Journal of Environmental Science and Engineering B 13 (2024) 21-38
doi:10.17265/2162-5263/2024.01.003

Performance Evaluation of Low-Carbon and Clean Transformation of China's Coal Economy

Liangfeng Zhu
Liu Guojun School of Management, Changzhou University, Changzhou 213159, China

Abstract: In China, the oversupply of coal occurred in 2009, and from that year onwards, China's coal economy began a low-carbon and clean transformation. Evaluating transformation performance is the research goal of this paper. The data collection for this paper includes data on deep processing of Chinese coal products from 2009 to 2020, as well as data on asset structure evolution and financial performance of 34 listed companies in the Chinese coal mining. Entropy value method is used to calculate the entropy value of low-carbon transformation, and the regression analysis is used to study the performance of cleaner transformation, the conclusion is as follows: (1) From 2009 to 2020, in China's total energy consumption, coal consumption accounted for 71.6% in 2009 and 56.8% in 2020, the goals set by the state have been achieved. (2) The national goal of reducing the proportion of coal consumption and reducing carbon emissions has forced the transformation of deep processing of coal products. The transformation of coal enterprises towards low-carbon and clean production has achieved remarkable results. (3) From 2009 to 2020, the non coal industry income of 34 listed companies in China's coal mining industry increased by 8.21% annually. At the same time, the asset structure was adjusted, and nearly 80% of the asset structure evolution showed an orderly development trend. (4) The regression analysis results show that the entropy value of coal deep processing products and the entropy value of asset structure adjustment are significantly related to transformation performance. The paper proposes to summarize the successful experience of China's coal energy economic transformation, lay a foundation for achieving the carbon peak and carbon neutral goals in the future, further increase the intensity of coal deep processing, increase the proportion of clean energy in total energy consumption, and strive to control asset operation towards the goal of increasing the proportion of non coal industry income.

Key words: Coal economy, low-carbon and clean transformation, deep processing of coal, evolution of asset structure, performance appraisal.

1. Current Situation of China's Coal Energy Economic Transformation

Since entering the 21st century, China's Coal Economy has undergone three major stages of development: (1) Economic growth and expansion of coal production capacity (2001-2008). From 2001 to 2008, the development speed of China's economy is very fast, with an average annual growth of 10.7% in GDP (Gross Domestic Product), resulting in tight coal, electricity, oil, and transportation. The highlight of the tension appeared in 2003 [1]. In order to alleviate the tense situation of coal energy, the State Council issued the "Several Opinions on Promoting the Healthy Development of the Coal Industry" in June 2005, explicitly requiring the implementation of "coal resource integration" work, namely, accelerating the construction of modern large coal bases, cultivating large coal enterprises and enterprise groups, and jointly reforming and restructuring medium-sized and small coal mines. The implementation of this measure has led to the rapid increase of China's coal production. In 2005, China's coal production reached 2.35 billion tons, which increased to 2.8 billion tons in 2008, an annual increase of 6%. (2) Coal overcapacity stage (2009-2015). Before 2008, China's coal consumption has been in short supply, but since 2009, there has been a state of oversupply in coal consumption. Since May 2012,

Corresponding author: Liangfeng Zhu, Ph.D., associate professor, research fields: financial management, resource economics, and management.

China's coal market has experienced a severe backlog of excess coal, resulting in a rapid decline in coal prices, and many coal enterprises have stopped production [2]. (3) Stable growth stage of coal production capacity (2016-2020). On February 5, 2016, the State Council issued the "Opinions on Resolving Excess Capacity in the Coal Industry and Realizing the Development of Poverty Alleviation", setting out the goals and tasks for proposed goals and tasks for reducing excess coal production capacity in the next three years, which are broken down to governments at all levels, and then implementing specific indicators for the amount of capacity removed to each coal production enterprise. The implementation of this policy has brought China's coal production capacity into a stage of balanced development between supply and demand [3].

In the process of developing the Coal Economy, the Chinese government has not only adjusted the relationship between coal supply and demand, but also focused on five major issues around the center of "low-carbon" transformation: first, focusing on greenhouse gas emission reduction. In November 2009, the Chinese government made a clear commitment to reduce carbon dioxide emissions per unit of GDP (Gross Domestic Product) by 40% to 45% compared to 2005 by 2020 [4]. This is a reference to the budding state of "low-carbon" transformation. In order to achieve this commitment, the Chinese government has established carbon emission targets through formulating energy development plans. According to the energy development plan of the Chinese government during the "12th Five Year Plan" (2011-2015), CO_2 emissions per unit of GDP in 2015 decreased by 17% compared to 2010; According to the energy development plan for the "13th Five Year Plan" (2016-2020) formulated by the Chinese government, the carbon dioxide emissions per unit of GDP in 2020 will decrease by 18% compared to 2015. Both of these planning goals were successfully and overfulfilled [5, 6]. This is the achievement of carbon peak in achieving emission reduction targets. Second, we will focus on adjusting the energy structure. The focus is to limit the consumption of fossil fuels with the highest carbon emissions (coal and oil) and develop clean energy consumption (natural gas and non fossil fuels for one-time use only). The national goal is to reduce the proportion of coal consumption in total energy consumption to less than 58% by 2020, strive to achieve 10% of natural gas consumption, and increase the proportion of non fossil energy consumption to more than 15%. The actual achievement of this goal is as follows: In 2009, the proportion of coal consumption in China was 71.6%, and in 2020, it decreased to 56.8%; The proportion of natural gas consumption increased from 3.5% in 2009 to 8.4% in 2020, and the proportion of non fossil energy consumption increased from 8.5% in 2009 to 15.9% in 2020. This is the achievement of the carbon peak high-speed energy structure. Third, focus on the management of carbon emissions trading quotas. It means setting carbon emission quotas for relevant enterprises. If the quota is exceeded, it is necessary to purchase carbon emission rights from enterprises with remaining quota indicators through the carbon emission trading market for emissions, otherwise, production will be stopped. In 2013, Shanghai, China, formulated a carbon emissions trading quota management plan for implementation, and other provinces and cities have also implemented the carbon emissions trading quota management policy, with significant implementation effects. Fourth, the state levies environmental protection taxes. From January 1, 2018, the state will levy an Environmental Protection Tax. Any unit that directly emits taxable pollutants into the environment must pay environmental protection tax to the state based on the amount of discharge. This effectively limits carbon emissions from the economic interests of enterprises. Fifth, comprehensively implement the "carbon peak and carbon neutral" policy. September 2020, China made a commitment to the world: strive to achieve "carbon peak" by 2030, and achieve "carbon neutral" by 2060 [7]. This is the comprehensive promotion of carbon peak to the world to make a commitment to transformation decision-making measures.

2. Research Framework Design for Low-Carbon and Clean Transformation of China's Coal Economy

From the above, it can be seen that the transformation of China's coal economy is highlighted in three aspects: the transformation of development speed, low-carbon transformation, and clean transformation. The year 2009 marks the beginning of the low-carbon and clean transformation of China's coal economy. From this point on, the transformation pressure from both the market and the government has forced the conversion of coal energy from single combustion consumption to deep processing into clean energy consumption, prompting coal enterprises to control coal production and develop into non coal industries, promoting the adjustment of the asset operation direction of coal enterprises, and transferring excess coal production funds to non coal industries. How to evaluate the transformation performance of "low-carbon and clean" Coal Economy is the goal of this paper. The research framework of the thesis is designed as follows (Fig. 1).

