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Research on the Green Transformation of the Steel Industry under the Dual Carbon Background: A Case Study of Listed Companies

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Abstract

As a pillar industry of the national economy, the carbon emissions of the steel industry account for 18% of the country's total carbon emissions, and the green and low-carbon transformation has become an urgent issue facing the steel industry. In the context of the country's vigorous advocacy of the "double carbon" goal, the development of iron and steel enterprises has declined, and at the same time, the environmental regulations are also increasingly serious, and the green transformation of iron and steel enterprises has become the general trend. It is of great significance for the green transformation of the steel industry to sort out the whole process of the green transformation of iron and steel enterprises and analyze their performance after transformation. Based on the green transformation of the steel industry, this paper studies the motivations, paths and performance of the green transformation of HBIS and Shougang. This paper first combs the relevant literature on the concept, motivation, path and economic consequences of green transition, defines the relevant concepts and types of green transition, and elaborates the major difficulties, performance evaluation methods and related theories of green transformation in the steel industry. Then, the industry and business operation of the case enterprise are introduced, the motivation of the green transformation of the pilot companies and non-pilot companies of the dual carbon policy is analyzed, and the process of green transformation of the enterprises is sorted out. Finally, the DID model is used to analyze the performance of the pilot companies and the non-pilot companies before and after the transformation, and the internal mechanism of the impact of green transformation on the performance of enterprises is summarized, and the corresponding research conclusions and enlightenments are drawn. Through the analysis of listed companies in the steel industry, this paper draws the following conclusions: First, the institutional framework and market mechanism under the dual carbon goal should be built under the policy drive. The dual carbon policy reshapes the development logic of the steel industry through the synergy of mandatory constraints and incentive tools; Second, in the ever-changing modern society, technological innovation has become an important fulcrum for the green transformation of the steel industry, which is mainly reflected in three directions: clean energy structure, low-carbon process flow, efficient resource recycling; Third, despite the remarkable transformation of steel companies, the steel industry still faces structural problems: high transformation costs and long return on investment cycles, key technical bottlenecks and insufficient collaborative innovation. Based on the above research conclusions, this paper draws the following implications for the green transformation of the steel industry: First, enterprises should: Choose the transformation method that suits you according to the industry and your own situation; Second, enterprises should pay attention to innovation and application in the process of green transformation; Third, enterprises should consciously disclose their own environmental information to enhance their awareness of environmental protection and responsibility; Fourth, the government should strengthen policy guidance and support, form a joint force for

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industrial development, and jointly respond to the challenges in the process of green transformation.

Keywords

DID Model; Double Carbon Policy; Green Transition.

1. Introduction

1.1. Background and Significance

1.1.1. Background

Global warming is a common environmental problem faced by mankind, and greenhouse gas emissions are the main cause. As the world's largest developing country and carbon dioxide emitter, China has put forward the "dual carbon" policy to promote energy conservation, emission reduction and low-carbon economic transformation, accelerate green technology innovation and green industry development, and build a green and low-carbon circular economic system. The iron and steel industry is the basic industry of the national economy and national defense construction, but in the past, it was dominated by extensive growth and neglected ecological protection. In 2023, the global crude steel output will be 1.888 billion tons, and China's crude steel output will be 1.019 billion tons, with overcapacity, weak demand and declining profitability in the industry. The Ministry of Ecology and Environment has included the steel industry in the carbon trading system to promote its green transformation and the coordinated development of resolving excess capacity, and the increase in industry concentration has become a trend.

In response to the "dual carbon" policy, the state has promoted the "high-end, intelligent and green" development of the manufacturing industry, and introduced policies to support the green transformation of the steel industry, such as improving the green energy consumption system and building a carbon footprint certification system. Through green transformation, iron and steel enterprises can improve energy efficiency, reduce production costs, produce low-carbon and environmentally friendly products, meet market demand, and enhance competitiveness. As a major carbon emitter, the steel industry can significantly reduce greenhouse gas emissions and achieve sustainable development through ultra-low emission transformation and low-carbon technology application.

