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Research on the Influencing Factors of Coal Industry Transformation Based on the DEMATEL–ISM Method

Shuheng Zhong, Dan Lin and Kangdi Yang * 

School of Energy and Mining Engineering, China University of Mining and Technology (Beijing), Beijing 100083, China

* Correspondence: yangkangdi@126.com

Abstract: The “carbon peak, carbon neutral” goal and the rapid development of new energy sources such as photovoltaic and hydrogen energy have accelerated the decline of the traditional coal industry. Therefore, the coal industry urgently needs to seize the opportunity for coal transformation and achieve high-quality development to improve its competitiveness. This study used a combination of literature analysis and case supplementation to identify 12 influencing factors of coal industry transformation. The DEMATEL method was used to classify the 12 influencing factors into four groups: strong cause, weak cause, strong outcome, and weak outcome. Then, the ISM method was used to construct a multi-level recursive structure of the factors influencing the transformation of the coal industry. The results show that the influencing factors of coal industry transformation can be divided into a three-layer hierarchical structure. Among them, policy traction is the most critical fundamental influence, technological change has the highest importance in the indirect influence layer, while safety production, related industries and support, and capital funding are the most effective direct influence. It should be the focus of attention.

Keywords: coal industry transformation; influencing factors; DEMATEL method; ISM method



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1. Introduction

As a basic energy source and industrial raw material in China, coal has long provided a strong guarantee for economic and social development and a stable supply of national energy security [1]. In 2020, the total primary energy production in China was 4.0×10^9 t. of which raw coal production was up to 3.9×10^9 t, an increase of 1.3% year on year. The total energy consumption was 4.98×10^9 tce, of which coal consumption accounted for 56.8% [2]. However, coal provides traditional high-carbon fossil energy, and its large-scale development and utilization have brought ecological damage, climate change, environmental pollution, and other problems that are increasingly prominent. Coal development and utilization are the main sources of carbon emissions in China, accounting for approximately 65% of China's carbon emissions, and are key areas of carbon emission reduction in China [3,4]. As the world's largest developing country, China has made an aggressive commitment to “peak carbon neutrality”, which has led to systemic changes in the country's energy sector [5–7]. At the same time, the international economic situation is severe, and the competition between major countries has led to a huge challenge in terms of energy security. Coal is a basic input factor for economic and social operations. It is closely related to high-quality economic development. It involves a series of socio-economic issues such as energy security, environmental protection, and safety production [8,9]. At present, China's economy is in a critical period of changing development mode, optimizing economic structure, and transforming growth momentum, which has a revolutionary and disruptive impact on the traditional energy industry. In the face of complex internal and external factors, the traditional coal industry can no longer meet the needs of the country's high-quality economic development. Coal consumption and utilization have shown a clean and diversified development mode, and it has become an industrial consensus and trend to promote the high-quality transformation development of the coal industry.

In recent years, academics have conducted a lot of research on the transformation of the coal industry. The main focus is on the following three directions. The first is to re-search the transformation path of the coal industry. For example, Zhang Yaning et al. studied the transformation path of the coal industry to geothermal energy resources development and proposed the transformation concept of expanding geothermal specialized services based on the existing engineering service capacity of the coal industry [10]. Wang G et al. introduced the development trend of China's coal industry 3.0 and believed that the current stage should be a breakthrough from three key technologies of intelligent coal mining, ecological coal mining, ultra-low emission, and environmental protection [11]. The second is to study the necessity of coal industry transformation. For example, Wang Shufei and Gao Peng, based on the national energy development idea and the requirements of the "double carbon" target on the adjustment of energy supply and demand structure with coal as the main energy source, believe that reducing the total amount of coal energy consumption is the primary choice and clean energy is the main response [12]. Starting from the macro development environment of the coal industry, Sun Xudong et al. systematically analyze the advantages, disadvantages, opportunities, and challenges of China's coal development in the medium and long term. The development trend and positioning of the coal industry transformation in three different stages are examined, and corresponding response strategies are proposed [13]. Thirdly, there are studies related to the factors influencing the transformation of the coal industry. For example, Zhao YQ et al. took the transformation of Jiaozuo as an example, summarized the lessons learned during the growth of Jiaozuo, and proposed the importance of resource endowment on the transformation of the coal industry [14]. Wang JQ et al. took the impact of renewable energy that Chinese coal enterprises are currently facing as the entry point and proposed that coal enterprises urgently need to make green transformation decisions, which illustrated the importance of market demand on the transformation of the coal industry [15].

Through the above literature, we can see that scholars' research on the transformation and development of the coal industry mainly focuses on the direction of its transformation, the necessity of transformation, and the importance of individual factors in transformation. There is a lack of research on the systemic influencing factors of the coal industry transformation. Additionally, research on the identification of key factors of coal industry transformation is severely lacking. As the cornerstone of China's energy industry, it is a key issue to achieve high-quality development of the coal industry by identifying its transformation influencing factors, exploring its transformation and upgrading paths, and achieving sustainable development of the coal industry. Given this, this paper uses a combination of literature and cases to derive a system of influencing factors for the transformation of China's coal industry. The DEMATEL–ISM model is used to analyze the influencing factors. The key influencing factors are identified and the mechanism of each influencing factor on the transformation development of the coal industry is clarified to provide some reference value for the high-quality transformation development of the coal industry.