3. Research on Performance Evaluation Methods for Low-Carbon and Clean Transformation of China's Coal Economy

Zhou [8] used VAR model (Vector Autoregression) and IRF (Impulse Response Function) models to study various influencing factors when studying the long-term equilibrium demand for energy during the period of China's economic transformation. He believed that the transformation of economic growth mode, industrial structure adjustment, industrialization process, and especially the proportion of heavy industrialization played a driving role in the balanced demand for energy. Pang [9] used the Total Factor Energy Efficiency Framework and the Total Factor Productivity Index (Malmquist) method to analyze the relationship between economic growth and total factor energy efficiency

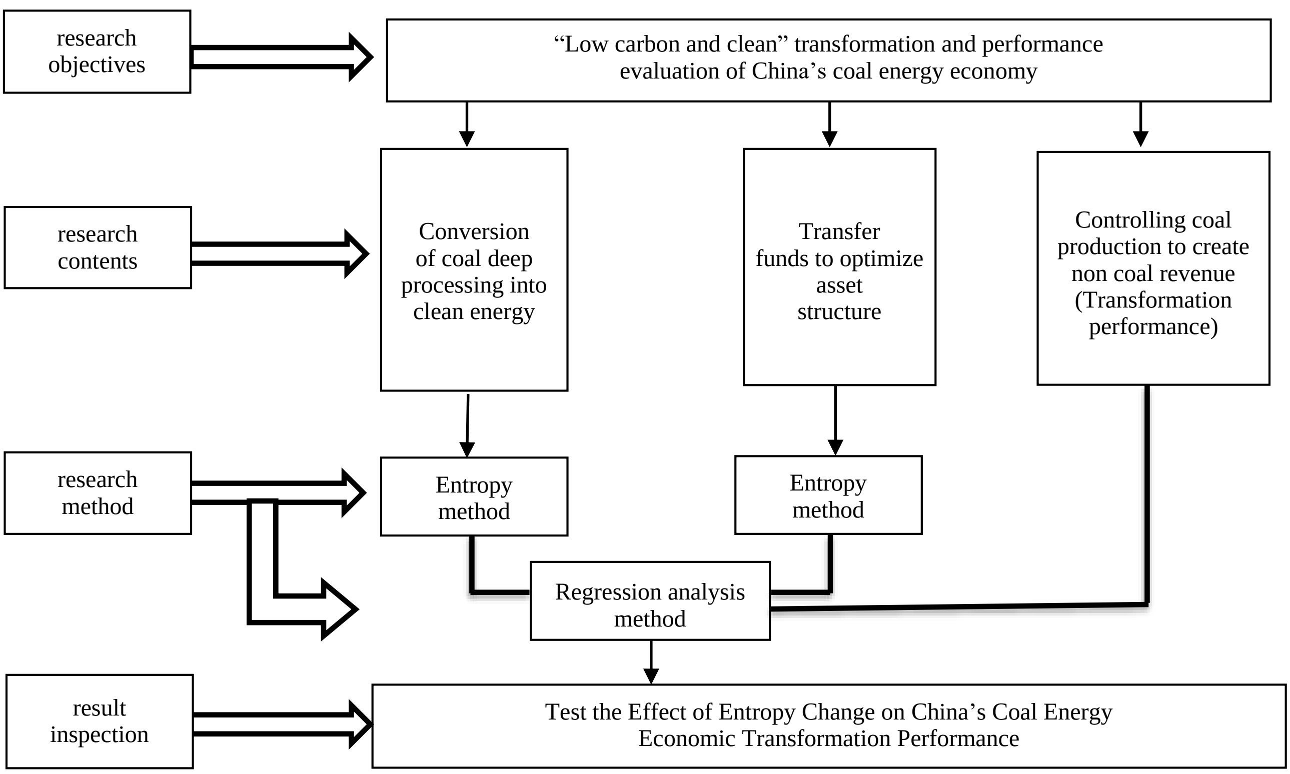

Fig. 1 Design diagram of the research framework of the paper.

in the industrial sector during China's transition period. He believed that there was a U-shaped curve relationship between per capita added value of China's industrial sector and total factor energy efficiency, and the relationship between industrial structure changes and total factor energy efficiency in China's industrial sector reflected the characteristics of heavy industrialization. This indicates that the growth of China's industry is still in an extensive stage, and energy efficiency urgently needs to be optimized and improved. Liu [10] adopted a comparative analysis method to identify five aspects of low-carbon transformation in China's resource-based cities: China's transportation low-carbon transformation, China's government low-carbon transformation, China's community low-carbon transformation, China's school campus low-carbon transformation, and China's consumption sector low-carbon transformation. Taking Daqing City of China as an example, Che and Zhang [11] adopted the coefficient of variation method, entropy method, and hierarchical analysis method to determine the change index of the transformation performance of the resource-based economy in Daqing City of China, including economic index, resource index, environmental index, and social index. The comprehensive index reflects the good economic transformation and operation effect of Daqing City of China. L. F. Zhu and X. Y. Zhu [12] used factor analysis to determine the "market environment constraint index" in the development of China's energy economy, and used regression analysis to determine the relationship between energy policy regulation and market environment constraints on the economic benefits of energy listed companies. They believed that the role index of China's energy policy is positively correlated with the economic benefits of China's energy listed companies, China's market environment constraint index is negatively correlated with the economic benefits of listed energy companies in China. X. Y. Zhu and L. F. Zhu [13] established a theoretical framework for the green transformation of coal resources towards capitalization using the "cohesive subgroup method", including the core content of theories such as capitalization and conservation, environmental protection, harmonious symbiosis, ecological industry, and circular development. Dong F et al. [14] used a spatial econometric model to analyze the relationship between industrial integration and GDE (Green Development Efficiency), and found that there is a close correlation between industrial agglomeration and regional GDE. Green innovation is an effective way for industrial integration to improve regional GDE. L. F. Zhu and X. Y. Zhu [15] used the entropy method to study the crowding effect of asset structure adjustment by listed companies in China's coal industry on the coal economy, and believed that the entropy value of asset structure evolution has a crowding effect on the development of the coal economy. Zhang et al. [16] took the economic transformation of seven typical coal cities in Northeast China as an example, using a balanced scorecard approach to study and determine the efficiency of economic transformation from five aspects: resource dependence, economic level, social welfare, ecological efficiency, and innovation drive. They believe that the transformation of the driving forces of economic growth in these seven cities has achieved the basic goals, among them, Liaoyuan has achieved good performance in developing secondary sector of the economy, and Fuxin has achieved good performance in industrial evolution and substitution, and the ecological efficiency of the seven cities has significantly improved. However, in terms of social welfare, technological innovation, and other aspects, they have not yet achieved the ultimate goal of economic transformation. The above review summarizes the evaluation methods for the transformation performance of China's energy economy, especially Coal Economy, including VAR model method, IRF model method, total factor energy efficiency framework method, total factor productivity index method, comparative analysis method, coefficient of variation method, analytic hierarchy process, factor analysis method, regression analysis method, balanced scorecard method, and entropy method. These methods have achieved the research objectives well. This paper selects entropy method to evaluate the performance of coal energy economic transformation. Although the entropy method is used in the above research, there are two biggest differences in the application of entropy in this article: first, judging whether the evolution of the research object is "orderly" through the entropy value calculated by the entropy method, not simply playing the role of entropy method weight; The second is to combine the results calculated by entropy method with regression analysis method, changing the limitations of single use of entropy method. In addition to using the entropy method to study whether the coal deep processing and capital structure adjustment are orderly, this article also uses the entropy value of the two research results to conduct regression analysis on the transformation performance model to explore whether adjusting the coal energy structure and capital structure has promoted the improvement of the transformation performance of non coal industries.