1.1.2. Implications for Research

(1) Theoretical significance

Compared with Western countries, Chinese scholars started late in the theoretical research on the green transformation of enterprises. Most of the domestic studies focus on the green transformation of cities and highly polluting industries, and lack of multi-dimensional in-depth discussion on the comprehensive environmental performance and financial performance of green transformation. For example, Hu Jun found that the carbon emission trading mechanism has improved the total factor productivity of emission control enterprises, but has not produced positive spillover effects. Fan Dan et al. studied the impact of carbon emission trading on the total factor productivity of enterprises, and Shen Hongtao et al. found that it failed to affect the long-term value of enterprises. Starting from the drivers of green transformation, this paper analyzes the green transformation path of enterprises and their financial, environmental and social performance, studies the green transformation cases of many listed companies, and proposes a green transformation framework suitable for the steel industry, which has certain reference value.

(2) Practical significance

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In the past, the steel industry mostly used traditional long-process steelmaking processes, relying on resources such as iron ore and coking coal, which had high energy consumption, high pollution, complex production processes and poor flexibility. Nowadays, with the implementation of the "dual carbon" policy, green transformation has become an inevitable trend in the development of the steel industry. On the one hand, the green transition can reduce the dependence on primary mineral resources, reduce carbon emissions by about 70%, and make the production organization more flexible. On the other hand, the use of new technology to upgrade traditional equipment can convert waste heat into electricity or heat, realize energy recycling, and reduce production costs. The green transformation of the steel industry not only meets the needs of environmental protection, but also enhances the competitiveness of enterprises and promotes the sustainable development of the industry. This paper selects representative listed companies in the steel industry as case studies to analyze their green transformation dynamics

1.1.3. Research Methodology

This paper mainly analyzes the case studies of some listed companies in the steel industry through literature research, case studies and DID model analysis, and the specific research methods are as follows:

Literature Research Method

This paper analyzes the development status of China's steel industry by retrieving and collecting the existing annual reports, social responsibility reports and some published related research papers of listed companies from various available channels, and analyzes the motivations, paths and performance of green transformation of listed companies on this basis.

DID model analysis

This paper carries out the operation of the difference-in-difference model by setting up multiple variables and controlling some exogenous factor variables, and compares the economic benefits of listed companies before and after the dual carbon policy and the comparison between pilot companies and non-pilot companies, and then obtains the feasible plans and suggestions for the green transformation of the steel industry under the influence of the dual carbon policy.

Case study method

This paper takes the green transformation of listed companies as the research object, combines the environment and specific conditions of the enterprises, summarizes the driving factors of the green transformation of listed companies, sorts out the specific transformation process, compares and analyzes the effects before and after the transformation, and finally summarizes the internal mechanism and specific reasons for the successful green transformation of some listed companies.

2. Overview Theory of Green Transformation in the Steel Industry

2.1. The Concept and Types of Green Transition

2.1.1. The Concept of Green Transition

The green transformation is the transformation from a high-pollution and high-energy consumption model to a resource-saving and environment-friendly model, aiming to achieve sustainable environmental, economic and social development. The main contents include energy transition, industrial structure adjustment, green technology innovation, ecological protection and green consumption.

2.1.2. Types of Green Transition

(1) Divided by industry sector

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Industrial green transformation: promote energy-saving transformation of high-energy-consuming industries such as iron and steel, chemical industry, and develop green industries such as new energy equipment, energy conservation and environmental protection; Green transformation of agriculture: promote ecological agriculture (such as organic agriculture and circular agriculture), reduce the use of chemical fertilizers and pesticides, and strengthen the resource utilization of agricultural waste; Green transformation of the service industry: develop eco-tourism and green logistics, optimize transportation routes, and promote new energy vehicles and environmentally friendly packaging.

(2) Divided according to the adjustment of energy structure

Renewable energy substitution: the development of solar energy, wind energy, hydropower, etc., and gradually replace fossil energy; Efficient use of energy: Promote energy-saving technologies, such as high-efficiency home appliances and industrial energy-saving transformation, to reduce energy waste.

(3) Divided by spatial scope

Green transformation of cities: building green infrastructure (parks, greenways), promoting public transportation, new energy vehicles and energy-efficient buildings; Regional green transformation: Optimize industrial layout, strengthen ecological protection and restoration, and promote cross-regional environmental protection cooperation.