2. Identification of Influencing Factors

2.1. Overview of Coal Industry Transformation

The transformation of the coal industry is mainly divided into two routes. One is to extend the industry chain based on the original industry chain, such as coal to oil and gas, coal to chemical, and coal to hydrogen. The other is the transformation of the layout of new energy fields such as energy storage (sodium ion batteries, flywheel energy storage, etc.), wind power photovoltaic operation, hydrogen, etc.

2.1.1. Analysis of the Coal Industry Chain in China

The coal industry chain refers to the strategic assemblage of upstream and downstream enterprise relationships formed in industrial production to carry out production activities around coal resources. Coal has a complete industrial chain in China. It consists of upstream coal production, midstream transportation, sales and storage, and downstream consumption and utilization (Figure 1). From the whole industrial chain process of coal,

the carbon emission from coal production accounts for approximately 10%, and the carbon emission from coal transportation, sales, storage, and utilization accounts for nearly 90% [4,16,17].

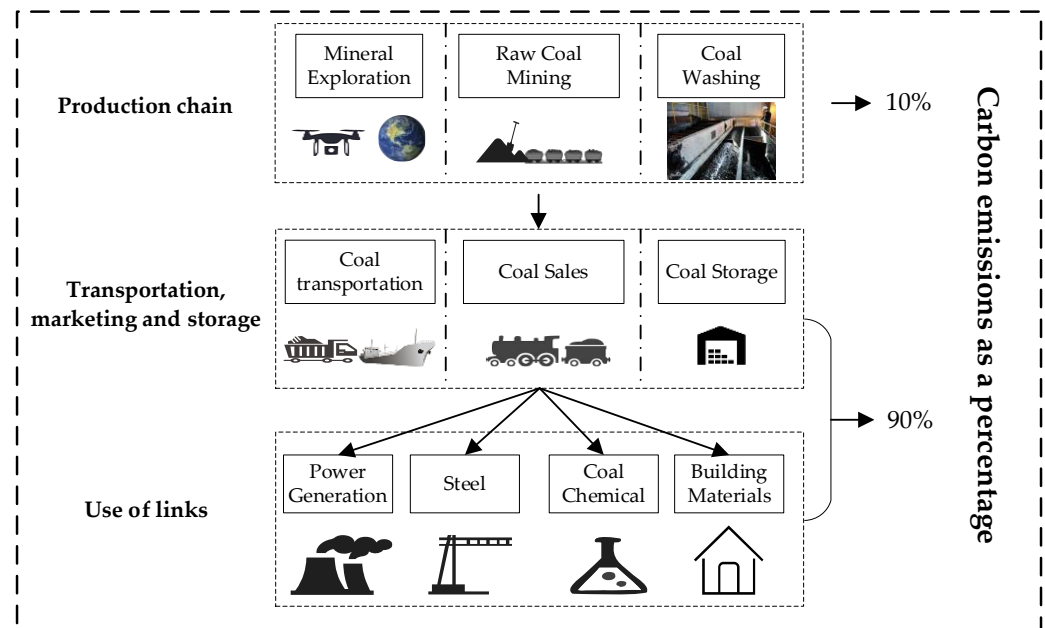


Figure 1. Coal Industry Chain.

The utilization pathways of coal point to the steel, coal chemical, power generation, and building materials industries, respectively. Their carbon emissions account for the carbon emissions of energy activities in China as shown in Figure 2.

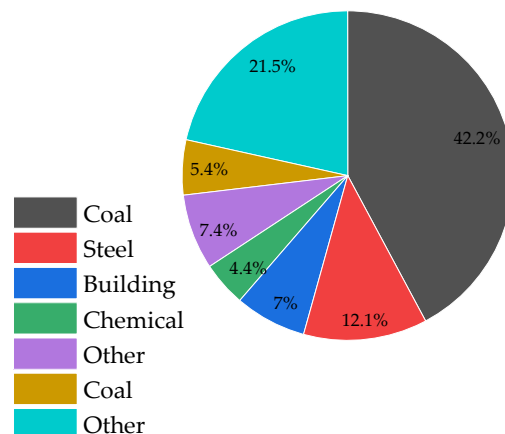


Figure 2. Percentage of carbon emissions from various energy activities in China.

Based on their resource endowment and strategic layout, more coal enterprises in China have formed a more mature coal-power industry chain and coal-chemical industry chain. The coal-electricity industry chain mainly uses less coalified bituminous coal and brown coal for the burning of power. Using the heat generated by burning coal, the thermal energy is converted into electrical energy that can be more easily stored and used. In the coal-chemical industry chain, the modern coal chemical industry, as an alternative supplement to petroleum products, has a large one-time construction investment, a long capital recovery period, and therefore high depreciation and amortization costs. The chemical products are mainly converted from coal, and the raw materials and power fuels mainly come from coal. There is high coal consumption per unit of chemical products, and high resource consumption. There is also high volatility of coal market price and high

raw material and fuel costs. In addition, coal chemical products have not yet achieved complete substitution for petrochemical products, and do not have a dominant position in the product market, so product sales revenue is greatly affected by fluctuations in international oil prices.

2.1.2. Analysis of Coal Industry Transformation

The development of the coal industry led by the traditional crude development has been difficult to adapt to the macro environment under the new economic normal. Further, the dramatic deterioration of the ecological environment marks the decline in the carrying capacity of natural resources. This all means that the various problems that have been concealed by the sustained high rate of development over the years have become bottlenecks that the entire industry must face and breakthrough.