4. Using Entropy Method to Study the Orderliness of Low-Carbon Transformation of China's Coal Economy

4.1 The Basic Principle and Application Steps of Entropy Method

In 1854, a German physicist, the founder of thermodynamics, R. Clausis, published a paper on "Another Form of the Second Law of Thermal Theory of Mechanics". When expressing the second law of thermodynamic reversible cycle processes in mathematical form, a new term was introduced to reflect the state parameter, named "entropy", and was extended to the entire universe for research. Later, the founder of cybernetics, N. Wiener, and the founder of information theory, C. E. Shannon, perfected "entropy" and proposed a broader concept, "information entropy", which was widely used in various fields, such as engineering and technology, economic and social fields. The entropy method formed today is to study the degree of dispersion of uncertain matters in information theory. The basic principle is that when people study certain (class) events, the amount of information can determine the magnitude of certainty. If the amount of information is larger, the degree of dispersion of events is smaller, and the calculated entropy value is smaller, the system is more orderly; On the contrary, the larger the calculated entropy value, the more chaotic the system is, and the worse the order of the system is.

In the field of economic management, in the past, entropy method was mostly used as a "weight" for research items, while Professor Zhu et al. [17] used entropy method as a method for determining the "order" of things. It is believed that the order of the development of things has a positive effect, while disorder has a negative effect. If the entropy value calculated for the event under study becomes smaller and smaller, the "degree of dispersion" of the event around the main target becomes smaller, and the degree of stability and variation becomes smaller. The evolution of the event becomes more orderly and the positive effect becomes greater; On the contrary, disorderly evolution will have a negative effect. The application steps of entropy method are as follows:

(1) Assume that the total composition of a research system is *G*, and that there are *N* components in the system structure, *N* being 1, 2, ..., *n* respectively, then:

$$G = G_1 + G_2 + G_3 + \cdots + G_n = \sum_{i=1}^{n} G_i \tag{1}$$

(2) Define the weight of entropy T_i:

$$T_i = G_i/G = G_i/\sum_{i=1}^{n} G_i \tag{2}$$

(3) Calculate the logarithm of entropy weight U_i:

$$U_i = Ln(T_i) \tag{3}$$

(4) Compute information entropy V_i:

$$V_i = -T_i \times U_i = -G_i/\sum_{i=1}^{n} G_i \times Ln(T_i) \tag{4}$$

(5) Calculate entropy W_i:

$$W_i = \frac{V_i}{Ln(n)} = -G_i / \sum_{i=1}^{n} G_i \times Ln(T_i)/Ln(n) \quad (5)$$

The "*n*" in Eq. (5) refers to the number of information entropy in the system.

4.2 Determination of Entropy Value and Evaluation of Orderliness of Coal Deep Processing Products

4.2.1 Determination of Entropy Value of Coal Deep Processing Products

Deep coal processing, also known as coal industry chain extension, refers to the process of extending and processing coal products (raw coal, coal washing, and coal preparation) into other physical products. What is the role of coal deep processing? The biggest effect is to reduce carbon emissions. Research shows that coal products are primary products. If burned directly as fuel, the result is: burning one ton of coal produces 16 kg of sulfur dioxide (SO_2), produces 10,000 m^3 of exhaust gas, and produces 200 kg of soot [18]. If coal processing is converted to clean energy use, carbon emissions will be greatly reduced. This is an important reason why the Chinese government is promoting the low-carbon and clean transformation of the coal industry.

The deep processing of coal in China produces five major products: first, conversion to electricity; second, conversion to heat; third, coking; fourth, coal to oil; fifth, conversion to coal gas. In the China Statistical Yearbook, the products of coal processing and conversion in the "Coal Balance Sheet" are divided into five categories: thermal power generation, heat supply, coking, coal to oil, and gas production (i.e. gas production). According to the application steps of entropy method, the process of calculating the entropy value of coal deep processing products is as follows:

(1) The total amount used for coal processing and conversion is *G*, and the *N* present in the system structure has five components, then:

G=*G1*+*G2*+*G3*+*G4*+*G5*=coal for thermal power generation+coal for heating+coal for coking+coal for coal to oil+coal for coal gas

The coal consumption for conversion of coal products into extension products in China from 2009 to 2020 is shown in Table 1.

Table 1 shows the output of coal products used for processing and conversion in China. In 2009, it was 2,041.7 million tons, increasing to 3,212.48 million tons in 2020, with an average annual increase of 4.21%. Among them, the fastest increasing rate is coal to oil, although the conversion amount is not large, but it increases by 34.72% per year (2010-2020), followed by coal for gas coal production, with an average annual increase of 9.13%, and again, coal for heating, annual average growth of 8.04%. In particular, the increasing speed of coal gas and heating coal reflects the importance that the Chinese government and its enterprises place on the needs of people's lives.

(2) Define the weight of entropy T_i:

$$T_i = G_i/G = G_i / \sum_{i=1}^{n} G_i \quad (6)$$

The proportion of coal products used for extended conversion products in China from 2009 to 2020 is shown in Table 2.

(3) Calculate the logarithm of entropy weight U_i:

$$U_i = Ln(T_i) \quad (7)$$

The calculation of the logarithm of coal products used for extended conversion products in China from 2009 to 2020 is shown in Table 3.

(4) Compute information entropy V_i:

$$V_i = -T_i \times U_i = -G_i / \sum_{i=1}^{n} G_i \times Ln(T_i) \quad (8)$$

The information entropy calculation of coal products used for extended conversion products in China from 2009 to 2020 is shown in Table 4.

(5) Calculate entropy W_i:

$$W_i = \frac{V_i}{Ln(n)} = -G_i / \sum_{i=1}^{n} G_i \times Ln(T_i)/Ln(n) \quad (9)$$

Table 1 **Coal consumption for conversion of China's coal products into extended products from 2009-2020 (Unit: 10,000 tons).**

Item	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
(1) Thermal power generation	143,967	153,742	175,579	183,531	195,177	189,525	179,568	182,666	193,925	205,197	210,159	212,400
(2) Heating	15,360	17,553	19,334	23,780	22,710	22,445	24,115	26,577	28,983	32,388	34,442	35,978
(3) Coking	43,692	49,950	56,060	56,768	62,536	63,944	60,874	60,649	58,910	61,603	65,673	65,658
(4) Coal to oil		213	346	378	459	650	679	1,105	1,568	2,497	3,240	4,204
(5) Coal gas	1,151	1,040	870	849	846	858	1,320	1,212	1,663	2,010	2,459	3,008
(6) Coal processing conversion volume total=1+2+3+4+5	204,170	222,498	252,189	265,306	281,728	277,422	266,556	272,209	285,049	303,695	315,973	321,248

Data source: China Statistical Yearbook published by the National Bureau of Statistics in various years.

Table 2 **Proportion of coal products used for extension conversion in China from 2009 to 2020 (Project No. continued Table 1).**

Item	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
(7) Proportion of thermal power generation=1/6	0.7051[a]	0.6910	0.6962	0.6918	0.6928	0.6832	0.6737	0.6710	0.6803	0.6757	0.6651	0.6612
(8) Proportion of heating=2/6	0.0752	0.0789	0.0767	0.0896	0.0806	0.0809	0.0905	0.0976	0.1017	0.1066	0.1090	0.1120
(9) Proportion of coking=3/6	0.2140	0.2245	0.2223	0.2140	0.2220	0.2305	0.2284	0.2228	0.2067	0.2028	0.2078	0.2044
(10) Proportion of coal to oil=4/6		0.0010	0.0014	0.0014	0.0016	0.0023	0.0025	0.0041	0.0055	0.0082	0.0103	0.0131
(11) Proportion of coal gas=5/6	0.0056	0.0047	0.0034	0.0032	0.0030	0.0031	0.0050	0.0045	0.0058	0.0066	0.0078	0.0094
(12) Coal processing conversion ratio total=7+8+9+10+11	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

[a] 143,967 (in the first row of Table 1) ÷ 204,170 = 0.7051 in the sixth row of Table 1; Other analogies.

