Low-Carbon Transformation of Chinese Steel Enterprises Under the Dual Carbon Goals: Taking Baowu Group as An Example

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Abstract. The profound changes in the environment have led to increasing global concerns about the negative impacts of carbon emissions. Against the backdrop of the environmental crisis, the concept of “dual carbon” emerged in China, aiming to achieve carbon peaking and carbon neutrality and mitigate the adverse effects of climate change. The establishment of these goals in 2020 marked a significant milestone in global efforts towards a more sustainable future. The paper initially delves into a comprehensive macro and micro analysis, reviewing significant policy measures introduced since the "dual carbon" goals were established in 2020. It pays particular attention to documents that have had a profound impact on the steel industry, emphasizing the urgency of low-carbon transformation among steel enterprises. Amidst the challenges posed by the macroeconomic environment and within the framework of the "dual carbon" policy, the paper takes Baowu Group, China's leading steel enterprise, as the focal point of this analysis. The paper meticulously scrutinizes seven specific measures implemented by Baowu Group in its journey towards low-carbon transformation, adopting a multifaceted perspective. It provides a comprehensive assessment of the effectiveness of Baowu Group's transformation from diverse perspectives, highlighting the successful outcomes of both Chinese government policies and corporate efforts. In conclusion, the paper presents tailored policy recommendations and transformation strategies tailored specifically for the steel industry.

Keywords: Iron and steel industry; dual carbon goals; low-carbon transition.

1. Introduction

With the proposal of China's "dual carbon" goals in September 2020, industries with large carbon emissions have officially opened the prelude to green transformation and low-carbon development [1]. All walks of life are facing huge pressure to reduce emissions, but at the same time, it also ushered in new opportunities for industry transformation and upgrading. To actively respond to the strategic goals of "dual carbon", enterprises need to adopt a series of reform measures from the perspectives of energy, research and development, manufacturing, management, and cooperation. By optimizing energy structure, improving energy utilization efficiency, developing green and low-carbon products, developing zero-carbon production technology, building green manufacturing systems, establishing carbon management systems, participating in carbon emission rights trading and other measures, enterprises can achieve green and low-carbon development, fulfill emission reduction targets, and contribute to the mitigation of global climate change. From the perspective of industrial categorization, the steel industry is an energy-intensive sector, accounting for approximately 15% of China's total carbon emissions. Among the 31 types of manufacturing industries, it ranks second, trailing only the power industry. The green and low-carbon transformation of the steel industry is indispensable for China to achieve its dual-carbon goals. Policy support and market mechanisms are of great significance in promoting the low-carbon development of steel enterprises. The "dual carbon" policy incentive mechanism should be led by the fiscal system and coordinated with the financial policies, maximizing the important role of finance in supporting carbon emission reduction, which promotes the optimization and upgrading of energy and industrial structure [2]. The path to realizing enterprise green transformation encompasses four crucial aspects. Firstly, enterprises adopt the new development concept as their guiding principle and strengthen their awareness of sustainable

development. Secondly, enterprises establish low-carbon production systems under the guidance of environmental policies. Thirdly, enterprises prioritize technological research and development (R&D) breakthroughs as their core competitiveness, aiming to optimize their production processes. Finally, the financial market continues to introduce innovative green financial products to better serve enterprises [3].

2. Dual Carbon Policy

2.1. The Policy

In October 2021, the State Council successively issued two important policy documents on carbon peak carbon neutrality, that is, the top-level design document of dual carbon, which is an important program of the "dual carbon" strategy. This document promotes the green transformation of the whole society as a leading banner and regards the green and low-carbon development of energy as a key support point. The document also sets short-, medium-, and long-term goals, and plans to reduce the share of fossil energy consumption to less than 20% by 2060.

Following the promulgation of programmatic documents, the central government has successively issued "N" policies to detail the top-level design documents, including implementation policies and support and guarantee policies for key industries with carbon emissions. The industry scope of "N" covers China's infrastructure, such as energy materials, manufacturing, urban planning, etc. Among them, the application of modern energy and hydrogen energy in the low-carbon transformation of energy, energy saving and emission reduction in energy saving and carbon efficiency, high-quality development of the steel industry related to the peak of carbon in the industrial field, and circular economy to help reduce carbon action are closely related to the steel industry.