(4) Divided by the transformation of development model

Circular economy transformation: follow the principle of "reduction, reuse, and recycling", optimize the production process, and improve the waste recycling system; Transition to a low-carbon economy: reduce carbon emissions, develop carbon capture technologies, electric vehicles, low-carbon buildings, etc., and respond to climate change; The green transformation covers multiple dimensions such as industry, energy, space and development model, aiming to achieve coordinated development of the economy and the environment.

3. Introduction to the Transformation Cases of Listed Companies in the Steel Industry under the Dual Carbon Policy

3.1. Analysis of the Drivers of Green Transformation of Hangzhou Iron and Steel, Fushun Special Steel, and Hegang

3.1.1. Economic Drivers: Seeking Sustainable Development and Enhancing Competitiveness

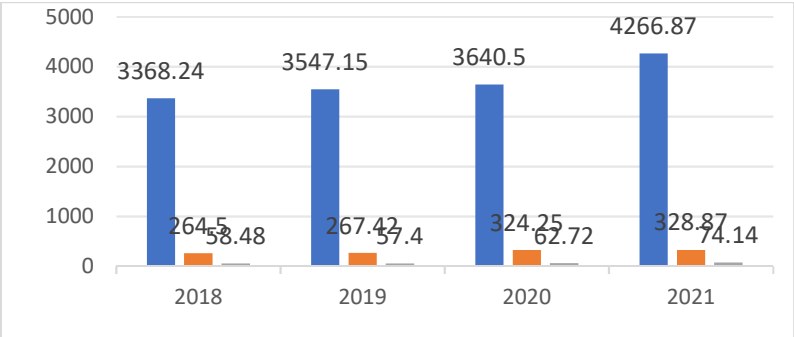


Fig. 1 2018-2021 operating income of dual carbon pilot companies (100 million yuan)

With the improvement of national environmental protection requirements, Hangzhou Iron and Steel is facing huge pressure on environmental protection costs. In order to reduce production costs and improve profitability, Hangzhou Iron and Steel has to seek a more efficient and clean production method, that is, green transformation.

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3.1.2. Environmental Motivation: Respond to environmental pressure and fulfill social responsibility

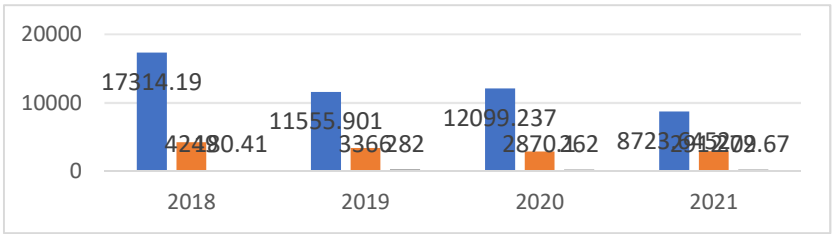


Fig. 2 Nitrogen oxide emissions from 2018-2021 dual-carbon pilot companies (tons)

In recent years, the Chinese government has taken environmental protection more seriously, and has issued a series of strict environmental protection policies and regulations. Environmental indicators such as nitrogen oxide emissions and sulfur dioxide emissions are included in the scope of strict supervision. From 2018 to 2021, Hangzhou Iron and Steel, Fushun Special Steel[2], and Hegang had to carry out green transformation in order to meet environmental protection standards and avoid environmental penalties, and nitrogen oxide and sulfur dioxide emissions decreased year by year.

3.2. Analysis of Green Transformation Measures of Hangzhou Iron and Steel, Fushun Special Steel, and HBIS

3.2.1. Technological Innovation: Leading the New Trend of Green Production

HBIS actively introduces and promotes low-carbon metallurgical technologies such as hydrogen metallurgy, and uses hydrogen instead of carbon as a reducing agent, which greatly reduces carbon emissions in the steel production process. At the same time, HBIS has also strengthened cooperation and exchanges with international steel enterprises and scientific research institutions, jointly developed green and low-carbon new technologies and products, and promoted the green transformation process of the steel industry.

3.2.2. Energy Structure Optimization: Promote Green and Low-carbon Development

HBIS pays more attention to the application of low-carbon metallurgical technology. The company actively promotes low-carbon technologies such as hydrogen metallurgy, and achieves low carbon emissions in the steel production process by replacing carbon with hydrogen as a reducing agent.