Table 3 **Calculation of logarithmic proportion of coal products used for extended conversion in China from 2009 to 2020 (Project No. continued in Table 2).**

Item	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
(13) Thermal power generation logarithm =*Ln* (*Line*7)	-0.3494[b]	-0.3696	-0.3621	-0.3685	-0.3670	-0.3810	-0.3950	-0.3989	-0.3852	-0.3921	-0.4078	-0.4137
(14) heating logarithm =*Ln* (*Line*8)	-2.5872	-2.5397	-2.5683	-2.4120	-2.5181	-2.5145	-2.4027	-2.3265	-2.2860	-2.2382	-2.2164	-2.1893
(15) coking logarithm =*Ln* (*Line*9)	-1.5418	-1.4939	-1.5038	-1.5419	-1.5052	-1.4675	-1.4768	-1.5015	-1.5766	-1.5953	-1.5710	-1.5878
(16) coal to oil logarithm =*Ln* (*Line* 10)		-6.9494	-6.5915	-6.5537	-6.4196	-6.0563	-5.9727	-5.5064	-5.2027	-4.8008	-4.5801	-4.3362
(17) coal gas logarithm =*Ln* (*Line*11)	-5.1783	-5.3657	-5.6694	-5.7446	-5.8082	-5.7787	-5.3076	-5.4144	-5.1439	-5.0177	-4.8559	-4.6709
(18) coal processing conversion logarithm total=13+14+15+16+17	-4.4783	-11.3527	-11.0257	-10.8762	-10.8100	-10.4193	-10.2472	-9.7333	-9.4505	-9.0264	-8.7752	-8.5270

[b] Ln (0.7051 in Line 7 of Table 2)=-0.3494; Other analogies.

Table 4 **Calculation of information entropy of China's coal products used for extended conversion Products from 2009 to 2020 (Project numbers continued in Tables 2 and 3).**

Item	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
(19) thermal power generation information entropy=-7×13	0.2464[c]	0.2554	0.2521	0.2549	0.2543	0.2603	0.2661	0.2677	0.2621	0.2649	0.2712	0.2736
(20) heating information entropy=-8×14	0.1946	0.2004	0.1969	0.2162	0.2030	0.2034	0.2174	0.2272	0.2324	0.2387	0.2416	0.2452
(21) coking information entropy=-9×15	0.3299	0.3354	0.3343	0.3299	0.3341	0.3383	0.3373	0.3345	0.3258	0.3236	0.3265	0.3245
(22) coal to oil information entropy=-10×16		0.0067	0.0090	0.0093	0.0105	0.0142	0.0152	0.0224	0.0286	0.0395	0.0470	0.0567
(23) coal gas information entropy=-11×17	0.0292	0.0251	0.0196	0.0184	0.0174	0.0179	0.0263	0.0241	0.0300	0.0332	0.0378	0.0437
(24) coal processing conversion information entropy total=19+20+21+22+23	0.7709	0.1946	0.1946	0.1946	0.1946	0.1946	0.1946	0.1946	0.1946	0.1946	0.1946	0.9000

[c] (-1) ×0.7051 (Table 2 Line 7) ×-0.349 (Line 13 of Table 3) = 0.2464; Other analogies.

In the formula, n: In 2009, there are four kinds of information entropy (thermal power generation information entropy, heating information entropy, coking information entropy, and coal gas making information entropy), $n = 4$, and in the remaining years, $n = 5$, then Ln(4) = 1.3863, and Ln(5) = 1.6094. The calculation of entropy value of coal products used for extended conversion products in China from 2009 to 2020 is shown in Table 5.

4.2.2 Evaluation of Entropy Value of Coal Deep Processing Products

From Table 5, it can be seen that the two entropy values used for coal processing and conversion in China decreased from 2009 to 2020: first, the entropy value of thermal power generation decreased. In 2009, it decreased from 0.1777 to 0.1700 in 2020; The second is the coking entropy value, which decreased from 0.2380 in 2009 to 0.2016 in 2020. This indicates that China's thermal power generation and coking coal are developing in an orderly and balanced manner. In fact, China's thermal power generation continues to be constrained, and the country continues to develop pollution-free hydropower, wind power, nuclear power, etc. In 2009, China's thermal power generation reached 2,982.8 billion kilowatt hours, accounting for 80.3% of China's total power generation of 3,714.7 billion kilowatt hours. In 2020, China's thermal power generation reached 5,330.2 billion kilowatt hours, accounting for 68.5% of China's total power generation of 7,779.1 billion kilowatt hours. In 2011, it decreased by 11.8 percentage points (80.3%-68.5%), and decreased by 1.07 percentage points in one year. China is the world's largest producer of coke. China's coke is mainly used for blast furnace ironmaking, and some of it is exported. Therefore, the consumption of coke in China largely depends on the development of the steel industry. In 2009, China produced 355.1 million tons of coke, increasing to 47.116 million tons in 2020, an annual increase of 2.6%, lower than the average annual growth rate of 6.1% in China's steel production during the same period. In 2009, China exported 540,000 tons of coke and semi coke, increasing to 3.19 million tons in 2020, with an annual increase of 17.5%, higher than the 7.2% annual growth rate of China's total export of goods during the same period. In other words, on the premise of ensuring normal domestic demand for coke, China has continuously increased exports in exchange for foreign exchange. The coal used to produce coke is developing in an orderly and balanced manner with the satisfaction of domestic and foreign markets. There are three coal processing products with a gradual increase in entropy: the entropy of heating increased from 0.1404 in 2009 to 0.1523 in 2020; The entropy value of coal to oil increased from 0.0041 in 2010 to 0.0353 in 2020, which can be ignored due to the small amount of coal used; The entropy value of coal gas production increased from 0.0211 in 2009 to 0.0272 in 2020, basically unchanged. Leaving aside the latter two, it is mainly coal for heating. China's heat supply is mainly used to provide heat for urban people's lives and production and operation of enterprises and institutions. The fuels include coal, heavy oil, and natural gas, and coal heating is the main body. Although using coal as fuel for heating is harmful to the environment, it is necessary to ensure the living needs of the people (using steam and hot water). Therefore, it is possible to reduce this indicator for orderly evaluation.

4.3 Determination of Entropy Value of Asset Structure Adjustment and Evaluation of Order in Coal Enterprises

4.3.1 Determination of Entropy Value for Asset Structure Adjustment of Coal Enterprises

The most important support for the low-carbon and clean transformation of China's coal economy is funding. When the supply of coal in China's energy market exceeds demand, the Chinese government requires coal companies to "remove excess coal capacity". At this time, coal enterprises must control coal production and transfer and invest operating funds for coal production to non coal industries. In this way, the asset structure of coal production enterprises will change. For example, the production of coal products requires tunneling machines, coal mining machines, coal lifting and transportation equipment, as well as corresponding working capital and manpower. In 2009, the combined operating capital of fixed assets and current assets of 34 coal listed companies in China accounted for 76.4% of the total assets. After more than a decade of adjustment to the non coal industry, this proportion decreased to 73.0% by 2020. Whether the evolution of this asset structure is scientific or orderly requires evaluation through entropy calculation.

(1) Total assets (*G*) of listed coal companies in China. There are 34 listed companies in China's coal industry (ST companies that have been suspended and specially treated have been canceled). Its total assets are divided into five categories: *G1* current assets (monetary capital, accounts receivable, inventory, etc.); *G2* non current asset investment (credit investment, other credit investment, long-term equity investment, other equity instrument investment, investment real estate, other non current financial assets), *G3* fixed assets (fixed asset entry value, ongoing construction, engineering materials, use rights assets, etc.), *G4* intangible assets (mining rights, land use rights, patent rights, trademark rights, etc.), *G5* other long-term assets (long-term unamortized expenses, long-term receivables, development expenses, etc.).

Total assets *G*=*G1*+*G2*+*G3*+*G4*+*G5*=current assets+non current asset investments+fixed assets+intangible assets+other long-term assets

It must be pointed out that there are many detailed classifications of "other long-term assets" projects, and the author uses the "backward calculation method" when calculating indicators, that is, on the premise of knowing the total amount of assets, *G5*=*G*-(*G1*+*G2*+*G3*+*G4*).