The essence of industrial transformation and upgrading is to follow the development of the times, to transform the previous extensive development and abandon the previous backward development methods. The previous extensive development method did bring a good impact and rich profits to the economy. However, if we keep insisting on this way of development, it will only bring damage to the environment and depletion of resources for human beings. Only through industrial transformation, the integration of various industries drives development. Through industrial transformation, the integration of various industries can bring the greatest social benefits and meet the diversified market demand under the premise of ensuring the ecological environment.

For these reasons, the coal industry has to extend the existing industrial chain for transformation and development, or invest in the layout of new energy fields—both to meet the objective requirements of the external business environment changes, but also to improve internal resource allocation, improve operational efficiency, and effectiveness of the inevitable choice.

2.2. Identification of Influencing Factors of Coal Industry Transformation

There are many factors influencing the transformation of the coal industry. However, the research on the transformation of the coal industry in domestic academic circles started late, and there are fewer studies on the influencing factors for the transformation and development of the coal industry. It is difficult to reflect the influencing factors of the coal industry transformation comprehensively through the literature research method alone. Based on this, in order to comprehensively extract the influencing factors of coal industry transformation development, a combination of literature and case study methods is used to identify the influencing factors.

Literature research method. The keywords “coal transformation” and “coal industry transformation” were used in this part to search the relevant literature through the platforms of “China National Knowledge Infrastructure” (<https://www.cnki.net/> accessed on 28 April 2022) and “Web of Science” (<https://www.webofscience.com/> accessed on 28 April 2022). When screening the literature, we focused on the relationship between its influencing factors and coal transformation. The final ten well-researched pieces of literature were screened. The influencing factors mentioned therein were also summarized and organized to obtain a preliminary list of influencing factors.

Then, the influencing factors are revised through the expert interview method. The 12 influencing factors are finally determined. The specific interpretations are shown in Table 1.

Table 1. List of factors influencing the transformation of the coal industry.

Number	Influencing Factor	Influencing Factors Interpretation
x_1	Resource Endowment	Refers to the coal industry which is based on coal mining, and its transformation and development are inevitably limited by the coal mine resource reserves, the amount available for mining, as well as the annual design capacity of the mine, scenic resources, and other factors [14]
x_2	Safe Production	Refers to the coal industry in the process of transformation and development affected by safety production factors [18]
x_3	Environmental Protection	Refers to the transformation of the coal industry influenced by current environmental protection factors such as low carbonization and cleanliness [19]
x_4	Policy Traction	Refers to the coal industry as a strong policy traction industry, its transformation and development are influenced by national and regional policies [20]
x_5	Market Demand	Refers to the influence of market demand on coal industry transformation under different paths of coal industry transformation [15]
x_6	Technological Change	Refers to the technological development progress, brought about by the impact of the transformation of the coal industry [21]
x_7	Horizontal Competition	Refers to the influence of horizontal competition in the process of transformation and development of the coal industry [22]
x_8	Labor	Refers to the coal industry facing a serious age discontinuity and the impact of different transformation paths on the corporate workforce [23]
x_9	Related Industries and Support	Refers to the impact of the transformation process of the coal industry, the upstream and downstream of the industry chain, and the support of related industries [23]
x_{10}	Capital Funding	Refers to the impact of sustained capital funding support on the transformation of the coal industry in the process of transformation
x_{11}	Location Advantage	Refers to the impact of the transformation process of the coal industry, and the enterprise's location advantages on the transformation [24]
x_{12}	Social Responsibility	Refers to the impact of social responsibility undertaken by the company itself on the transformation of the coal industry [25]

3. DEMATEL–ISM Analysis Methods

The DEMATEL method and the ISM method, as two commonly used system analysis methods to study the relationship between the components of complex systems, have been widely used in many fields [26–29]. The DEMATEL method creates a relationship matrix by an expert assessment of the inter-influence relationships between the factors in the system. It uses the influence degree, influenced degree, centrality degree, and cause degree to determine the category of each factor, that is whether the factor is a causal factor or an outcome result factor, and the degree of influence the factor has on the complex system. Finally, it determines the key factors of the system. However, this method cannot effectively identify the hierarchical structure of the factors in the system. ISM focuses on analyzing the hierarchical relationship between each element.

This paper adopts a combination of DEMATEL and ISM. Firstly, the influence degree among the factors is calculated by the DEMATEL model to find out the key factors. Then, the hierarchical recursive structure among the influencing factors of coal industry transformation is constructed by the ISM model, and the directed topological diagram among the factors is drawn. The specific implementation steps are as follows.

(1) Clarify the elements of the system. Explicitly analyze the elements of which the system is composed, which can be marked as x_1, x_2, \dots, x_n .

(2) Examine the influence relationship between different factors and set the corresponding scale, compare the influence of x_i on x_j by expert scoring method, so as to determine

the degree of direct influence between different factors, and the direct influence matrix A can be obtained.

$$A = \begin{bmatrix} 0 & x_{12} & \cdots & x_{1n} \\ x_{21} & 0 & \cdots & x_{2n} \\ \vdots & \vdots & & \vdots \\ x_{n1} & x_{n2} & \cdots & 0 \end{bmatrix} \quad (1)$$

where factor x_{ij} ($i = 1, \dots, n; j = 1, \dots, n; i \neq j$) indicates the degree of direct influence of factor a_i on factor a_j . If $i = j$, then $x_{ij} = 0$.

