [0.2,0.4] |
|                    | Q22                  | [0.025,0.225] | [0.175,0.375] | [0.25,0.45] | [0.3,0.5] | [0.05,0.25] |
|                    | Q23                  | [0.075,0.275] | [0.125,0.325] | [0.275,0.475] | [0.225,0.425] | [0.1,0.3] |
|                    | Q24                  | [0.05,0.25] | [0.15,0.35] | [0.225,0.425] | [0.275,0.475] | [0.1,0.3] |
|                    | Q25                  | [0.05,0.25] | [0.175,0.375] | [0.325,0.525] | [0.175,0.375] | [0.075,0.275] |
|                    | Q26                  | [0.05,0.25] | [0.075,0.275] | [0.225,0.425] | [0.3,0.5] | [0.15,0.35] |
|                    | Q31                  | [0.05,0.125] | [0.225,0.3] | [0.375,0.45] | [0.15,0.225] | [0.125,0.2] |
|                    | Q32                  | [0.15,0.225] | [0.275,0.35] | [0.225,0.3] | [0.175,0.25] | [0.1,0.175] |
|                    | Q33                  | [0.125,0.2] | [0.25,0.325] | [0.325,0.4] | [0.2,0.275] | [0.025,0.1] |
|                    | Q34                  | [0.125,0.2] | [0.25,0.325] | [0.25,0.325] | [0.175,0.375] | [0.125,0.2] |
|                    | Q41                  | [0.225,0.375] | [0.275,0.425] | [0.175,0.375] | [0.075,0.225] | [0.1,0.25] |
|                    | Q42                  | [0.075,0.225] | [0.3,0.45] | [0.175,0.325] | [0.15,0.3] | [0.15,0.3] |
|                    | Q43                  | [0.125,0.275] | [0.325,0.475] | [0.275,0.425] | [0.075,0.225] | [0.05,0.2] |
|                    | Q44                  | [0.15,0.3] | [0.225,0.375] | [0.275,0.425] | [0.1,0.25] | [0.1,0.25] |
Table 5. Comprehensive evaluation results of the YC vague value comments on vague value.

| Primary Indicators | Secondary Indicators | Vague Value Evaluation Results |
|--------------------|----------------------|-------------------------------|
|                    |                      | $V_1$                         |
| Q1                 | $Q_1$                | [0.00821, 0.01368]            |
|                    | $Q_11$               | [0.01641, 0.02188]            |
|                    | $Q_12$               | [0.01368, 0.01915]            |
|                    | $Q_13$               | [0.00684, 0.01231]            |
|                    | $Q_14$               | [0.00410, 0.00957]            |
| Q2                 | $Q_2$                | [0.00595, 0.01189]            |
|                    | $Q_21$               | [0.00595, 0.01189]            |
|                    | $Q_22$               | [0.02081, 0.02676]            |
|                    | $Q_23$               | [0.01635, 0.02230]            |
|                    | $Q_24$               | [0.00908, 0.01635]            |
| Q3                 | $Q_3$                | [0.00114, 0.00206]            |
|                    | $Q_31$               | [0.00114, 0.00206]            |
|                    | $Q_32$               | [0.00798, 0.01711]            |
|                    | $Q_33$               | [0.01140, 0.02053]            |
|                    | $Q_34$               | [0.00439, 0.00829]            |
| Q4                 | $Q_4$                | [0.00146, 0.00536]            |
|                    | $Q_41$               | [0.00146, 0.00536]            |
|                    | $Q_42$               | [0.0244, 0.00634]             |
|                    | $Q_43$               | [0.00920, 0.01738]            |
|                    | $Q_44$               | [0.01221, 0.02441]            |
| Q5                 | $Q_5$                | [0.00204, 0.00128]            |
|                    | $Q_51$               | [0.00204, 0.00128]            |
|                    | $Q_52$               | [0.00578, 0.00887]            |
|                    | $Q_53$               | [0.00887, 0.01902]            |
|                    | $Q_54$               | [0.00546, 0.01431]            |
| F                  | $F_1$                | [0.00283, 0.01414]            |
|                    | $F_11$               | [0.00283, 0.01414]            |
|                    | $F_12$               | [0.00753, 0.01026]            |
|                    | $F_13$               | [0.01070, 0.01497]            |
|                    | $F_14$               | [0.00041, 0.00957]            |

Furthermore, according to Formulas (4)–(8), the evaluation matrix of a vague set, and the weight $W$ of the index system were multiplied, and the weighted vague value evaluation of each index was obtained, and then through the finite sum operation, the comprehensive evaluation result of vague value of YC coal-fired power enterprises was obtained, as shown in Table 5.