See Table 6 for the annual summary data of asset distribution of 34 listed companies in China's coal mining from 2009 to 2020.

(2) The asset structure (T_i) of listed coal companies in China. Using the data in Table 6, the data of various indicators are divided by the total assets to obtain the proportion of various indicators. The asset structure of 34 listed companies in China's coal mining from 2009 to 2020 is calculated based on annual summary data, as shown in Table 7.

(3) Calculation of various asset entropy values (W_i) of listed coal companies in China. In order to save space in the article, the entropy value formula (W_i) is directly used to calculate the entropy value of various assets. The calculation of various asset entropy values of 34 listed companies in China's coal mining from 2009 to 2020 is shown in Table 8.

4.3.2 Evaluation of Entropy Value of Asset Structure Adjustment in Coal Enterprises

From Table 8, it can be seen that from 2009 to 2020, the entropy values of various assets calculated by 34 listed companies in China's coal mining decreased in three ways: first, the entropy value of current assets decreased from 0.2284 in 2009 to 0.2199 in 2020; The second is the entropy value of fixed assets, which decreased from 0.2271 in 2009 to 0.2221 in 2020; The entropy value of other long-term assets decreased from 0.1394 in 2009 to 0.0998 in 2020. The development of these three types of assets in an orderly manner indicates that listed companies in China's coal industry have actively transferred operating funds (especially fixed asset funds and current asset funds) to non coal industries under the background of national "capacity reduction" and carbon emission restrictions, achieving good performance.

The entropy value of non current asset investment shows an upward trend, rising from 0.0510 in 2009 to 0.1207 in 2020; The entropy value of intangible assets also showed an upward trend, rising from 0.1576 in 2009 to 0.1708 in 2020. The former refers to expenditures incurred by enterprises in purchasing real estate, making long-term equity investments, and investing in other equity instruments. Generally speaking, during the transformation period of Chinese coal enterprises, expanding non coal businesses is the first choice. Non current assets investing is not necessarily a wise behavior,

Table 5 Calculation of entropy value of coal products used for extended conversion in China from 2009 to 2020 (Project No. Continued in Table 4).

Item (year 2009 ÷1.3863[#])	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
(25) entropy value of thermal power generation =19/1.6094	0.1777[d]	0.1587[e]	0.1566	0.1584	0.1580	0.1617	0.1654	0.1663	0.1628	0.1646	0.1685	0.1700
(26) entropy value of heating=20/1.6094	0.1404	0.1245	0.1223	0.1343	0.1261	0.1264	0.1351	0.1411	0.1444	0.1483	0.1501	0.1523
(27) entropy value of coking=21/1.6094	0.2380	0.2084	0.2077	0.2050	0.2076	0.2102	0.2096	0.2079	0.2025	0.2011	0.2029	0.2016
(28) entropy value of coal to oil=22/1.6094		0.0041	0.0056	0.0058	0.0065	0.0088	0.0095	0.0139	0.0178	0.0245	0.0292	0.0353
(29) entropy value of coal gas=23/1.6094	0.0211	0.0156	0.0122	0.0114	0.0108	0.0111	0.0163	0.0150	0.0186	0.0206	0.0235	0.0272
(30) entropy value of coal processing conversion total=25+26+27+28+29	0.5561	0.4957	0.4923	0.5035	0.4982	0.5071	0.5194	0.5292	0.5275	0.5385	0.5507	0.5592

#：In Table 5, only the entropy values for 2009 are 4 (see numbers 25, 26, 27, 29), so Ln (4)=1.3863 is used as the denominator for the information entropy in Table 4, that is: 0.2464 (Line 19 of Table 4) ÷Ln(4) = 0.2464 ÷1.3863 = 0.1777，0.1946 ÷Ln (4)=0.2464 ÷1.3863=0.1004 in the 20th row of Table 4, 0.3299 ÷Ln (4)=0.2464 ÷1.3863=0.2380 in the 21st row of Table 4, 0.0292 ÷Ln (4)=0.2464 ÷1.3863=0.0211 in the 23rd row of Table 4; However, in Table 5, there are 5 entropy values for each year from 2010 to 2020, so Ln (5)=1.6094 is used as the denominator of the information entropy in Table 4, that is: [e] 0.2554 (Line 19 of Table 4) ÷Ln(5) = 0.2554 ÷1.6094 = 0.1587; Other analogies.

Table 6 Annual summary data sheet of asset distribution of 34 listed companies in China's coal mining from 2009 to 2020 (Unit: 100 million yuan).

Item	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
(1) current assets	2,608.42	3,334.08	3,977.83	4,138.35	4,020.70	4,308.58	4,619.36	4,678.46	5,351.64	6,456.95	5,578.08	6,026.22
(2) non current asset investment	157.80	208.74	264.88	351.82	411.89	503.00	564.47	663.11	822.08	989.01	1,663.43	1,667.19
(3) fixed assets	3,040.71	4,293.73	5,335.30	6,647.90	6,585.43	8,554.56	9,186.56	9,177.02	9,259.22	8,832.24	9,197.71	10,188.61
(4) intangible assets	882.02	1,129.08	1,505.05	2,044.79	2,031.27	2,085.20	2,216.27	2,377.38	2,590.73	2,715.56	2,868.37	3,101.18
(5) other long-term assets	706.42	199.94	404.55	590.95	1,890.03	785.03	859.39	945.05	947.80	959.90	919.96	1,235.64
(6) total assets =1+2+3+4+5	7,395.37	9,165.57	11,487.61	13,773.81	14,939.32	16,236.37	17,446.05	17,841.02	18,971.47	19,953.66	20,227.55	22,218.84

Data source: According to Zhongcai. Com (https://www.cfi.net.cn/) "Balance sheet" related data of 34 listed companies in the coal industry are summarized by year.

Table 7 Annual summary data calculation of the asset structure of 34 listed companies in China's coal mining from 2009 to 2020 (Project No. Continued in Table 6).

Item	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
(7) Proportion of current assets=1/6	0.3527[a]	0.3638	0.3463	0.3005	0.2691	0.2654	0.2648	0.2622	0.2821	0.3236	0.2758	0.2712
(8) Proportion of non current asset investment=2/6	0.0213	0.0228	0.0231	0.0255	0.0276	0.0310	0.0324	0.0372	0.0433	0.0496	0.0822	0.0750
(9) Proportion of fixed assets=3/6	0.4112	0.4685	0.4644	0.4826	0.4408	0.5269	0.5266	0.5144	0.4881	0.4426	0.4547	0.4586
(10) Proportion of intangible assets=4/6	0.1193	0.1232	0.1310	0.1485	0.1360	0.1284	0.1270	0.1333	0.1366	0.1361	0.1418	0.1396
(11) Proportion of other long-term assets=5/6	0.0955	0.0218	0.0352	0.0429	0.1265	0.0484	0.0493	0.0530	0.0500	0.0481	0.0455	0.0556
(12) Proportion of total assets =7+8+9+10+11	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

[a] 2,608.42 (in the first line of Table 6) ÷7,395.37 (in the sixth line of Table 16) = 0.3527; Other analogies.

Table 8 Calculation table of entropy value of various assets of 34 listed companies in China's coal mining from 2009 to 2020 (Project No. Continued in Table 6).