In 2022, the carbon reduction transformation of the steel industry has received the attention of many departments in the country, and enterprises have formulated carbon reduction planning charts in accordance with national regulations to show the potential of sustainable development to the public. In terms of enterprise management, enterprises should optimize the organizational structure, set posts and staff, implement performance management and strengthen staff training, reduce and improve operating costs, and improve operational efficiency and competitiveness. In May of the same year, in order to support green and low-carbon development more efficiently and intensively, the Ministry of Finance issued a time plan as a "dual carbon" timetable.

In May 2023, the European Union promulgated the Carbon Border Adjustment Mechanism (CBAM), which is a carbon tariff adjustment mechanism covering six sectors including steel, cement, aluminum, fertilizer, electricity, and hydrogen. This policy tool increases the cost of China's export products, weakens the export competition of China’s enterprises, and safeguards the development of green manufacturing in Europe. It is still in the transitional adjustment period, and its basic requirement is that imported products need to provide carbon emission reports. And carbon tariffs will be effectively imposed from 2026. China occupies an important position in the European Union's steel market. Problems such as high inter-market trade dependence, significant carbon footprint of steel products exported by enterprises to the European Union, and large price differences in carbon emission trading hinder the cooperation between China and the European Union to promote the realization of the "dual carbon" goals [4].

2.2. Iron and Steel Industry

In recent years, the steel industry as a whole has experienced a downward cycle, which is mainly influenced by the macro environment. First, the restriction of production capacity has replaced the past expansion of production capacity, and the introduction of policies such as "capacity replacement" has exerted economic pressure on enterprises. Second, the tense and complex international relations have worsened the international steel trade, in addition to the disappearance of China's demographic dividend, China's "golden era" of low steel exports is difficult to re-emerge. Third, the steel industry has reformed from the supply side in the "13th Five-Year Plan", making the overall supply and

demand of the industry basically reach a balance, but the "double carbon" goals in 2020 have put forward a higher transformation standard for the energy consumption and carbon emissions of the steel industry.

A country's steel production scale and industry development level can be reflected by crude steel production. In 2020, China's crude steel production reached a peak of 1.065 billion tons. In the past three years, crude steel production has entered the plateau period under the influence of the level control policy. In 2024, the state will still implement austerity policies for the steel industry to strictly control new capacity and resolve excess capacity, so it is expected that crude steel production will decline.

2.3. Micro Perspective

There are still some problems existing in steel enterprises. First, the structure of steel products is unreasonable. There is overcapacity in low-end products and insufficient innovation capacity in high-end products. Second, Iron and steel enterprises generate large carbon emissions. The carbon emissions of China's steel industry account for more than 60% of the total carbon emissions of the global steel industry, and it is the largest source of carbon emissions in the global steel industry. Third, raw material prices fluctuate greatly. The supply of raw materials such as iron ore and coke in the steel industry is unstable, while downstream demand is stable. Fourth, the enterprise's regional distribution is affected by history and resource endowment, resulting in uneven distribution of processing regions and unbalanced development.

3. Case Study on Baowu Group

3.1. Background Information

On the whole, the steel industry is in a downturn stage, but as the world's largest steel production company, China Baowu Steel Group Corporation Limited (Baowu Group for short) has unique advantages. First, Baowu Group has four geographically advantageous manufacturing bases in Baoshan in Shanghai, Qingshan in Wuhan, Meishan in Nanjing, and Dongshan in Zhanjiang, which is helpful for Baowu Group to optimize resource allocation and improve operational efficiency. Through reasonable logistics layout and collaborative operation, the bases can realize resource sharing and complementary advantages, and improve the competitiveness of the whole group. Second, as a leading state-owned enterprise in the steel manufacturing industry, Baowu Group has a powerful national background and advantages in policy, finance, and resources, which are unmatched by ordinary steel enterprises. Third, Baowu Group is at the forefront of low-carbon green technology, and the enterprise has the foresight to actively lay the frontier low-carbon technology such as Hydrogen-enriched Carbon Recycling Oxygen Furnace (HyCROF) and hydrogen metallurgy, which prepares to cope with future challenges to achieve sustainable development.

