Analysis of Vertical Integration Motivation in Coal-Electric Energy Supply Chain Using ISM-MICMAC

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Abstract. Vertical integration is one of the important means to achieve coal-electricity joint ventures. According to the comprehensive analysis of domestic and foreign literature, based on the field survey, nine key drivers of vertical integration of coal-electric energy supply chain are proposed. This basis, using interpretative structural modelling (ISM), a five-level hierarchical structure model of the vertical integration motivation of the coal-electric energy supply chain is constructed, which clearly characterization of the hierarchical relationship between the various drivers. Using MICMAC, find the independent and dependent factors. Furthermore, it reveals the most direct motivation and the most fundamental motivation for driving the vertical integration of coal-electric energy supply chain. At the same time, it can clearly show the role of each driver in the vertical integration of coal-fired energy supply chain.

1. Introduction
As China’s economic development enters a new normal, the coal industry faces serious overcapacity problems. To solve the problem, the State Council issued the “Opinions on Resolving the Excessive Capacity of the Coal Industry to Realize the Development of the Depletion”. With the steady progress of the de-capacity policy, coal production has fallen, prices have risen, and the economic benefits of coal companies have improved. However, due to the increase in fuel costs, thermal power companies in the power industry have experienced poor profitability and serious difficulties in business operations. How to solve the problem of coal-electricity conflict has become a hot spot for the government and scholars.

Vertical integration has a wide range of applications in the energy sector, such as power sales [1]. Du(2016) using structural equation model to exploring the influence factors of coal enterprise vertical integration in China, it can be further improved China’s coal enterprise vertical integration[2]. This paper conducts an in-depth study on the analysis of the vertical integration motivation of coal-fired
energy supply chain under the coal-electricity joint venture policy. Li et al. (2017) established a model measuring the industrial collaboration degree of coal enterprises to quantitatively reflect the collaboration degree between various industries[3].

2. ISM- MICMAC

2.1. Interpretative Structural Modeling
Interpretative Structural Modeling (ISM) was proposed by Professor Warfield, also known as the Interpretative Structural Model, which uses human experience to simplify the system to form a structural matrix. Interpretative structural modeling is widely used in the energy sector [4-6]. The analysis steps are as follows:

(1) Identify system elements. The system elements are defined as follows:

$$C_i \ (i = 1, 2, \ldots, n)$$ (1)

(2) Determine the relationship between features. Construct an adjacency matrix \( A = \left[ a_{ij} \right] \) based on the influence relationship between system elements, where the elements \( a_{ij} \) in A is:

$$a_{ij} = \begin{cases} 1 & (i \text{ influence } j) \\ 0 & (i \text{ does not influence } j) \end{cases}$$ (2)

(3) Solving reachable matrix. \( A + I \) is the sum of the adjacency matrix A and the unit matrix I, used an integer \( n \) on the matrix \( A + I \) for a power operation until the following formula holds:

$$M = (A + I)^{n+1} = (A + I)^n \neq \ldots \neq (A + I)$$ (3)

The power operation is based on the Boolean algebra algorithm (0 + 0 = 0, 0 + 1 = 1, 1 + 0 = 1, 1 + 1 = 1, 1 × 0 = 0, 1 × 1 = 1), matrix \( M = (A + I)^n \) called the reachable matrix.

(4) Level division. The region and the inter-stage decomposition are performed on the reachable matrix \( M \). Before each decomposition, the reachable set, the antecedent set and the Intersection are found for each element. The definition is:

The antecedent set:

$$R(C_i) = \left\{ C_{(Column)} \mid m_{ij} = 1 \right\}$$ (4)

The antecedent set:

$$P(C_i) = \left\{ C_{(Row)} \mid m_{ij} = 1 \right\}$$ (5)

The Intersection:

$$T(C_i) = R(C_i) \bigcap P(C_i)$$ (6)

(5) Drawing a multi-level hierarchical directed graph.

2.2. MICMAC
The matriced impacts croisés multiplication appliquée à un classement (MICMAC) method was developed by Michel Godet and François Boursel[7]. The MICMAC analysis method applies the matrix multiplication principle, and calculates the stable indirect matrix by the formula (3), which is also the final reachable matrix in the ISM method.

The MICMAC analysis results are visually represented by the coordinate axes, also referred to as the driving force-dependent matrix, the abscissa represents the dependence, and the ordinate represents the driving force. Calculate the driving force and dependence of each factor according to the reachable
matrix: the driving force of the element can be obtained by calculating the number of elements that can be reached, and the dependence can be obtained by calculating the number of elements reaching it, which divides the element into 4 Cluster: autonomous, dependent, linkage, independent.

### 3. Structural model of coal-electric energy supply chain vertical integration motivation

#### 3.1. Identify system elements

Through the vertical integration policy and enterprise research of coal-electric energy supply chain, the system elements of this paper are: Vertical integration of coal-electric energy supply chain S0, Coal-electricity joint venture policy support S1, Environmental protection restriction S2, Market environment reverse forced S3, Enterprise choose S4, Encourage policy S5, Reduce transaction cost S6, Reduce production cost S7, Improve market competitiveness S8, Coal-electricity joint project priority S9, New policy priority pilot S10, Project operation S11, Income distribution S12.