Item	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
(13) entropy value of current assets	0.2284[b]	0.2286	0.2282	0.2245	0.2195	0.2187	0.2186	0.2181	0.2218	0.2268	0.2207	0.2199
(14) entropy value of non current asset investment	0.0510	0.0535	0.0540	0.0582	0.0615	0.0669	0.0690	0.0760	0.0845	0.0925	0.1276	0.1207
(15) entropy value of fixed assets	0.2271	0.2207	0.2213	0.2185	0.2244	0.2098	0.2098	0.2125	0.2175	0.2241	0.2227	0.2221
(16) entropy value of intangible assets	0.1576	0.1603	0.1654	0.1759	0.1686	0.1638	0.1629	0.1669	0.1689	0.1686	0.1721	0.1708
(17) entropy value of other long-term assets	0.1394	0.0518	0.0732	0.0839	0.1625	0.0910	0.0921	0.0967	0.0930	0.0907	0.0873	0.0998
(18) entropy value of total assets =13+14+15+16+17	0.8034	0.7149	0.7422	0.7610	0.8364	0.7502	0.7524	0.7702	0.7858	0.8029	0.8305	0.8334

[b] 0.3527 (in line 7 of Table 7) ×Ln(0.3527) ×(-1) ÷Ln(5) = 0.3527 ×(-1.0421) ×(-1) ÷1.6094 = 0.2284; Other analogies.

and entropy values also appear to be "disorderly"; The latter is mainly caused by listed companies in the coal industry purchasing mining rights (including stock mining rights, newly purchased exploration rights, and mining rights), and land ownership. In the past, Chinese coal enterprises have used the mining rights of the state for a long time without compensation. In September 2006, China began to convert the mining rights obtained without compensation in the past into paid use in the coal industry. Each coal mining enterprise must pay the mining right price for the existing mineral resources, and must pay the market price for obtaining new mining rights in the future. Many new mines also have to buy land use rights (China's land ownership belongs to the state). These two expenditures are not the initial expenditures of coal mining enterprises, but the expenditures brought about by changes in national policies, and their entropy value is reflected as "disorderly".

Overall, the asset structure of 34 listed companies in China's coal mining has shown an orderly development trend. Taking the data from 2020 as an example, the current assets of 34 listed companies with a declining entropy value accounted for 27.12%, with fixed assets accounting for 45.86%, and other long-term assets accounting for 5.56%, accounting for 78.54% (see Table 6 for data). That is, nearly 80% of assets are in an "orderly" operating state.

5. Using Regression Analysis to Study the Performance of China's Coal Enterprises in Clean Transformation

5.1 Setting of Dependent Variables and Data Collection and Evaluation Variables

There are two significant signs of the "low-carbon" transformation of China's coal economy: (1) reducing the proportion of coal consumption in energy consumption and increasing the proportion of clean energy [19]; (2) reducing carbon emissions from coal consumption [20]. This has forced Chinese coal enterprises to transform towards clean energy: first, to further process coal into clean energy for use [21]; The second is to develop non coal industries without carbon emissions [22]. Developing non coal industries is an important indicator of the degree of clean transformation of Chinese coal enterprises, which is the long-term development strategic positioning of Chinese coal enterprises. "Non coal industry revenue ratio" (NoCoaRev) is set as the dependent variable of the clean transformation model for Chinese coal enterprises. The calculation formula is as follows:

Proportion of non coal industry revenue=1 - Proportion of coal main business revenue

From 2009 to 2020, 34 listed companies in the coal industry made statistics on the proportion of coal main business revenue and non coal industry revenue based on annual summary indicators, as shown in Table 9.

Based on the "non coal industry revenue proportion" data in Table 9, Excel software is used to draw a line chart, and then a trend line is added to reveal the line equation, as shown in Fig. 2 below.

From Table 9 and Fig. 2, it can be seen that the proportion of non coal industry revenue of 34 listed companies in the coal industry continued to rise from 2009 to 2020. From a broken line perspective, the proportion of non coal industry revenue in 2009 rose to 43.63%, rising to 46.64% in 2020, with the highest point being 46.79% in 2017; From the perspective of the trend line, the proportion of non coal industry revenue has shown a continuous upward trend. Using the equation, it was 40.38% in 2009 ($y = 0.0038 \times 1 + 0.4 = 0.4040$, where "1" is the first ordinal year of 2009), and 44.56% in 2020 ($y = 0.0038 \times 12 + 0.4 = 0.4456$, where "12" is the 12th ordinal year in 2020), with an average annual increase of 0.90%. In other words, China's coal enterprises have been gradually developing during the transformation process, with the proportion of non coal revenue generated by transferring coal production funds to non coal production funds accounting for almost one percentage point (0.90%) of total revenue each year.

Table 9 Proportion of coal main business revenue and non coal industry revenue by 34 listed companies in the coal industry according to annual summary indicators from 2009 to 2020.

Item	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
(1) Proportion of coal main business revenue	0.5633	0.5720	0.5992	0.6027	0.6072	0.5911	0.6233	0.5441	0.5321	0.5521	0.5810	0.5336
(2) Proportion of non coal industry revenue = 1- Proportion of coal main business revenue	0.4367	0.4280	0.4008	0.3973	0.3928	0.4089	0.3745	0.4559	0.4679	0.4479	0.4190	0.4664

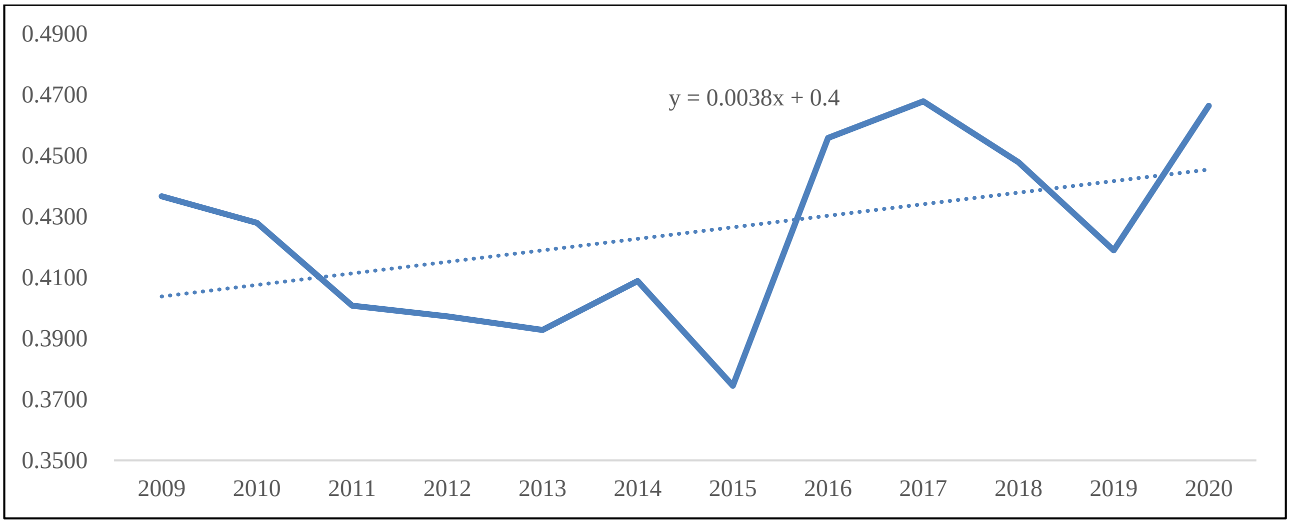

Fig. 2 Broken line and trend chart of non coal industry revenue of 34 listed companies in China's coal mining from 2009 to 2020.

5.2 Setting of Independent Variables and Data Collection

The first is the setting of conversion variables (entropy values) for coal deep processing, including: thermal power generation entropy (*ThermEnt*), heating entropy (*TeatiEnt*), coking entropy (*CokinEnt*), coal to oil entropy (*CoaLiEnt*), and coal gas production entropy (*GasEnt*).

The second is the setting of the asset structure adjustment variable (entropy value) of coal enterprises, including: current asset entropy (*CurreEnt*), non current asset entropy (*NoCurEnt*), fixed asset entropy (*FixAsEnt*), intangible asset entropy (*IntAsEnt*), and other long-term asset entropy (*OtlonEnt*).