According to the evaluation results calculated in Table 5 and using Formulas (4)–(8), the score value of the evaluation grade corresponding to the performance of YC coal-fired power enterprises was obtained, and the results are shown in Table 6.

According to the score results, $J_{YC1} > J_{YC2} > J_{YC3} > J_{YC4} > J_{YC5}$, so the performance of YC coal-fired power enterprises meets the requirements of enterprise development. To compare and analyze the performance evaluation results of various coal-fired power enterprises more clearly, the corresponding score was set for the evaluation grade of the index, as shown in Table 7.
By multiplying the score value of each evaluation grade calculated above by the score value of the corresponding grade, the performance evaluation results of each coal-fired power enterprise could be quantified.

\[ J^* = 100 \times J_1 + 80 \times J_2 + 60 \times J_3 + 40 \times J_4 + 20 \times J_5 \]

For example, the scores of each rating obtained by YC coal-fired power enterprises were as follows: \( J_{YC1} = 1.7763 \), \( J_{YC2} = 1.7207 \), \( J_{YC3} = 1.7090 \), \( J_{YC4} = 1.6987 \), \( J_{YC5} = 1.6914 \), and the quantized result is \( J^*_{YC} = 100 \times 1.7763 + 80 \times 1.7207 + 60 \times 1.7090 + 40 \times 1.6987 + 20 \times 1.6914 = 519.602 \). As a result, the quantitative results of the performance scores of eight coal-fired power enterprises could be obtained, as shown in Table 8.

Table 8. The performance scores of eight coal-fired power enterprises.

|     | YC  | DA  | NK  | ZJM | JN  | KL  | PM  | DY  |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| \( V_1 \) | 1.7763 | 1.5519 | 1.6548 | 1.3194 | 1.61943 | 1.5834 | 1.6095 | 1.8335 |
| \( V_2 \) | 1.7207 | 1.7572 | 1.8037 | 1.2626 | 1.75846 | 1.7503 | 1.6397 | 1.6727 |
| \( V_3 \) | 1.709 | 1.6749 | 1.7005 | 1.4584 | 1.5413 | 1.7991 | 1.7601 | 1.5709 |
| \( V_4 \) | 1.6987 | 1.5775 | 1.6997 | 1.2413 | 1.5626 | 1.5917 | 1.8633 | 1.6391 |
| \( V_5 \) | 1.6914 | 1.5187 | 1.5938 | 1.2126 | 1.4126 | 1.6934 | 1.5731 | 1.5982 |
| Result | 519.602 | 489.7488 | 394.3673 | 485.8594 | 511.67 | 503.846 | 503.726 | 508.948 |

From the results of performance evaluation in Table 8, the organizational performance of the YC coal-fired power enterprise was the best, and JN was the second. The results show that the organizational performance of YC coal-fired power was completely in line with the requirements of enterprise development, and the performance of JN coal-fired power was in line with the requirements of enterprise development. Among them, the Q13, Q42, Q43, Q41, Q21 and Q44 indexes had great influences, indicating that to improve the organizational performance of coal-fired power enterprises, they need to focus on the improvement of the above indicators. These findings can provide technical and intellectual support for the transformation and development of coal-fired power enterprises.

6. Discussion

6.1. Sensitivity Analysis

In the research process, we found that there was a significant correlation between the weight of the fuzzy comprehensive evaluation method based on VAE and the evaluation results. For this reason, the first six indicators, Q13, Q42, Q43, Q41, Q21 and Q44, with the largest weight were selected for sensitivity analysis. The weights were adjusted proportionally, and the weights of each evaluation index were symmetrically adjusted by ±5%, ±20% and ±50%, respectively. To ensure that the sum of the weights was always 1, the weights were standardized, and the change results are shown in Figure 2.

Figure 2 shows the changes in the performance evaluation value of eight sample coal-fired power enterprises when the weights of six indicators were floating. The surface change represents the influence of weight on the performance results. Among them, when the weight of each index changed, the organizational performance evaluation result of YC coal-fired power enterprise was always the best, and the sensitivity of six indicators was less than 0.8. This showed that the index with a larger weight had good stability, and it can be concluded that the other 14 indexes with relatively small weight have better stability. Therefore, it can be said that the evaluation result has stability.
6.2. Comparative Analysis

To judge the pros and cons of different methods to evaluate the organizational performance of coal-fired power enterprises, this paper selected compatibility and difference to compare and analyze the representativeness of the evaluation methods. The greater the degree of compatibility, the stronger the representativeness of the program and the higher the reliability; the degree of difference refers to the ranking of the evaluation programs as the benchmark value, and the smaller the degree of difference, the better the evaluation method.