(3) Normative direct influence matrix. In this paper, the normalization is performed using the row and maximum value method. First, each row of matrix A is summed. Then, the maximum value is taken among these values. Finally, the factors of the matrix are normalized to obtain the normalized direct influence matrix. According to Formula (1), the direct influence matrix A is normalized to obtain the normalized direct influence matrix B .

$$B = \frac{x_{ij}}{\max(\sum_{j=1}^n x_{ij})} \quad (2)$$

(4) Calculate the comprehensive influence matrix T among the system influencing factors. The comprehensive influence matrix represents the combined effect of direct and indirect influences among system factors. B (the normalized direct influence matrix) will converge to 0 for all values of the matrix after self-multiplication all the time, that is $\lim_{k \rightarrow \infty} B^k = 0$. Therefore, the comprehensive impact matrix T ($T = [t_{ij}]_{n \times n}$) is obtained by the following formula.

$$T = (B + B^2 + \cdots + B^k) = \sum_{k=1}^{\infty} B^k = B(I - B)^{-1} \quad (3)$$

where I is the unit matrix.

(5) Calculate the influence degree, influenced degree, centrality degree, and cause degree of each factor.

The influence degree refers to the sum of the values of each row in T . It represents the combined influence value of the corresponding element of each row on all other elements. It is denoted as D_i .

$$D_i = \sum_{j=1}^n x_{ij}, (i = 1, 2, \dots, n) \quad (4)$$

The degree of being influenced is the sum of the values of each column in T . It represents the combined influence value of the corresponding element in each column on the other elements. It is denoted as C_i .

$$C_i = \sum_{j=1}^n x_{ji}, (i = 1, 2, \dots, n) \quad (5)$$

The centrality indicates the position of the factor in the evaluation system and the magnitude of its role. The centrality of factor i is the sum of the degree of influence and the degree of being influenced. It is denoted as M_i .

$$M_i = D_i + C_i \quad (6)$$

The cause degree is obtained by subtracting the influence degree and the influenced degree of factor i denoted as R_i .

$$R_i = D_i - C_i \quad (7)$$

If the cause degree is greater than 0, this means that the element has a great influence on other elements and is called the cause element. On the contrary, it is called the result element.

(6) Plotting cause–effect diagrams. Using the centrality degree as the horizontal coordinate and the cause degree as the vertical coordinate, a cause–effect diagram is drawn.

(7) Determine the global impact matrix. The global impact matrix E ($E = [e_{ij}]_{n \times n}$) is composed of the comprehensive impact matrix T plus the unit matrix I .

(8) Determine the reachable matrix. Here, it is necessary to introduce a threshold value λ to eliminate relationships with a small degree of influence between factors and to facilitate the division of the hierarchical structure. the value of λ is usually determined by experts or decision makers according to the actual situation. The elements in matrix E are processed by introducing the threshold λ to obtain the reachable matrix F ($F = [f_{ij}]_{n \times n}$).

$$f_{ij} = \begin{cases} 1, & e_{ij} \geq \lambda (i, j = 1, 2, \dots, n) \\ 0, & e_{ij} < \lambda (i, j = 1, 2, \dots, n) \end{cases} \quad (8)$$

(9) Delineate the hierarchy. The reachable set $R(x_i) = \{x_i | f_{ij} = 1\}$ is the set of factors in the corresponding rows of the x_i -element of the reachable matrix F that contain 1. $R(x_i)$ denotes the set of all factors that can be reached from factor x_i . The antecedent set $A(x_i) = \{x_i | F_{ij} = 1\}$ is the set of factors in the corresponding columns of the x_i -element of the reachable matrix F that contain 1. $A(x_i)$ denotes the set of all factors that can be reached from the factor x_i .

If $R(x_i)$ and $A(x_i)$ satisfy $R(x_i) \cap A(x_i) = R(x_i)$, this means that all the x_i factors corresponding to $R(x_i)$ can find the antecedents in $A(x_i)$. The factor is called a factor at a higher level. Then, the corresponding rows and columns are crossed out from the reachable matrix F . The highest-level factors are then extracted from the remaining matrix. The process is repeated until all rows and columns are crossed out.

(10) Plotting the multi-level structure model between factors. Plot the multi-level recursive structure of the multi-layer topology between the factors of the system according to the order in which the factors are delimited.

4. Model Construction and Analysis

This section may be divided into subheadings. It should provide a concise and precise description of the experimental results, their interpretation, as well as the experimental conclusions that can be drawn.

4.1. DEMATEL–ISM Model Construction

According to the constructed list of influencing factors of coal industry transformation (Table 1), 10 experts and scholars of coal industry transformation were invited to score the relationships of influencing factors in Table 1 by using the Delphi method. To ensure the reliability of the scoring results, the invited experts are those closely involved in the coal transition. These include university teachers, corporate researchers, coal industry managers, and employees.

The degree of influence between two influencing factors is indicated by assigning values to each of five levels, such as no influence (0 points), less influence (1 point), general influence (2 points), greater influence (3 points), and very great influence (4 points). The direct influence matrix $A = [x_{ij}]_{n \times n}$ of the coal industry transformation impact factors is constructed. 10 initial direct influence matrices are averaged to eliminate individual differences in expert scoring (rounded). The final obtained direct influence matrix of coal industry transformation influencing factors is shown in Table 2.