3.3. Analysis of the Green Transformation Process of Hangzhou Iron and Steel, Fushun Special Steel, and Hegang

3.3.1. Implementation Strategy: Pay Equal Attention to Technological Innovation and Structural Adjustment

HBIS put forward the development strategy of "high-end, intelligent and green", actively promoted the application of low-carbon metallurgical technologies such as hydrogen metallurgy, and cooperated with domestic and foreign scientific research institutions to build the world's first hydrogen metallurgy demonstration project. At the same time, HBIS pays attention to the integration of digitalization and intelligence, builds smart factories, and promotes intelligent manufacturing. In terms of economic indicators, its operating income and net profit maintained stable growth during the green transition period, and its technical level and market competitiveness were significantly improved. In terms of environmental indicators, the emission of pollutants such as nitrogen oxides and sulfur dioxide has dropped significantly.

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3.4. Fiscal Performance Studies

3.4.1. Detailed Analysis of the Financial Performance of the Pilot Company

Table 1. HBIS 2018-2023 operating income, net profit

	Operating income	Net profit
2018	3368.24	36
2019	3547.15	25
2020	3640.5	16
2021	4266.87	26
2022	4006.68	14
2023	4015.93	10

HBIS's operating income increased from 2018 to 2021, driving the revenue to reach a peak of 426.687 billion yuan in 2021 through technological upgrading, structural optimization, development of new products (235 before 2021, 19 to fill the domestic gap) and expansion of high-end markets. From 2022 to 2023, due to fluctuations in market demand and industry competition, the revenue will be adjusted to 401.593 billion yuan, but a sharp decline will be avoided by strengthening supply chain management and promoting location adjustment. Net profit from 2018 to 2020 due to rising costs and declining market competition. In 2021, it will rebound to 2.6 billion yuan, but from 2022 to 2023, it will face pressure such as environmental protection investment and R&D intensity to maintain more than 3%. By deepening the reform of state-owned enterprises, optimizing management and comprehensive budget control, HBIS strives to balance costs and benefits and maintain stable profits.

3.4.2. Detailed Analysis of the Financial Performance of Non-pilot Companies - taking Shougang as an Example

Table 2. Shougang's operating income and net profit from 2018 to 2023

year	Operating income	Net profit
2018	657.77	27.22
2019	691.51	12.51
2020	799.51	17.86
2021	1340.34	70.24
2022	1181.42	11.26
2023	1137.61	6.64

Shougang's operating income increased year by year from 2018 to 2021, mainly due to the optimization and upgrading of the steel business and the promotion of projects. The iron and steel industry deeply cultivates the "five advantages", focuses on the "four manufacturing", and implements projects such as Macheng iron ore mine and new energy electrical steel to enhance product competitiveness and market share. At the same time, the industrial revival of Shougang Park has driven the development of related businesses and promoted revenue growth. From 2022 to 2023, revenue will drop to 118.142 billion yuan and 113.761 billion yuan, affected by cyclical fluctuations in the steel industry, weakening market demand and high raw material prices.

Net profit developed steadily from 2018 to 2020, and the steel business maintained profitability through cost control and market stability, but the growth momentum was insufficient. In 2021, the net profit will increase highly, due to the optimization of the steel product structure, the market share of the three strategic products will rank among the top three in China, and high-end products such as electrical steel will rank among the world's first echelon, the proportion of high value-added products will increase, and the quality of operation will improve. Net profit

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will decline in 2022-2023 due to the deterioration of the industry environment, falling steel prices, rising costs, and large upfront investment in long-term projects such as park development and technological innovation, which will drag down profits.

3.5. Environmental Performance Analysis

3.5.1. Detailed Analysis of the Environmental Performance of the Pilot Company

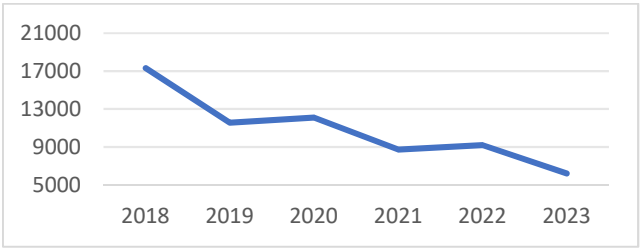


Fig. 3 HBIS nitrogen oxide emissions from 2018 to 2023 (tons)