#### 3.2. Determine the relationship between features

In order to study the vertical integration motivation of coal-electric energy supply chain, the interaction of 13 important influencing factors is analysed, as shown in Table 1.

|       | S0  | S1  | S2  | S3  | S4  | S5  | S6  | S7  | S8  | S9  | S10 | S11 | S12 |
|-------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| S0    | 1   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| S1    | 1   | 1   | 0   | 0   | 0   | 1   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| S2    | 1   | 0   | 1   | 0   | 1   | 1   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| S3    | 1   | 0   | 0   | 1   | 1   | 1   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| S4    | 1   | 0   | 0   | 0   | 0   | 1   | 0   | 0   | 1   | 1   | 0   | 0   | 0   |
| S5    | 1   | 0   | 0   | 0   | 0   | 0   | 1   | 0   | 0   | 0   | 1   | 1   | 0   |
| S6    | 1   | 0   | 0   | 0   | 0   | 0   | 0   | 1   | 0   | 0   | 0   | 0   | 1   |
| S7    | 1   | 0   | 0   | 0   | 0   | 0   | 0   | 1   | 0   | 0   | 0   | 0   | 0   |
| S8    | 1   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 1   | 0   | 0   | 1   | 1   |
| S9    | 1   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 1   | 0   | 1   | 1   |
| S10   | 1   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 1   | 0   | 1   | 1   |
| S11   | 1   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 1   | 0   | 1   |
| S12   | 1   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 1   |

According to the influence relationship between system elements, we can obtain the adjacency matrix.

#### 3.3. Solving reachable matrix

From equation (3), the reachable matrix is available.

#### 3.4. Level division

From formula (4-6), reachable set, Antecedent set and Intersection. It can be seen that S0 is the first layer element, the corresponding row and column in the reachable matrix M are deleted, the second layer element is obtained in the same way, and so on, and the hierarchical division of each influencing element is shown in Table 2.
3.5. Draw a multi-level hierarchical directed graph

Establish an analytical model for the vertical integration of the coal-electric energy supply chain, as shown in Figure 1.

![Multi-level hierarchical directed graph](image)

**Figure 1.** Vertical integration of coal-electric energy supply chain.

3.6. MICMAC Analysis

In order to MICMAC Analysis the vertical integration motivation of coal-electric energy supply chain, the dependence power and driving power of 13 important influencing factors is calculated, as shown in Table 3.

| No. | Dependence power | Driving power |
|-----|------------------|---------------|
| S0  | 13               | 1             |
| S1  | 1                | 11            |
| S2  | 1                | 11            |
| S3  | 1                | 11            |
| S4  | 4                | 7             |
| S5  | 4                | 6             |
| S6  | 5                | 4             |
| S7  | 5                | 4             |
| S8  | 5                | 4             |
| S9  | 5                | 4             |

**Table 3.** Dependence power and driving power
MICMAC analysis of coal-electric energy supply chain vertical integration motivation is shown in figure 2.

**Figure 2.** MICMAC analysis of coal-electric energy supply chain vertical integration motivation.

### 4. Analysis and recommendations

In this paper, the ISM and MICMAC models are used to study the coal-electric energy supply chain vertical integration motivation. The main conclusions are as follows:

1. The coal-electric energy supply chain is divided into five levels. The factors at each level are closely related. All factors affect the vertical integration of the coal-fired energy supply chain through different paths and methods. In practice, the intrinsic link between different factors is often overlooked. By establishing a system structure model, the intrinsic relationship and importance between factors can be clearly reflected.

2. According to the ISM model, vertical integration of coal-electric energy supply chain S0, Coal-electricity joint venture policy support S1, Environmental protection restriction S2, Market environment reverse forced S3, Enterprise choose S4, respectively located on the fifth and fourth. The layer is the basic factor for the vertical integration of the coal-fired energy supply chain. According to the MACMIC model, the vertical integration of coal-electric energy supply chain S0, Coal-electricity joint venture policy support S1, Environmental protection restriction S2, Market environment reverse forced S3, Enterprise choose S4, is in the independent area, which has low dependent, high driving
characteristics, and other factors have a great impact. Therefore, for the above factors, it is necessary to pay attention to and improve these factors.

(3) According to the ISM model, Encourage policy S5, Reduce transaction cost S6, Reduce production cost S7, Improve market competitiveness S8, Coal-electricity joint project priority S9, New policy priority pilot S10, in the fourth layer and the third layer. According to the MACMIC model, Encourage policy S5, Reduce transaction cost S6, Reduce production cost S7, Improve market competitiveness S8, Coal-electricity joint project priority S9, New policy priority pilot S10, in a autonomous area with low dependent and low driving characteristics. Therefore, it is necessary to manage these factors as a whole and give full play to their respective effectiveness.

(4) According to the ISM model, Project operation S11, Income distribution S12, is on the second floor. According to the MACMIC model, Project operation S11, Income distribution S12, which is in a dependent area, has high dependence and low driving characteristics. Therefore, the above factors need to be monitored to assess the vertical integration of the coal energy supply chain.

5. Conclusion
In this paper, the ISM and MICMAC models are used to study the vertical integration of coal-electric energy supply chain, and the following conclusions are drawn:

(1) The dynamic factors of vertical integration of coal-electric energy supply chain are distributed in five levels, and the factors at each level are closely related, and all factors have strong correlation. In the process of vertical integration of coal-electric energy supply chain, we should pay attention to the internal relationship between different factors.

(2) Using the ISM method to obtain a hierarchically integrated structural model of the coal-electric energy supply chain, providing a complete framework for the vertical integration of the coal-electric energy supply chain, and vertically integrating the coal-electric energy supply chain. Establishing the theoretical basis; using the MICMAC model method, the driving –dependence matrix of the vertical integration dynamic factors of the coal-electric energy supply chain is obtained, which can identify the high driving and the high dependent factors, which is the longitudinal direction of the coal-electric energy supply chain practice provides theoretical guidance.

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