Table 2. Direct influence matrix A .

a_{ij}	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}
x_1	0	0	0	0	2	1	3	0	4	3	3	1
x_2	1	0	2	3	0	3	0	3	2	4	0	2
x_3	2	1	0	1	0	3	0	3	1	2	0	2
x_4	0	4	3	0	3	3	1	2	3	4	0	1
x_5	0	2	2	1	0	4	3	2	2	4	1	0
x_6	0	3	3	2	2	0	2	1	3	4	1	0
x_7	0	1	2	1	3	2	0	2	2	3	0	0
x_8	0	2	2	2	1	3	1	0	0	2	0	1
x_9	0	1	1	2	2	3	3	0	0	3	0	1
x_{10}	0	3	2	1	1	4	3	2	4	0	0	1
x_{11}	0	1	0	0	3	0	3	0	2	2	0	0
x_{12}	0	3	3	0	0	2	0	4	0	3	0	0

The matrix of Table 2 is normalized by applying the row and maximum value method. The calculated row sum maximum is 24. The canonical influence matrix can be obtained according to Formula (2). The canonical influence matrix is calculated according to Formula (3), and the comprehensive influence matrix T can be obtained, which is shown in Table 3.

Table 3. Comprehensive impact matrix T .

t_{ij}	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}
x_1	0.0273	0.2236	0.2154	0.1573	0.2537	0.3451	0.3277	0.1894	0.3970	0.4449	0.1534	0.1289
x_2	0.0852	0.3055	0.3695	0.3252	0.1948	0.5115	0.2299	0.3758	0.3763	0.5678	0.0401	0.2117
x_3	0.1117	0.2587	0.2113	0.1919	0.1425	0.3990	0.1704	0.3035	0.2576	0.3839	0.0365	0.1745
x_4	0.0595	0.5066	0.4610	0.2591	0.3404	0.5979	0.3155	0.3933	0.4714	0.6564	0.0465	0.1990
x_5	0.0473	0.3833	0.3760	0.2616	0.2101	0.5619	0.3616	0.3418	0.3937	0.5860	0.0797	0.1312
x_6	0.0517	0.4195	0.4106	0.2994	0.2834	0.4197	0.3226	0.3106	0.4306	0.5882	0.0774	0.1392
x_7	0.0377	0.2812	0.3122	0.2133	0.2753	0.4088	0.1955	0.2870	0.3219	0.4566	0.0332	0.1043
x_8	0.0371	0.3011	0.2951	0.2340	0.1794	0.4054	0.2004	0.1976	0.2222	0.3880	0.0290	0.1363
x_9	0.0361	0.2926	0.2866	0.2522	0.2489	0.4482	0.3130	0.2217	0.2580	0.4707	0.0336	0.1415
x_{10}	0.0486	0.4146	0.3755	0.2648	0.2442	0.5571	0.3496	0.3420	0.4534	0.4378	0.0395	0.1719
x_{11}	0.0212	0.1964	0.1566	0.1160	0.2349	0.2264	0.2594	0.1412	0.2478	0.3130	0.0219	0.0644
x_{12}	0.0412	0.3325	0.3279	0.1617	0.1262	0.3693	0.1540	0.3531	0.2088	0.4124	0.0258	0.1041

Calculating Table 3 according to Formulas (4)–(7), the centrality degree and cause degree of each influencing factor can be obtained, as shown in Table 4.

Table 4. Calculation results of centrality and cause degree.

Factors	Centrality Degree	Cause Degree
x_1	3.4682	2.2590
x_2	7.5087	−0.3221
x_3	6.4393	−1.1561
x_4	7.0432	1.5702
x_5	6.4679	1.0005
x_6	9.0034	−1.4976
x_7	6.1266	−0.2728
x_8	6.0828	−0.8313
x_9	7.0417	−1.0358
x_{10}	9.4048	−2.0067
x_{11}	2.6158	1.3826
x_{12}	4.3241	0.9101

Based on the centrality and cause degree values of each influencing factor calculated in Table 4, the cause–effect diagram of coal industry transformation influencing factors is drawn using MATLAB 9.7 R2019b software, as shown in Figure 3.

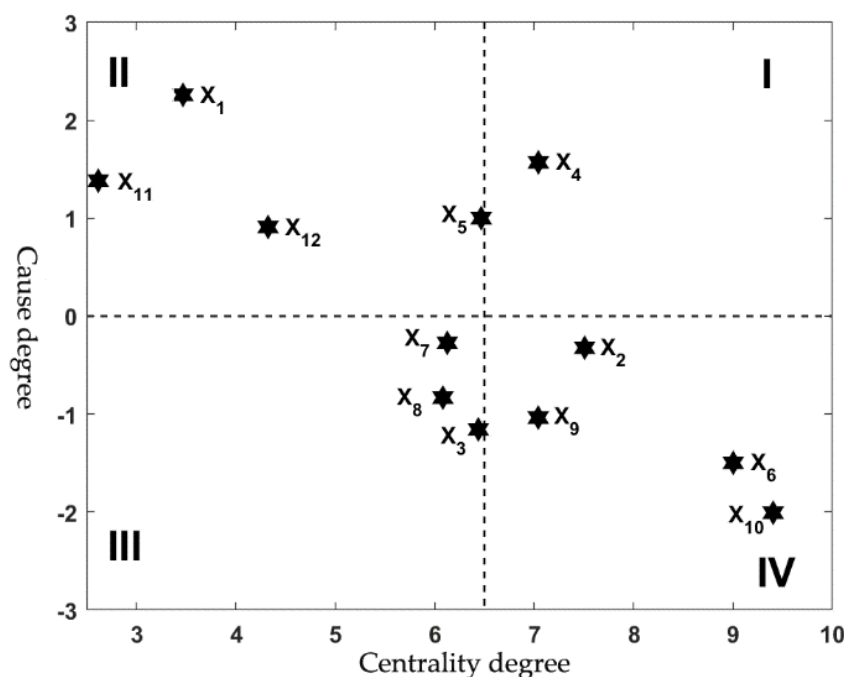


Figure 3. Relation diagram of influencing factors.