HBIS's overall NOx emissions from 2018 to 2023 showed a significant downward trend. Ultra-low emission transformation: In 2020, HBIS invested 1.58 billion yuan to implement 30 ultra-low emission transformation projects, and the nitrogen oxide emissions per ton of steel were reduced by 38% year-on-year, all of which reached the best level of environmental protection performance of iron and steel enterprises, which directly promoted the decline in emissions. Application of hydrogen metallurgy technology: In December 2022, the first phase of HBIS's world's first 1.2 million tons of hydrogen metallurgy demonstration project was completed, reducing nitrogen oxide emissions per ton of steel by more than 70% compared with the long process of "blast furnace-converter" of the same scale, and achieving a significant reduction in pollutants from the source. Green process transformation: Shigang New Area adopts a short-process smelting process for all-scrap steel.[3]

3.5.2. Detailed Analysis of the Environmental Performance of Non-pilot Companies - Taking Shougang as an Example

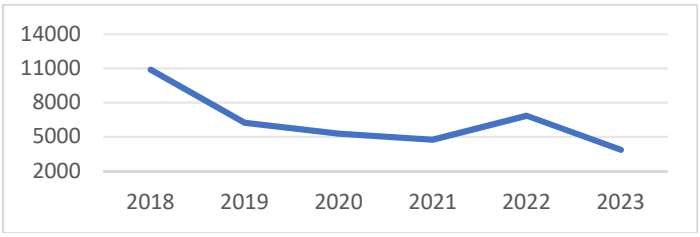


Fig. 4 Shougang's nitrogen oxide emissions from 2018 to 2023 (tons)

From 2018 to 2023, Shougang Group's NOx emissions decreased overall, with small fluctuations in between. From 2018 to 2021, Shougang Qiangang reduced its nitrogen oxide emissions by 59% compared with before the implementation of the whole process of emission reduction measures, and in 2022, Qiangang and Jingtang reduced their nitrogen oxide emissions by 74.3% and 68.8% respectively compared with 2018. In 2022, emissions increased slightly due to production adjustments and equipment commissioning. In 2023, Shougang will deepen its management and reduce emissions again.

4. DID Model Construction and Index Selection

4.1. Model Construction

Based on the company's annual report data from 2018 to 2023, the impact of the promulgation of the "dual carbon" policy on iron and steel enterprises will be analyzed, and the difference-in-difference method will be used to analyze the research topic. Analyzing the carbon emissions

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of iron and steel enterprises before and after the promulgation of the "double carbon" policy, China has promulgated pilot cities for carbon emissions, and this paper takes Shougang as the enterprise representative of the non-pilot city as the control group, and Hangzhou Iron and Steel, Fushun Special Steel, and Hegang as the enterprise representatives of the pilot city as the experimental group.

Based on the above discussion, a difference-in-difference model is constructed:

$$Y_{\mathrm{it}} = \alpha + \beta D_i + \gamma T_t + \delta(D_i \cdot T_t) + \varepsilon_{it}$$

Wherein: Y_{it} is the carbon emission value of enterprise i at time, D_{i} which is an indicator variable for the treatment group (1 for the treatment group and 0 for the control group), T_t a time indicator variable (0 before the treatment and 1 after the treatment), $D_i \cdot T_t$ and an interaction between the treatment and the time.

4.2. Description of Variables

4.2.1. Explanatory Variables

Carbon emissions are the basis for measuring the carbon emission performance of enterprises and the embodiment of the benchmark level of enterprises. The "Work Plan for Accelerating the Construction of a Dual Control System for Carbon Emissions" issued by the General Office of the State Council clearly states that carbon emission indicators will be included in the national economic and social development plan and managed as binding indicators. It shows that carbon emissions are a key indicator to measure whether an enterprise implements the national dual carbon policy.

4.2.2. Control Variables

Based on the understanding of carbon emissions and the reliability of the data, the total assets and operating income will be selected as the control variables, and the carbon emissions of enterprises of different sizes are different, and the total assets and operating income of enterprises affect the carbon emissions of enterprises to a certain extent. Therefore, we will select total assets and operating income as control variables

4.3. Data Sources

This paper will select the enterprise data of Shougang, Hangzhou Iron and Steel, Fushun Special Steel and Hegang from 2018 to 2023 as samples, and the data sources have a certain degree of authority, including the annual report data published on the official websites of each company.