The above coal deep processing conversion variable data uses Table 5, "China's coal products used for extending the entropy value of conversion products from 2009 to 2020", and it is necessary to allocate the entropy value of each year to 34 coal listed companies; The above variable data of asset structure adjustment of coal enterprises are used by China Finance Network (https://www.cfi.net.cn/). The relevant data on the "balance sheet" of 34 listed coal companies have calculated the "entropy value of various assets of 34 listed companies in China's coal mining from 2009 to 2020".

5.3 Construction and Application of Regression Analysis Model

5.3.1 Establishment of a Clean Transformation Performance Model for Chinese Coal Enterprises

The performance model of China's coal enterprises' clean transformation is constructed as follows:

$$NoCoaRev = \alpha_0 + \alpha_1 ThernEnt + \alpha_2 TeatiEnt + \alpha_3 CokinEnt + \alpha_4 CoalLiEnt + \alpha_5 GasEnt + \alpha_6 CurreEnt + \alpha_7 NoCurEnt + \alpha_8 FixAsEnt + \alpha_9 IntAsEnt + \alpha_{10} OtlonEnt + \varepsilon$$

5.3.2 Application of a Regression Model for the Performance of China's Coal Enterprises in Cleaner Transformation

Log into Zhongcai.com (https://www.cfi.net.cn/), collect the "proportion of non coal industry revenue" data of 34 listed companies in China's coal mining from 2009 to 2020—dependent variable data and independent variable data, and operate the SPSS26.0 statistical software to obtain the following regression analysis results, as shown in Table 10.

From Table 10, it can be seen that the adjusted regression analysis chi-square (Adj R^2) coefficient is 0.976, which is far greater than the critical value of 0.5, indicating that the model's independent and dependent variables have a good fit and are highly interpretable. A total of 10 independent variables, namely, the entropy value of deep processing of coal products and the entropy value of asset structure, are compared with the dependent variable of the proportion of non coal industry revenue. The regression result shows that except for the fact that the coking entropy value does not have a significant sign (referring to the regression analysis table, the significance coefficient is actually 0.508, which is greater than the standard value of 0.1), the remaining 9 have passed the significance test (the significance coefficient is less than 0.05 or 0.1), This indicates that the deep processing of coal products and the adjustment of asset structure have significantly increased the proportion of non coal industry revenue.

Table 10 Regression results of the proportion of non coal industry and the entropy value of deep processing of coal products and asset structure of 34 listed companies in China's coal mining from 2009 to 2020.

Variable	Dependent variable: proportion of non coal industry revenue
Constant	5.021*** (172.516)
Entropy value of thermal power generation	-37.609*** (-145.457)
Entropy value of heating	16.518*** (194.129)
Entropy value of coking	24.381*** (158.395)
Entropy value of coal to oil	17.027*** (189.830)
Entropy value of coal gas	-6.362*** (-62.115)
Entropy value of current assets	-32.852*** (-176.161)
Entropy value of non current asset investment	-4.988*** (-167.316)
Entropy value of fixed assets	16.575*** (153.695)
Entropy value of intangible assets	-8.940*** (-155.818)
Entropy value of other long-term assets	-3.486*** (-176.911)
Annual	Dummy variable
R^2	0.998
Adj R^2	0.976
F	9447.777
N	11
ε	residual

The values in parentheses are t coefficients; ***, **, * indicate a significant level of1%, 5% and 10%, respectively

6. Research Conclusions and Implications

The conclusions of the paper are as follows: (1) The “low-carbon” transformation of China’s coal economy began in 2009 when coal supply exceeded demand. The government and the market have conducted regulation and regulation around the “double reduction” goal, achieving remarkable results [23]: Under the “one reduction” goal, in 2009, China’s coal consumption accounted for 71.6% of the total energy consumption, which decreased to 56.8% in 2020. However, during the same period, the proportion of clean energy consumption increased from 12.0% in 2009 (natural gas consumption accounted for 3.5%+primary power and other energy consumption accounted for 8.5%) to 24.3% in 2020 (natural gas consumption accounted for 8.4%+primary power and other energy consumption accounted for 15.9%), basically achieving the national energy development goal of “reducing the proportion of coal consumption to below 58% by 2020”. The proportion of clean energy consumption increased to over 25% (strive to achieve 10% of natural gas consumption+increase the proportion of non fossil energy consumption to over 15%); Under the “second reduction” goal: The national energy development plan determines that the SO_2 emissions per unit of GDP in 2015 will decrease by 17% compared to 2010, and the carbon dioxide emissions per unit of GDP in 2020 will decrease by 18% compared to 2015. Both of these planning goals were successfully and overfulfilled. (2) The goal of “double reduction” forces the transformation of deep processing of coal products to reduce carbon emissions [24]. In 2009, the amount of coal products used for processing and conversion in China increased from 2,041.7 million tons to 3,212.48 million tons in 2020, with an average annual increase of 4.21%. Among them, the coal used for thermal power generation increased from 1,439.67 million tons in 2009 to 2124.00million tons in 2020, with an average annual increase of 3.60%. In 2020, the proportion of coal used for thermal power generation reached 66.12%, achieving the goal of “increasing the proportion of coal used for power generation to over 55% of coal consumption” set in the national energy development plan. The entropy value of thermal power generation calculated using the entropy method also decreased from 0.1777 in 2009 to 0.1700 in 2020, showing an orderly development trend; At the same time, coking entropy also presents an orderly development trend. (3) The goal of “double reduction” forces coal enterprises to transform into non coal industries [25]. Two major achievements have been achieved: First, the non coal industry revenue of 34 listed companies in China’s coal mining increased from 173.56 billion yuan in 2009 to 513.314 billion yuan in 2020, with an annual increase of 8.21%. The proportion of non coal industry revenue in total business revenue also increased from 43.67% in 2009 to 46.64% in 2020; The second is the orderly evolution of the asset structure with the industrial transformation, with nearly 80% (78.54% in fact) of the total asset value calculated using the entropy method decreasing, including the entropy value of current assets, fixed assets, and other long-term assets, showing an orderly evolution trend. (4) Using a regression analysis model to examine the relationship between the entropy value of deep processing of coal products, the entropy value of asset structure, and the revenue ratio of non coal industries, a conclusion was reached that is “highly fitting” and “significant”, indicating that the transformation of deep processing of products and the adjustment of asset operation direction have significantly increased the revenue ratio of non coal industries, and the transformation performance of coal enterprises in low-carbon and clean transformation is significant [26].

The policy recommendations put forward in the paper are as follows: (1) From 2009 to 2020, the successful experience of China’s Coal Economy in the transformation and development of “low-carbon and clean” is that the country conducts macroeconomic regulation and the market conducts effective regulation [27]. We need to further summarize our experience in this area and lay the foundation for China to achieve the "carbon peak" goal by 2030 and the "carbon neutral" goal by 2060. (2) We should further strengthen the deep processing of coal products and formulate new price guidance policies to increase the proportion of clean energy consumption [28]. (3) We should grasp the direction of the asset operation structure of coal enterprises and further allocate more funds to achieve the goal of increasing the proportion of revenue in non coal industries [29]. (4) It is necessary to further study performance evaluation methods and analyze the micro changes in the transformation of coal enterprises in the context of macro energy economic transformation, so that the research conclusions reflect both individual characteristics and common characteristics, reflecting both the subjective efforts of coal enterprises and the external objective environment [30], thereby improving the reliability and credibility of the research conclusions.

Funding

National social science fund major project "Research on China's Natural Resources Capitalization and Corresponding Market Construction" (No.: 15zdb163); Construction project of key disciplines of business administration in Jiangsu Province during the 14th five-year plan (SJYH2022-2/285).