The global impact matrix is obtained by adding the comprehensive impact matrix of Table 3 to the unit matrix I . The global impact matrix E calculated is shown in Table 5.

Table 5. Global impact matrix E .

e_{ij}	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}
x_1	1.0273	0.2236	0.2154	0.1573	0.2537	0.3451	0.3277	0.1894	0.3970	0.4449	0.1534	0.1289
x_2	0.0852	1.3055	0.3695	0.3252	0.1948	0.5115	0.2299	0.3758	0.3763	0.5678	0.0401	0.2117
x_3	0.1117	0.2587	1.2113	0.1919	0.1425	0.3990	0.1704	0.3035	0.2576	0.3839	0.0365	0.1745
x_4	0.0595	0.5066	0.4610	1.2591	0.3404	0.5979	0.3155	0.3933	0.4714	0.6564	0.0465	0.1990
x_5	0.0473	0.3833	0.3760	0.2616	1.2101	0.5619	0.3616	0.3418	0.3937	0.5860	0.0797	0.1312
x_6	0.0517	0.4195	0.4106	0.2994	0.2834	1.4197	0.3226	0.3106	0.4306	0.5882	0.0774	0.1392
x_7	0.0377	0.2812	0.3122	0.2133	0.2753	0.4088	1.1955	0.2870	0.3219	0.4566	0.0332	0.1043
x_8	0.0371	0.3011	0.2951	0.2340	0.1794	0.4054	0.2004	1.1976	0.2222	0.3880	0.0290	0.1363
x_9	0.0361	0.2926	0.2866	0.2522	0.2489	0.4482	0.3130	0.2217	1.2580	0.4707	0.0336	0.1415
x_{10}	0.0486	0.4146	0.3755	0.2648	0.2442	0.5571	0.3496	0.3420	0.4534	1.4378	0.0395	0.1719
x_{11}	0.0212	0.1964	0.1566	0.1160	0.2349	0.2264	0.2594	0.1412	0.2478	0.3130	1.0219	0.0644
x_{12}	0.0412	0.3325	0.3279	0.1617	0.1262	0.3693	0.1540	0.3531	0.2088	0.4124	0.0258	1.1041

In order to obtain the reachable matrix, it is necessary to introduce a threshold value λ to eliminate relationships with a small degree of influence. Selecting the value of λ based on expert experience is less objective. Additionally, using the calculation of the sum of mean and standard deviation based on statistical distribution can reduce the influence of subjectivity [18,19]. Therefore, the threshold value λ is calculated as follows.

$$\lambda = \alpha + \beta$$

In the formula, α is the mean of all factors in the combined influence matrix T ; β is the standard deviation of all factors, calculate the threshold λ according to the above formula and the results are as follows: $\alpha = 0.2622$, $\beta = 0.1477$; $\lambda = \alpha + \beta = 0.4099$.

The global influence matrix E (Table 5) is simplified according to the value of λ , and thus the reachable matrix F ($F = [f_{ij}]_{n \times n}$) in the ISM model is calculated. According to Formula (8), the reachable matrix F of the factors influencing the transformation of the coal industry is shown in Table 6.

Table 6. Reachable matrix F .

f_{ij}	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}
x_1	1	0	0	0	0	0	0	0	0	1	0	0
x_2	0	1	0	0	0	1	0	0	0	1	0	0
x_3	0	0	1	0	0	0	0	0	0	0	0	0
x_4	0	1	1	1	0	1	0	0	1	1	0	0
x_5	0	0	0	0	1	1	0	0	0	1	0	0
x_6	0	1	1	0	0	1	0	0	1	1	0	0
x_7	0	0	0	0	0	0	1	0	0	1	0	0
x_8	0	0	0	0	0	0	0	1	0	0	0	0
x_9	0	0	0	0	0	1	0	0	1	1	0	0
x_{10}	0	1	0	0	0	1	0	0	1	1	0	0
x_{11}	0	0	0	0	0	0	0	0	0	0	1	0
x_{12}	0	0	0	0	0	0	0	0	0	1	0	1

The reachable set, the antecedent set, and the intersection of the two factors are determined from the reachable matrix F . When $R(x_i) \cap A(x_i) = R(x_i)$, then $R(x_i)$ is the highest-level factor. Repeat this operation after dividing the hierarchical factors. Until all the levels of the influencing factors are divided, the multi-level recursive structure of the multi-layer topology is obtained.

$$R(x_i) \cap A(x_i) = R(x_i) \quad (9)$$

The first calculation results of the system structure analysis are shown in Table 7.