This year, under the continuous reform and transformation of the steel industry, the low-carbon transformation has gained initial results and achieved improved quality and efficiency. In the third quarter of 2023, the performance of Baoshan Iron and Steel Co., LTD. (Baosteel for short, which is the core enterprise of Baowu Group) gradually improved, and the construction expenditure for Baosteel's low-carbon transformation project has also withstood the peak, meaning costs will gradually decline later. The corporation’s profits will rebound, showing an increasingly steady transformation process.

Baowu Group, a prominent state-owned steel company, accounts for over 10% of China's annual crude steel production. Under the pressure to reduce production capacity, the overall trend in China's crude steel output has been downward. However, the crude steel output of Baowu Group has continued to rise year by year, reflecting the robust production capabilities and advanced level of low-carbon innovation demonstrated by leading enterprises, as evident in Figure 1.

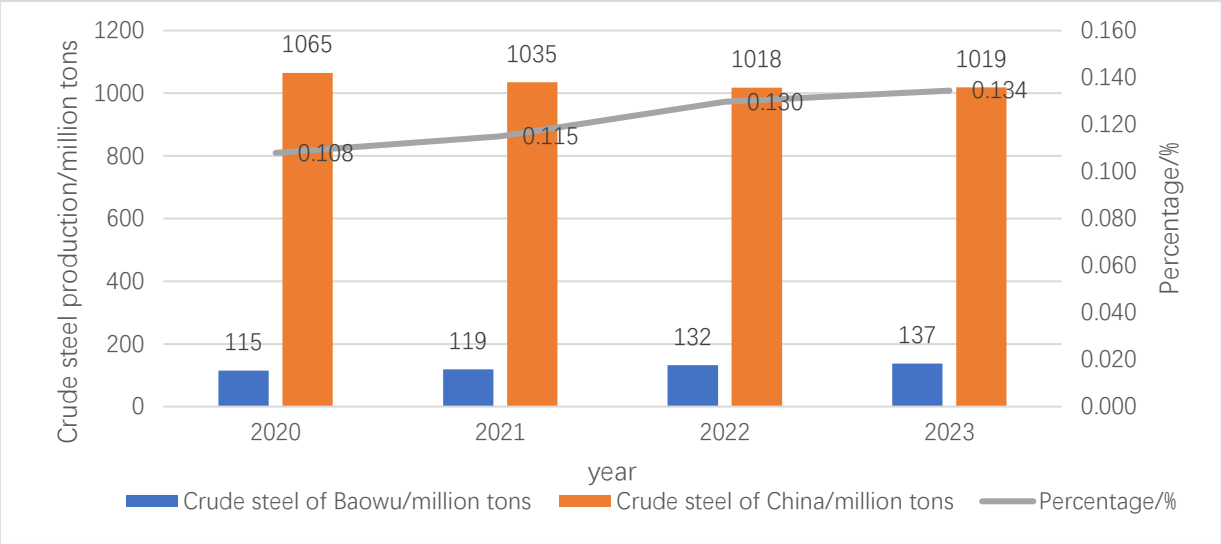

Fig. 1 Crude steel production of Baowu Group and China and the ratio between them

3.2. Baowu Group's Transformation

3.2.1 Carbon reduction target

In January 2021, Baowu Group took the initiative in the domestic steel industry by announcing its carbon reduction targets: a roadmap for low-carbon metallurgy in 2021, a carbon peak by 2023, a technological capability for 30% carbon reduction by 2025, a 30% carbon reduction by 2035, and carbon neutrality by 2050.

3.2.2 Carbon reduction technology

In 2021, the low-carbon metallurgical technology roadmap issued by China Baowu Group focused on the deployment and implementation of low-carbon development in six major paths: extreme energy efficiency in steel production, reconstruction of blast furnace process technology, hydrogen metallurgy technology, short-process near-final manufacturing technology, circular economy, and carbon dioxide resource utilization technology.