References

[1] Zhang, L. L. 2004. "Examine the Overheating of Energy Economy." *Energy and Energy Conservation* 34 (3): 8-9+14.

[2] Zhu, L. F. 2017. *Study on the Support Theory and Operation Efficiency about Capitalization of Coal Resource.* Beijing: China Economic Publishing House.

[3] Zhu, L. F., and Zhu, X. Y. 2018. "Analysis and Countermeasures of Coal Capacity Removal." *Finance & Accounting* 32 (6): 67-9.

[4] Xinhua Network. 2009. "Announced Clear Quantitative Targets for Greenhouse Gas Emission Reduction for the First Time." https://news.ifeng.com/world/special/gebenhagenqihou/zuixin/200911/1126_8755_1452735.shtml.

[5] Ministry of Environmental Protection and Environmental Protection of the People's Republic of China. 2015. *China environmental Situation Bulletin.* https://www.mee.gov.cn/hjzl/sthjzk/zghjzkgb/201606/P020160602333160471955.pdf.

[6] Ministry of Ecology and Environment of the People's Republic of China. 2021. Bulletin on China's Ecological Environment in 2020. https://www.mee.gov.cn/hjzl/sthjzk/zghjzkgb/202105/P020210526572756184785.pdf.

[7] Xinhua Network. 2020. Xi Jinping's Speech at the General Debate of the Seventy-Fifth United Nations General Assembly. https://baijiahao.baidu.com/s?id=1678546728556033497&wfr=spider&for=pc.

[8] Zhou, J. 2007. "The Studies on the Long Run Equilibrium and Short Run Fluctuation on Energy Dem and during China Economy Transition Periods from 1978 to 2005." *Nankai Economic Studies* 28 (3): 3-18+46. doi: 10.14116/j.nkes.2007.03.001.

[9] Pang, R.-Z. 2009. "Industrial Sector Growth and Total Factor Energy Efficiency during Chinese Economic Transformation Period." *China Industrial Economics* 27 (3): 49-58. doi: 10.19581/j.cnki.ciejournal.2009.03.005.

[10] Liu, X. M. 2009. "The Road of Low-Carbon Development Requires Dual Transformation of Economy and Energy Structure." *China Venture Capital* 8 (7): 39-41.

[11] Che, X. C., and Zhang, P. Y. 2011. "Achievement Evaluation of Economic Transformation of Resource—Based Cities Based on Multi-quantitative Methods." *Journal of Industrial Technological Economics* 30 (2): 129-36.

[12] Zhu, L. F., and Zhu, X. Y. 2019. "Energy Policy, Market Environment and the Economic Benefits of Enterprises: Evidence from China's Petrochemical Enterprises." *Natural Hazards* 95 (1-2): 113-27. doi: 10.1007/s11069-019-03579-3.

[13] Zhu, X. Y., and Zhu, L. F. 2020. "Construction of Green Theoretical Framework of Coal Resource Capitalization." *International Journal of Clean Coal and Energy* 9 (2): 15-25. doi: org/10.4236/ijcce.2020.92002.

[14] Dong, F., Li, Y., Qin, C., and Sun, J. 2021. "How Industrial Convergence Affects Regional Green Development Efficiency: A Spatial Conditional Process Analysis." *Journal of Environmental Management* 300: 113738.

[15] Zhu, L. F., and Zhu, X. Y. 2021. "Crowding Effect of Coal Industry Capacity Reduction and Asset Structure Adjustment on Coal Economy." *Resource Science* 43 (2): 316-27. doi: 10.18402/resci.2021.02.10.

[16] Zhang, M.-S., Zhang, P.-Y., and Li, H. 2021. "Characteristics and Evaluation Methods of Economic Transformation Performance of Resource-Based Cities: An Empirical Study of Northeast China." *Journal of Natural Resources* 36 (8): 2051-64. doi: 10.31497/zrzyxb.20210811.

[17] Zhu, X.-Y., Gu, X.-Y., and Gu, D.-L. 2019. "Research on Entropy Order of Asset Structure Evolution Taking Coal Listed Companies in China as an Example." *Resource Development & Market* 35 (11): 1391-7. doi: 10.3969/j.issn.1005-8141.2019.11.010.

[18] BaiduWenku. 2024. "Calculation and Results of Waste Gas from Bituminous Coal Combustion." http://wenku.baidu.com/link?url=gZ3xqPRd1_jWLYhVtXg-VxDQRGfa4oh0HheYBxApni9C5RBeDg6P6DuMP5afIESFxBvgGdeXqQM9b6_PJbSqYPxO5z3nCTDe1u5vdX2_Fpy.

[19] Sun, J., and Dong, F. 2022. "Decomposition of Carbon Emission Reduction Efficiency and Potential for Clean Energy Power: Evidence from 58 Countries." *Journal of Cleaner Production* 363: 132312.

[20] Dong, F., Hu, M., Gao, Y., Liu, Y., Zhu, J., and Pan, Y. 2022. "How Does Digital Economy Affect Carbon Emissions? Evidence from Global 60 Countries." *Science of the Total Environment* 852: 158401.

[21] Liu, R., Ding, Z. H., Wang, Y. W., Jiang, X. H., Jiang, X., Sun, W. B., Wang, D. W., Mou, Y. P., and Liu, M. Z. 2021. "The Relationship between Symbolic Meanings and Adoption Intention of Electric Vehicles in China: The Moderating Effects of Consumer Self-identity and Face Consciousness." *Journal of Cleaner Production* 288: 11.

[22] Jiang, X., Ding, Z., and Liu, R. 2020. "How Cultural Values and Anticipated Guilt Matter in Chinese Residents' Intention of Low Carbon Consuming Behavior." *Journal of Cleaner Production* 246: 119069.

[23] Zhong, Z. Q., Chen, Z. L., and He, L. Y. 2022. "Technological Innovation, Industrial Structural Change and Carbon Emission Transferring via Trade: An Agent-Based Modeling Approach." *Technovation* 110: 102350.

[24] Wang, Y. Q., and He, L. Y. 2022. "Can China's Carbon Emissions Trading Scheme Promote Balanced Green Development? A Consideration of Efficiency and Fairness." *Journal of Cleaner Production* 367: 132916.

[25] He, L. Y., Wu, C., Yang, X. L., and Liu, J. 2019. "Corporate Social Responsibility, Green Credit, and Corporate Performance: An Empirical Analysis Based on the Mining, Power, and Steel Industries of China." *Natural Hazards* 95 (1-2): 73-89.

[26] Zhu, L. F., and Zhu, X. Y. 2021. "Crowding Effect of Coal Industry Capacity Reduction and Asset Structure Adjustment on Coal Economy." *Resource Science* 43 (2): 316-27. doi: 10.18402/resci.2021.02.10.

[27] Liu, R. Y., He, L. Y., Liang, X., Yang, X., and Xia, Y. 2020. "Is There Any Difference in the Impact of Economic Policy Uncertainty on the Investment of Traditional and Renewable Energy Enterprises? A Comparative Study based on Regulatory Effects." *Journal of Cleaner Production* 255: 120102.

[28] Ding, Z. H., Feng, C. C., Liu, Z. H., Wang, G., He, L., and Liu, M. 2017. "Coal Price Fluctuation Mechanism in China Based on System Dynamics Model." *Natural Hazards* 85 (2): 1151-67.

[29] Wang, D. Q., Li, X. M., Tian, S. H., He, L., Xu, Y., and Wang, X. 2021. "Quantifying the Dynamics between Environmental Information Disclosure and Firms' Financial Performance Using Functional Data Analysis." *Sustainable Production and Consumption* 28 (10): 192-205.

[30] Zhu, L. F. 2015. "Analysis of the Relationship between the Economic Benefits of Coal Enterprises and External Force and Internal Funds Operation." *Resources Science* 37 (12): 2414-20.