Table 7. Results of the first-level calculation.

x_i	$R(x_i)$	$S(x_i)$	$R(x_i) \cap S(x_i)$
x_1	x_1, x_{10}	x_1	x_1
x_2	x_2, x_6, x_{10}	x_2, x_4, x_6, x_{10}	x_2, x_6, x_{10}
x_3	x_3	x_3, x_4, x_6	x_3
x_4	$x_2, x_3, x_4, x_6, x_9, x_{10}$	x_4	x_4
x_5	x_5, x_6, x_{10}	x_5	x_5
x_6	$x_2, x_3, x_6, x_9, x_{10}$	$x_2, x_4, x_5, x_6, x_9, x_{10}$	x_2, x_6, x_9, x_{10}
x_7	x_7, x_{10}	x_7	x_7
x_8	x_8	x_8	x_8
x_9	x_6, x_9, x_{10}	x_4, x_6, x_9, x_{10}	x_6, x_9, x_{10}
x_{10}	x_2, x_6, x_9, x_{10}	$x_1, x_2, x_4, x_5, x_6, x_7, x_9, x_{10}, x_{12}$	x_2, x_6, x_9, x_{10}
x_{11}	x_{11}	x_{11}	x_{11}
x_{12}	x_{10}, x_{12}	x_{12}	x_{12}

The elements satisfying Formula (9) are x_2 , x_3 , x_8 , x_9 , x_{10} , and x_{11} . Then, safe production, environmental protection, labor, related industries and support, capital funding, and location advantage are the factors of the first level.

The second calculation results of the system structure analysis are shown in Table 8.

Table 8. Results of the second-level calculation.

x_i	$R(x_i)$	$S(x_i)$	$R(x_i) \cap S(x_i)$
x_1	x_1	x_1	x_1
x_4	x_4, x_6	x_4	x_4
x_5	x_5, x_6	x_5	x_5
x_6	x_6	x_4, x_5, x_6	x_6
x_7	x_7	x_7	x_7
x_{12}	x_{12}	x_{12}	x_{12}

Factors x_1 , x_6 , x_7 , and x_{12} meet the requirements of Formula (9), then resource endowment, technological change, horizontal competition, and social responsibility are the factors of the second level.

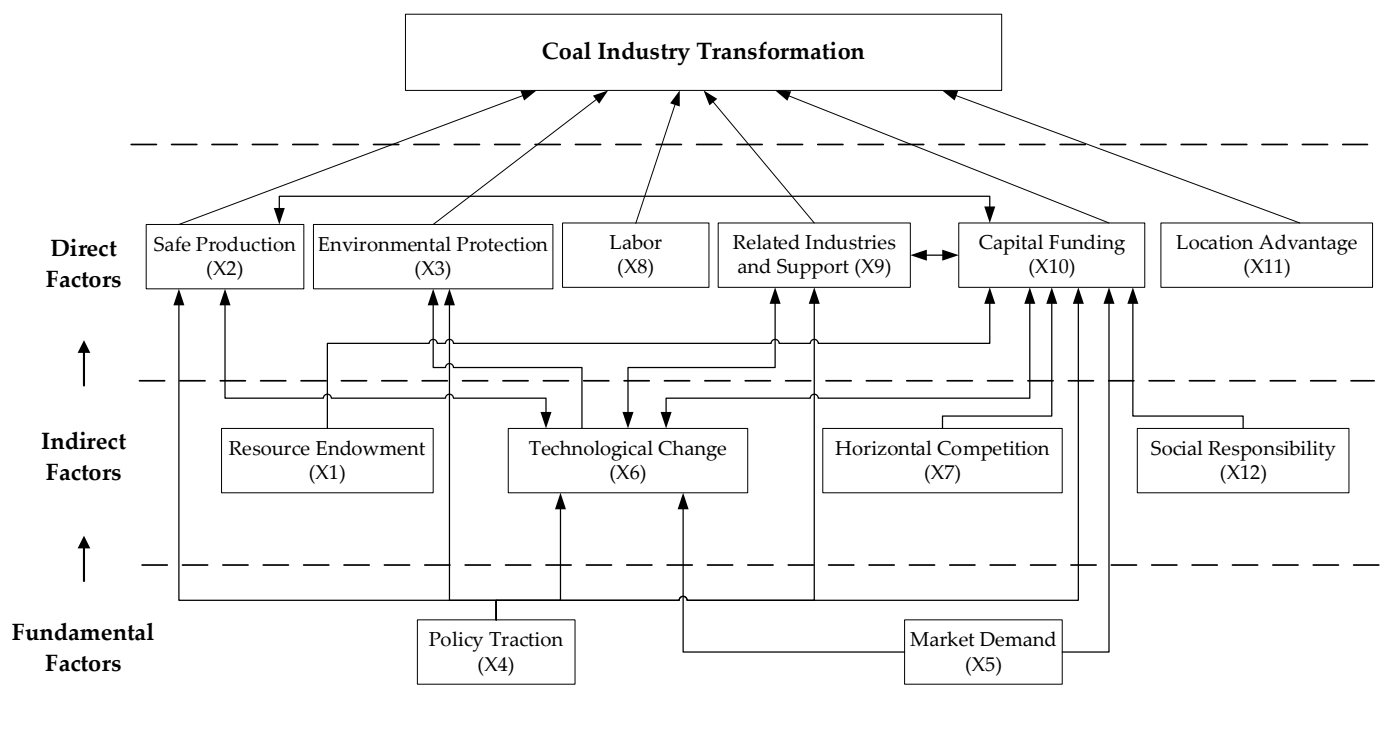
The third calculation results of the system structure analysis are shown in Table 9.