First, the enterprise considers extreme energy efficiency as a pivotal aspect in reducing carbon emissions. Baosteel studied the theoretical and technical limits of the energy consumption model and established the available technology database for energy saving and carbon reduction. It also integrated the fields of intelligent manufacturing, interface energy efficiency improvement, and waste heat and waste energy for resource utilization to approach the best energy efficiency. In 2022, the company implemented an extreme energy efficiency and energy consumption benchmark, with an investment of 550 million yuan.

Second, by reconstructing Blast Furnace (BF) ironmaking technology, the enterprise can significantly reduce carbon emissions. The BF process is the primary method for iron and steel production. By leveraging technological innovation, the enterprise can optimize the utilization efficiency of carbon within the BF. Integrated with hydrogen-rich ironmaking technology, the enterprise can establish a technological system for a hydrogen-rich carbon-recycling BF. This approach can reduce the carbon emission intensity per ton of iron by approximately 30% compared to traditional blast furnaces. In July 2022, the world's first industrial-grade Hydrogen-enriched Carbonic oxide Recycling Oxygenate Furnace (HyCROF) with a capacity of 400 cubic meters was commissioned. After three months of industrial testing, the HyCROF demonstrated a reduction in solid fuel consumption by 30% and carbon emissions by more than 20%. This significant achievement paves the way for a more sustainable and environmentally friendly iron and steel production process.

Third, through the hydrogen metallurgy technology, the enterprise can achieve the carbon reduction goals better. By replacing carbon with hydrogen, the energy structure of steel production is optimized, and the process flow is reconstructed, so as to achieve green, low-carbon, and high-quality

development. Compared with the traditional BF + Basic Oxygen Furnace (BOF) of the same production scale, the hydrogen metallurgy technology significantly reduces the emission of pollutants. On December 23, 2023, the million-ton Hydrogen-Based Shaft Furnace (HBSF) was successfully ignited and put into operation in Zhanjiang, Guangdong Province. The "HBSF + high-efficiency Electric Furnace (EF)" will form a net zero carbon emission production line, which is expected to be put into operation in 2025 and will provide low-carbon and zero-carbon products for downstream users.

Fourth, the enterprise achieves carbon reduction by short-process near-net shape manufacturing technology. Different from the traditional production methods, the short-process near-net shape manufacturer will build a technological platform and carry out research on “EF + near net shape” manufacturing technology to achieve extremely low carbon emissions in the steel processing process.

Fifth, the enterprise mitigates carbon emissions by implementing circular economy practices. In the process of steel production, there is ongoing research and development into the utilization of steel recycling materials, iron and carbon-containing solid waste, multi-source biomass, and other resources. This aims to reduce fossil energy consumption and further minimize the carbon emission intensity per ton of steel.

Finally, carbon dioxide (CO_2) resource utilization technology is being explored for carbon reduction. This involves the low-cost and large-scale capture and resourceful utilization of carbon dioxide generated during steel production, seeking to develop deep carbon reduction techniques within the steelmaking process.

3.2.2 Carbon management system

In 2022, Baosteel's smart carbon data platform was officially launched, which provided quantitative tools and massive data for Baosteel's strategic decision-making on energy conservation and carbon reduction. The development direction of "intelligent + green" was adopted, and the construction of a green manufacturing system was accelerated [5].

Baowu Group actively promotes its listed companies to improve their Environmental, Social, and Governance (ESG) organizational leadership system. According to the results of the ESG survey conducted among 312 listed companies of central enterprises in 2022, nearly 40% of Baowu Group's listed companies have established ESG institutions at the board level, which is 5.4% higher than the average level.

Baowu Group continues to fully integrate the concept of social responsibility into corporate strategy and major decisions, daily operations, and supply chain management. At present, 30.8% of listed companies have formulated a clear ESG strategic plan, and 46.2% of listed companies have integrated ESG-related content into their corporate strategy. According to the actual situation of the company, the enterprise will benchmark domestic and foreign ESG indicators and clarify the qualitative and quantitative disclosure requirements.