4.4. Empirical Results and Analysis

4.4.1. Model Results

Table 3. DID results

outcome		coefficient	standard error	t	P
Before	Control Group	6171.361			
	Treated	1577.688			
	Diff(T-C)	-4593.672	3174.824	-1.447	0.165
After	Control Group	3255.717			
	Treated	1227.938			
	Diff(T-C)	-2027.779	1795.114	-1.13	0.273
Diff-in-Diff		2565.893	1676.373	1.531	0.143

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The DID[1] results showed that the significance P value was 0.143, which did not show significance at the level, and did not reject the null hypothesis, and the coefficient was 2565.893, indicating that there was little difference in the impact of the "dual carbon" policy on the pilot enterprises and the non-pilot enterprises.

4.4.2. Regression Results

Table 4. Regression results

Interactions	coefficient	standard error	t	P	95% confidence interval	
const	9167.811	719.486	12.742	0.000	7564.695430851323	10770.925569148687
time	-7027.312	769.163	-9.136	0.000	-8741.114097236798	-5313.509902763206
Before-2.0	-6406.694	888.153	-7.214	0.000	-8385.622204354815	-4427.7657956451785
Before-1.0	-1979.621	888.153	-2.229	0.050	-3958.549371021487	-0.6929623118460313
current	-1148.042	888.153	-1.293	0.225	-3126.970537688153	830.8858710214872
After1.0	-581.715	888.153	-0.655	0.527	-2560.643337688154	1397.213071021487
After2.0	-2828.15	888.153	-3.184	0.010	-4807.078537688154	-849.2221289785134
2019.0	-4653.909	769.163	-6.051	0.000	-6367.711597236799	-2940.1074027632003
2020.0	1430.217	769.163	1.859	0.093	-283.58509723679845	3144.0190972367977
2021.0	888.74	769.163	1.155	0.275	-825.0622972367981	2602.541897236798
2022.0	2996.425	769.163	3.896	0.003	1282.6229027632007	4710.227097236797

The coefficient of the interaction item reflects the difference between the treatment group and the control group in a given year. It is generally hoped that the coefficient before the event is not significant, indicating that the parallel trend hypothesis is satisfied, and then it is significant to reflect the effect of the policy.

Visualize the results

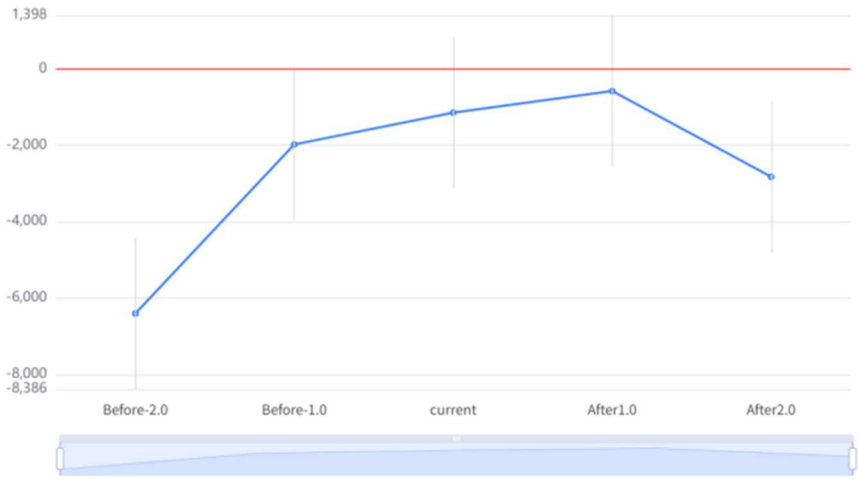


Fig. 5 Graph of regression results

The content of the figure is a visualization of the table content, which can more intuitively see the positive and negative effects of the policy. If the 95% confidence interval contains a value of 0, it means that there is no significant difference between the treatment group and the control group, and it is generally desirable that this situation occur before the event. If the 95% confidence interval is exceeded, it indicates that the policy effect is obvious, and it is generally hoped that this situation will occur after the event, and its value of 0 above and below represents the positive and negative effect of the policy.