The difference between the evaluation methods is as follows:

\[
r_{ab} = \frac{1}{m(m^2 + 1)} \sum_{i=1}^{m} \left( Q_i^{(a)} Q_i^{(b)} \right)^2
\]  

(9)
Among them, $Q_x^{(a)}$ represents the ranking order of the $x$ evaluation index in evaluation method $a$ and evaluation method $b$, $a, b = 1, 2, \ldots, m$.

The compatibility of each evaluation method is as follows:

$$d_j = \frac{1}{n} \sum_{k=1}^{n} d_{jk}, j, k = 1, 2, \ldots, n$$  \hspace{1cm} (10)$$

Among them, $d_j$ represents the degree of difference between an evaluation plan and other evaluation plans $n$; $d_{jk}$ represents the evaluation objects of the evaluation plan within a certain serial number range, and the number of evaluation objects that exceed the specified serial number range in evaluation plan $j$.

The compatibility and difference of each evaluation scheme are shown in Table 9. Compared with the other two evaluation methods, the VAE method had the largest degree of compatibility and the smallest degree of difference. Therefore, it can be said that the method proposed for the organizational performance evaluation of coal-fired power enterprises in this paper is robust and reliable.

Table 9. Compatibility and difference of three evaluation methods.

| Method | Compatibility | Difference | Comprehensive Rank |
|--------|---------------|------------|--------------------|
|        | Score Rank    | Score Rank |                   |
| VAE    | 0.963 1       | 1          | 1 1 1              |
| ANP    | 0.669 2       | 1          | 1 1 2              |
| TOPSIS | 0.657 3       | 2          | 2 2 3              |

7. Conclusions

The steady improvement of organizational performance is the key to coal-fired power enterprises in the period of transformation and development. In this paper, the organizational performance of coal-fired power enterprises in China was evaluated using a hybrid method including the Variational Auto-Encoder algorithm and improved fuzzy comprehensive evaluation technology based on a vague set. This research can accurately determine the development status and can even determine the issues of coal-fired power enterprises related to their transformation, which is of great significance to the smooth transformation and sustainable development of coal-fired and power enterprises. Eight coal-fired power companies were selected for empirical analysis, and the results are as follows:

(1) The organizational performance evaluation index system of coal-fired power enterprises was built. Compared with the original coal-fired power enterprise evaluation index system, the importance of organizational management, the proportion of high-skilled talents, the level of intelligent environmental protection technology, the application of carbon capture technology and the level of power supply guarantees were strengthened, reflecting the guiding role of the “Dual-Carbon” goals. In the context of energy reform, coal-fired power enterprises have the dual development tasks of social responsibility and economic benefits. This paper provides a new perspective for the operation management and comprehensive performance evaluation of coal-fired power enterprises during the period of transformation, reform and development.

(2) An evaluation method for organizational performance of coal-fired power enterprises was proposed. The VAE algorithm was applied to the organizational performance evaluation of coal-fired power enterprises, which combines the advantages of subjective and objective feature selection and importance method, enhances the representativeness of performance evaluation indicators and reflects the interdependence and feedback between multiple performance indicators. The empirical result showed that the organizational performance of the YC coal-fired power enterprise was the best, and the JN coal-fired power enterprise was second, while the organizational performance of the NK coal-fired power enterprise was the worst. Through the sensi-
tivity analysis and comparison of various evaluation methods, the compatibility of the proposed model in this paper was the largest, and the difference was the smallest, indicating that it is representative and reliable. This paper strengthens the objectivity and interrelationship of the indexes, which increases the scientific rationality of the model and expands the application field of intelligent algorithms.

The main contributions of this research are as follows: one is to propose a comprehensive evaluation method for the organizational performance evaluation of coal-fired power enterprises, which combines the Variational Auto-Encoder algorithm and improved fuzzy comprehensive evaluation technology based on a vague set; another is to provide a new research perspective for the comprehensive organizational performance evaluation of coal-fired power enterprises, including economic operation performance, organizational and management performance, environmental performance and social value performance.

The method proposed in this paper, which combines the Variational Auto-Encoder algorithm and improved fuzzy comprehensive evaluation technology based on a vague set, can evaluate the organizational performance evaluation of coal-fired power enterprises. According to the sensitivity and comparative analysis results, the proposed method in this paper is robust and feasible.

The evaluation method has a certain generalization, but due to the limited number of samples, the design of the performance evaluation system of coal-fired power enterprises in the transitional period and after the transition needs to be further studied and optimized.

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