3.2.3 Product structure adjustment

The plan for low-carbon and zero-carbon steel products by 2035 has been constantly promoted. First, in 2022, in order to meet the carbon reduction needs of key industries and customer's supply chains, Baosteel established the BeyondEco low-carbon series. While fully meeting performance requirements, it significantly reduces carbon emissions and strikes a balance between environmental protection, efficiency, and sustainability. Second, Baowu Group provides high strength, high energy efficiency, corrosion resistance, and long life of automotive panels, silicon steel, and photovoltaic steel. These provide solutions for multiple industries such as automobile, energy, construction, and home appliances to achieve green, low-carbon, and sustainable development.

3.2.4 Transformation of energy structure and promotion of clean energy

First, the enterprise promotes green electricity trading and green certificate trading. In 2022, the company transacted 577 million kilowatt-hours of green electricity and continued to search for green electricity resources. Second, the company continues to increase investment in photovoltaics.

Baosteel continues to increase the development of rooftop photovoltaic projects, and the installed capacity of the rooftop photovoltaic of Baoshan Base has exceeded 120 Megawatt, which is the largest rooftop photovoltaic project group in the world.

3.2.5 External information disclosure and information sharing

First, Improving ESG information disclosure is essential. The preparation of ESG reports has been completed by all listed companies of the Baowu Group. Second, the company's sustainability report is advanced by the end of April, and the disclosure of quantitative data increases to 116 items. At the same time, the greenhouse gas inventory was prepared according to the ISO14064 standard, and the greenhouse gas verification statement was issued by an independent third party to increase the credibility of the report. The company's website has been optimized to maintain its ESG foreign policy, while also improving the disclosure content of the sustainable development section. Enterprise optimizes its company websites, including maintaining its external ESG policies and improving the disclosure content of the sustainable development section.

3.2.6 Cooperate with upstream and downstream

The enterprise has established a green and low-carbon industrial chain, providing environmental protection indicators such as carbon emissions and energy consumption of its products. On November 22, 2022, Baosteel and Beijing Benz jointly built a low-carbon green steel supply chain, providing electro-galvanized low-carbon steel. They were committed to using greener materials in the vehicle manufacturing process and built a low-carbon green automotive steel supply chain. This is the first time that Chinese steel companies have provided steel products with a clear carbon reduction value to car companies.

3.2.7 Facilitating industry consolidation

Baosteel actively implements the policy of optimizing production capacity regulation, deepens the reform of factor allocation, and carries out mergers and reorganizations. On December 8, 2023, Baosteel acquired 48.61% equity from the Rizhao enterprise, which was a strong alliance to enhance the ability to obtain resources and promote the high-quality development of iron and steel enterprises. The continuous integration measures in the steel industry have improved the concentration of resources in the steel industry, and a large number of resources have been concentrated in the top steel enterprises, enhancing the entire steel industry chain and the market bargaining power.

3.3. Implementation evaluation

The study investigates the implementation effect of the measures from two perspectives. First, by examining the actual reduction in greenhouse gas emission intensity, the enterprise's carbon reduction effectiveness can be evaluated. The greenhouse gas emission intensity of Baosteel's four bases decreased from 1.910 in 2019 to 1.861 tons of carbon dioxide equivalent per ton of crude steel in 2022, achieving a decrease of 3% compared with 2019 in Table 1. In the next year when the dual control of carbon emissions was proposed, enterprises still reduced the intensity of greenhouse gas emissions despite meeting with traditional problems such as weakening market demand and fluctuations in raw material prices.