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4.5. Parallel Trend Testing

According to the basic assumption of the difference-in-difference estimation method, there should be no significant difference between the control group and the experimental group, so the change trend of the two groups of samples should be the same before the implementation of the "dual carbon" policy. Therefore, this paper will perform a parallel trend test and build a model as follows:

$$Y_{it} = \alpha + \sum \beta_m D_i^m + \gamma T_t + \delta(D_i \cdot T_t) + \varepsilon_{it}$$

Among them, it D_i^m is a temporal dummy variable, and the trend change of the index sample from the first three years to the implementation of the "dual carbon" policy is the same as that of the difference-in-difference model.



Fig. 6 Parallel trend test

According to the test results reported in the figure, there was no significant difference between the control group and the experimental group before the implementation of the "dual carbon" policy, and the model passed the parallel trend test, and the difference-in-difference estimation results were valid. After the implementation of the "double carbon" policy, the carbon emissions of the control group and the experimental group decreased, which indicates that after the implementation of the "double carbon" policy, iron and steel enterprises actively responded to the national policy and vigorously reduced carbon emissions.

5. Conclusion and Implications

5.1. Conclusion

5.1.1. Policy-driven: Build an Institutional Framework and Market Mechanism under the Dual Carbon Goals

The dual carbon policy reshapes the development logic of the steel industry through the synergy of mandatory constraints and incentive tools. In 2024, the Ministry of Ecology and Environment will clearly require the carbon emission quota of iron and steel enterprises to shift

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from "free allocation" to "intensity control", and from 2025, punitive fees will be levied on enterprises whose carbon emissions per ton of steel exceed the benchmark value, forcing high energy-consuming production capacity to withdraw. For example, in 2024, the average transaction price of carbon allowances for iron and steel enterprises in the pilot area will reach 85 yuan/ton, an increase of 28% compared with 2023, directly pushing up the cost of carbon emissions by about 12 billion yuan/year, forcing enterprises to accelerate process innovation.

In terms of market mechanisms, the carbon trading system and green finance are strongly combined. In 2024, the scale of green bond issuance in the steel industry will reach a new high, focusing on supporting the construction of hydrogen metallurgy demonstration projects and CCUS (carbon capture, utilization and storage) projects, and accelerating the low-carbon transformation of the entire industrial chain.

5.1.2. Technological Breakthroughs: Low-carbon Processes Reconstruct the Industrial Technology Paradigm

In the ever-changing modern society, technological innovation has become an important fulcrum for the green transformation of the steel industry, which is mainly reflected in three directions:

(1) Clean energy structure

Hydrogen metallurgy technology using hydrogen energy instead of coal as a reducing agent has entered the pilot stage. According to the big data screening, Baowu Group has built the first 300 cubic meter hydrogen-based shaft furnace in China in Xinjiang Bayi Iron and Steel, using renewable energy to produce hydrogen, which has greatly reduced carbon emissions per ton of steel. At the same time, the "photovoltaic-energy storage-electric furnace" short-process steelmaking model has been widely promoted in coastal areas, for example, a steel enterprise in Shandong has built a 1GW photovoltaic power station, supporting a 500,000 tons/year scrap steel processing base, increasing the proportion of short-process steelmaking from 15% to 40%, and reducing energy consumption per unit of output value by 45%.

(2) Decarbonization of the process

Oxy-fuel technology increases fuel efficiency by 12%-15% and NOx emissions by 40% by increasing the oxygen concentration in the furnace (from 21% to 25%-30%). In 2024, 38 steel enterprises across the country have completed the transformation of more than 120 blast furnaces for oxygen enrichment, saving about 2.8 million tons of standard coal annually.

(3) Efficient resource recycling

The construction of the scrap recycling system has accelerated, and the national scrap consumption will reach 320 million tons in 2024, accounting for 35% of crude steel production, an increase of 12 percentage points compared with 2020. The resource utilization rate of solid waste such as steel slag and blast furnace gas exceeded 90%. The upgrade of the waste energy recovery system has increased the power generation capacity of waste heat per ton of steel from 35kWh to 55kWh, which is equivalent to saving about 4 million tons of standard coal per year.