Table 9. Results of the third-level calculation.

x_i	$R(x_i)$	$S(x_i)$	$R(x_i) \cap S(x_i)$
x_4	x_4	x_4	x_4
x_5	x_5	x_5	x_5

The factors that meet the requirements of Formula (9) are x_4 and x_5 , so policy traction and market demand are at the third level.

To sum up, the system structure can be divided into three levels: $L1 = \{x_2, x_3, x_8, x_9, x_{10}, x_{11}\}$, $L2 = \{x_1, x_6, x_7, x_{12}\}$, $L3 = \{x_4, x_5\}$. The multi-level structure model is shown in Figure 4.

**Figure 4.** Hierarchical structure model.

4.2. Analysis of Results

4.2.1. DEMATEL Analysis

The centrality degree of the factor indicates the importance and the role of the factor in the transformation of the coal industry. The greater the centrality, the greater the degree of influence of the factor on the transformation of the coal industry. The influencing factor with the degree of a cause greater than zero is the cause factor. Additionally, the greater the degree of cause, the stronger the influence on other factors. For an influencing factor whose cause degree is less than zero, the factor is the resulting factor.

The relationship diagram (Figure 1) of coal industry transformation influencing factors obtained from the DEMATEL calculation shows that coal industry transformation influencing factors can be divided into four categories. The first category is the set of strong causal factors (Area I). This type of factor has a very significant influence on the transformation of the coal industry and has a greater influence on other outcome-type factors. The second category is the set of weak causal factors (Area II). This type of factor also has an influence on the coal industry transformation and has some influence on other outcome-type factors. The 3rd category is the set of weak outcome factors (Area III). This type of factor is the result of the combined effect of other cause-type factors and has a certain influence on the transformation of the coal industry. The fourth category is the strong outcome factor set (Area IV). This type of factor is also the result of the combined effect of other cause-type factors and has a very important influence on the transformation of the coal industry. The greater the centrality, the greater the degree of its influence. Therefore, we need to focus on the strong cause factor set in Area I and the strong result factor set in Area IV, which are capital financing (x_{10}), technological change (x_6), safety production (x_2), policy traction (x_4), and related industries and support (x_9) in descending order of centrality.

4.2.2. ISM Analysis

The ISM method can visually present the interaction relationship and hierarchical structure among the factors influencing the transformation of the coal industry.

From the results of ISM analysis (Figure 4), it can be seen that there are more complex relationships among coal industry transformation influencing factors such as homogeneous or cross-level linkages. In this model, coal industry transformation factors are divided into three major factor sets: direct factors, indirect factors, and fundamental factors. Among them, safety production (x_2), environmental protection (x_3), labor (x_8), related industries and support (x_9), capital financing (x_{10}), and location advantage (x_{11}) are the direct factors of the coal industry transformation. Resource endowment (x_1), technological change (x_6), horizontal competition (x_7), and social responsibility (x_{12}) are the indirect factors of the coal industry transformation. Policy traction (x_4) and market demand (x_5) are the fundamental factors of the coal industry transformation.

In the ISM model, the factors with more node degrees are safety production (x_2), environmental protection (x_3), policy traction (x_4), market demand (x_5), technological change (x_6), related industries and support (x_9), and capital financing (x_{10}). These factors are generally consistent with the factors with large centrality values analyzed by DEMATEL and need to be focused on.

4.2.3. DEMATEL–ISM Integrated Analysis

A comprehensive analysis of DEMATEL–ISM reveals that the indirect influencing factors of technological change (x_6) in ISM is the strong set of outcome factors that DEMATEL focuses on. Another three strong sets of outcome factors of safety production (x_2), related industries and support (x_9), and capital financing (x_{10}) are the direct factors that ISM focuses on. The two fundamental factors (policy traction and market demand) in the ISM analysis are exactly those causal factors in the DEMATEL analysis. The factor with the lowest node degree in the ISM model is a locational advantage. It is consistent with the value of the least centrality in the DEMATEL analysis. From the above analysis, it can be found that there is a high degree of consistency between the two methods in terms of importance and type of classification

of factors influencing the transformation of the coal industry. This is further evidence of the scientific validity and accuracy of the model analysis.

The comprehensive analysis results show that policy traction (x_4) is the most critical fundamental influencing factor. In the indirect influencing factor layer, technological change (x_6) has the highest importance. Among the direct influencing factors, safety production (x_2), related industries and support (x_9), and capital funding (x_{10}) are important to the coal industry transformation.

5. Conclusions and Recommendations

(1) Based on the combination of literature research and cases, the influencing factors are then revised by the expert interview method. Twelve influencing factors of the coal industry transformation were finally identified.

(2) The attributes of each influencing factor of coal industry transformation were derived using DEMATEL modeling. Five key influencing factors with high importance were screened out based on the cause–effect relationships between factors. Among them, policy traction is the causal factor, and capital financing, technological change, safety production, related industries and support are the outcome factors. The interactions among the influencing factors were analyzed in depth using the ISM method.

(3) The analysis results show that policy traction and market demand are the fundamental influencing factors of the coal industry transformation. Based on this, corresponding strategies and suggestions are proposed for the transformation of the coal industry.

At present, research on coal transformation mainly focuses on path studies and the impact of a particular factor on coal transformation. This study selects 12 factors, including resource endowment, policy traction, market demand, peer competition, and social responsibility, and adopts the DEMATEL–ISM method to study the impact of these factors on coal transformation and the extent of their influence, and further investigates the interactions between these factors. This study is informative and comprehensive, and the findings can provide a reference for further research on the coal industry transformation.

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