Second, the study examines the implementation effect of measures by observing changes in energy utilization efficiency. Baosteel has made joint efforts in technology innovation, process optimization, energy management, and other aspects to approach the ultimate energy efficiency. In terms of energy efficiency, Baosteel's comprehensive energy consumption per ton of steel has decreased from 4.70 megawatt-hours per ton of crude steel in 2019 to 4.61 in 2022 in Figure 2. In the same year, the company invested 550 million yuan in implementing extreme energy efficiency and benchmarking process energy consumption. According to the plan from 2022 to 2027, the technical energy saving target of the ultimate energy efficiency project is 1.069 million tons of standard coal, and the technical energy saving of the project in 2022 is 243,000 tons of standard coal, which greatly exceeds the annual target.

Table 1. Greenhouse gas emissions intensity of Baosteel's four bases

Year	Greenhouse gas emissions intensity/ (Tons of carbon dioxide equivalent weight/Tons of crude steel)
2019	1.910
2020	1.870
2021	1.870
2022	1.861

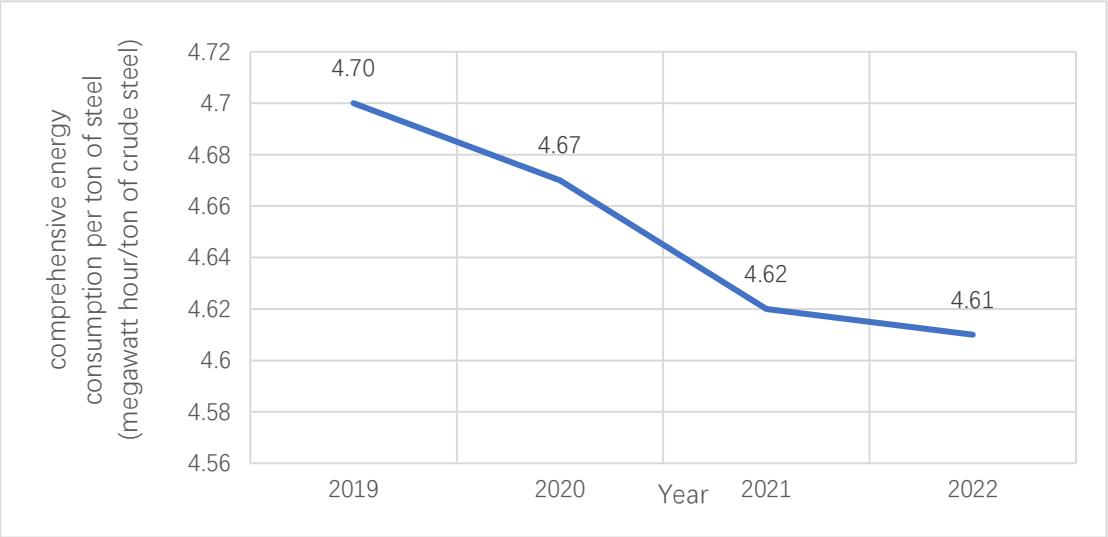

Fig. 2 Comprehensive energy consumption per ton of steel (megawatt hour/ton of crude steel)

In addition to examining the implementation effect of the measures, the article also evaluates whether the enterprise's measures are sustainable or not. Baosteel established long-term carbon emission management in 2022, and its smart carbon data platform was officially launched. First, the operation of the data platform accurately monitors and evaluates the carbon emissions in its production process, and then develops more scientific and effective emission reduction measures. Second, the data support provided by the platform helps Baosteel to achieve green and low-carbon transformation at all levels such as strategic planning, production operation, and decision-making management. Third, the platform provides carbon emission trend prediction and early warning functions to help enterprises identify potential carbon emission risks in advance and formulate coping strategies to ensure the sustainable development of enterprises.

Finally, the study integrates the evaluation of third-party institutions and public opinion to provide a comprehensive assessment of the enterprise's transformation measures, particularly emphasizing metrics such as ESG. The company's internal management system has been optimized continuously, the external ESG information disclosure has been improved persistently, which has been highly recognized by government departments. With the help of the sound ESG system and good ESG performance, Baosteel was selected as Forbes 2022 China ESG50.