5.1.3. Existing Challenges: The Triple Constraints of Cost, Technology and Institutions

Despite the remarkable transformation, the steel industry still faces structural challenges:

(1) The cost of transformation is high and the return on investment cycle is long

A 10-million-ton steel mill needs to invest 8 billion to 10 billion yuan to complete the whole process of ultra-low emission transformation, accounting for 15%-20% of the company's asset scale, and the carbon trading revenue can only cover 10%-15% of the cost. The investment in a single demonstration project of cutting-edge technologies such as hydrogen metallurgy exceeds 5 billion yuan, and the depreciation period is as long as 20 years, which is difficult for small and

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medium-sized enterprises to bear. In 2024, the industry's profit margin will fall to 3.2%, nearly halved from the peak in 2019 (6.8%), restricting enterprises' ability to invest in green.

(2) Key technical bottlenecks and insufficient collaborative innovation

The core equipment of hydrogen metallurgy (such as high-temperature and high-pressure hydrogen pipeline network and high-efficiency catalyst) relies on imports, and the failure rate of domestic equipment is 15% higher than the international level; The cost of CCUS technology per ton of carbon capture exceeds 500 yuan, and there is a lack of industrial-grade application scenarios, and the current industry-wide carbon sequestration rate is less than 0.5%. The industry-university-research collaboration mechanism has not yet been perfected, and the ratio of R&D investment between universities and enterprises has reached 1:9, but the conversion rate of achievements is only 28%, which is lower than the average level of the manufacturing industry (45%).

5.1.4. Conclusion

Under the dual carbon policy, the green transformation of the steel industry has shifted from "passive compliance" to "active change", and policy-driven and technological innovation have jointly promoted the energy efficiency improvement and structural optimization of the industry, but challenges such as cost pressure, technical bottlenecks and intensified international competition still require systematic solutions. In the future, it is necessary to reduce the cost of transformation through institutional innovation, build core capabilities through technological breakthroughs, and break down trade barriers through global collaboration, so as to finally realize the fundamental transformation of the steel industry from a "high-carbon basic industry" to a "low-carbon pillar industry", and provide a Chinese solution for carbon neutrality in the global industrial field.

5.2. Research Implications

5.2.1. Pay Attention to Technological Innovation and Application

Technological innovation is an important fulcrum for the green transformation of the steel industry. Shougang, for example, has made remarkable achievements in green innovation. In terms of production technology, Shougang Jingtang has created a high-proportion pellet smelting process, which has increased the proportion of pellets to more than 55%, greatly reduced the fuel ratio and slag volume of blast furnace, and reduced CO2 emissions per ton of iron by more than 167kg; In terms of energy utilization, Shougang has built rooftop distributed photovoltaic power generation facilities in many places, and the photovoltaic project of Shougang Qiangang produces about 6.8 million kWh of green electricity per year, reducing carbon emissions by about 6,000 tons.

At the same time, promoting digital empowerment is also the key, and strengthening the R&D and application of resource recycling technologies should not be neglected. The steel industry should use digital means to achieve refined management and intelligent control of the production process, optimize energy distribution and utilization, and reduce energy consumption and carbon emissions.

5.2.2. Strengthen Policy Guidance and Coordination

Government policies play an important role in guiding the green transformation of the steel industry. Policies such as the special action plan for energy conservation and carbon reduction in the steel industry issued by the government provide clear directions and requirements for the green transformation of enterprises. Enterprises should actively respond to the call of policies, formulate green transformation strategies in line with their own realities, and strive for policy support. At the same time, industry collaboration is essential. Iron and steel enterprises should strengthen cooperation with industry associations, universities, scientific research institutions and upstream and downstream enterprises to jointly carry out technology

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research and development, standard formulation, market promotion and other work, form a joint force for industrial development, and jointly respond to the challenges in the process of green transformation.

5.2.3. Enhance the Awareness of Environmental Protection and Responsibility

Iron and steel enterprises should run environmental protection requirements through the whole production process, continue to promote ultra-low emission transformation, and improve ecological environmental awareness and environmental management level. Many iron and steel enterprises have actively carried out ultra-low emission transformation, reduced pollutant emissions, improved the quality of the surrounding environment, and established a good corporate image. In addition, enterprises should also actively fulfill their social responsibilities and pay attention to ecological environmental protection and sustainable social development. Iron and steel enterprises should pay attention to ecological and social benefits while pursuing economic benefits, so as to realize the harmonious coexistence of enterprises, society and the environment.

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