4. Policy Recommendation

First, from the perspective of regional heterogeneity, the impact of environmental regulations on the eastern, central, and western regions is different. The eastern region is more affected by environmental regulations, and the central and western regions are less affected by environmental regulations [6]. Due to the unitary industrial structure and imperfect regulation, environmental regulation has no significant effect on the central and western regions. The country should help enterprises in the central and western regions to complete the transformation by implementing stricter

supervision on enterprises with high carbon emissions and strengthening the local government's responsibility to enhance the impact of environmental laws and regulations in the central and western regions.

Second, the more developed the technical level is, the higher the green economic benefits will be, and the two alternatives change in the same direction. However, the correlation between the two variables is weak, which may be caused by the lack of high-quality personnel, technology, and equipment related to environmental protection research [7]. Insufficient R&D investment leads to the insignificant positive impact of technological progress on the efficiency of a low-carbon economy. China's financial system can provide green loans for enterprises undergoing green and low-carbon transformation, in addition to differentiated credit policies, credit mechanism innovation, linkage between investment and loan to support green industries, etc. The financial system can also provide the necessary capital flow for enterprises to carry out technological transformation, which will improve their low-carbon economic efficiency and promote economic and social benefits.

Third, regardless of whether or not products are differentiated, production and consumption in equilibrium will be lower than those in non-equilibrium conditions [8]. Apart from strictly limiting the expansion of new production capacity and encouraging the merger and reorganization of backward production capacity, the government should also encourage steel enterprises to develop high-end, intelligent, and green products. Through upgrading the technology and adjusting product structure, the enterprises improve product quality and added value.

Fourth, at present, the Scrap-Electric Arc Furnace (Scrap/EAF) is better than the Blast Furnace-Basic Oxygen Furnace (BF-BOF) in energy saving and carbon reduction capacity, but the BF-BOF is still the most widely used technology due to the shortage of raw material supply and the cost of electricity [9]. Here are several measures that can help enterprises promote Scrap/EAF. First, the government can increase the tax rebate ratio of scrap steel to reduce the raw material cost of the Scrap/EAF. Secondly, in the short term, the government will provide subsidies for the electricity prices for iron and steel enterprises that adopt the Scrap/EAF approach. Additionally, it will oversee and direct the allocation of electricity consumption among these enterprises, ensuring that they adhere to the pertinent technical specifications and safety standards. In the longer term, the government aims to steer enterprises toward utilizing cleaner and more environmentally friendly energy sources to ultimately attain near-zero emissions in steel manufacturing.

Fifth, although there are many scientific research and technological development achievements on carbon reduction in the steel industry, the applications of the technology are lacking. The reasons run as follows. To begin with, the environment is changing too fast, so the development of technology cannot keep up with the needs of environmental requirements. Second, the promotion of technology has a large overdraft on funds. Third, the supply and demand relationship and price mechanism in the market have not played a significant role in promoting technology promotion. Fourth, the service provided by technical service institutions is not sophisticated [10]. The government should improve the low-carbon achievement transformation service system, strengthen the construction of intermediary institutions, and provide an effective docking platform for the supply and demand of low-carbon technology achievements. The government should also participate in the incubation process of low-carbon technology to improve the service quality and efficiency of intermediary enterprises.

5. Conclusion

The article evaluates the low-carbon transformation measures and their effects on the steel industry, analyzing from both the overall industry and specific enterprise perspectives. Based on this analysis and assessment, the article then proposes relevant policy recommendations and measures, primarily emphasizing the government's role in promoting enterprise optimization and transformation, green development, and the low-carbon, high-end, and intelligent development of the steel industry. Specifically, the government should strengthen environmental regulations to assist enterprises in the

central and western regions with their transformation, balance regional development, and enhance low-carbon benefits. Additionally, the financial system should support green transformation enterprises by providing green loans and differentiated credit policies. Furthermore, the government encourages steel enterprises to carry out green transformation by offering short-term subsidies for electricity prices and guiding them towards using cleaner energy in the long run. Moreover, the government needs to improve the low-carbon transformation service system, strengthen the establishment of intermediary institutions, and provide an effective docking platform for enterprises. These measures aim to promote sustainable enterprise development, enhance economic and social benefits, and jointly achieve the "double carbon" goals.

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