

Commentary

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Achieving low carbon finance of the iron and steel industry in China

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Abstract

As a key sector characterized by high energy consumption and carbon emissions, the low-carbon transition of the iron and steel industry is crucial for achieving national emission reduction targets. Although China's iron and steel industry has made some progress in reducing total energy demand through capacity control, it still faces challenges in terms of technological paths toward industrial decarbonization. Financing low-carbon technologies during the transition process will have to deal with significant funding gaps and a capital structure mismatched with technological development. We propose policies and methods to promote financing for the iron and steel industry's low-carbon transition. We suggest strengthening public investment guidance, promoting green financial policies, and innovating carbon finance instruments. Emphasis should be placed on the role of policies such as green credit, carbon pricing, and R&D subsidies, while highlighting the importance of integrating financial policies with technology and flexibly adjusting them throughout the "financing lifecycle".

Keywords: Steel, low-carbon transition, mitigation technologies, carbon finance

EMISSION REDUCTION STRATEGIES FOR THE IRON AND STEEL INDUSTRY

The iron and steel industry is characterized by high energy consumption and carbon emissions, accounting for approximately 7% of global carbon dioxide emissions in 2019^[1]. China produced over 1 billion tons of crude steel in 2023, accounting for more than half of the global total^[2]. Steel production is primarily divided



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into the long process using blast furnace-basic oxygen furnace (BF-BOF) and the short process using scrap melting-electric arc furnace (Scrap-EAF). Compared to the former, the latter reduces energy consumption by 50%^[3]. However, China's scrap utilization rate is currently low, and the long process still dominates the production structure, accounting for about 90% of production^[4]. The iron and steel industry accounts for 14% of China's total energy consumption and contributes approximately 15% of the national emissions, second only to the power sector^[5]. Therefore, strictly controlling carbon emissions in the iron and steel industry is crucial for achieving the nation's emission reduction targets^[6]. The transition to sustainable development requires a fundamental shift in the flow of capital, moving away from unsustainable technologies toward sustainable ones^[7-10].

Capacity control is considered a key measure for promoting the low-carbon development of China's iron and steel industry^[11,12]. Many studies predict that China's crude steel demand will gradually decline to a stable level^[13-16]. However, simply reducing production capacity and eliminating outdated capacities will not be sufficient to achieve the emission reductions needed to meet China's carbon neutrality goals. The iron and steel industry in China urgently needs to explore technological pathways for low-carbon transition^[17-19].

First, adjusting the production structure is a long-term solution for reducing emissions in the iron and steel industry^[6,20]. Currently, the capacity ratio of BF-BOF to Scrap-EAF in China's iron and steel industry is 9:1^[21,22], with the proportion of EAF being lower than the global average^[19]. Since it does not require coal and coke as reducing agents, producing crude steel by recycling scrap metal consumes less energy and significantly reduces carbon dioxide emissions^[23,24].

Second, promoting the application of energy-saving technologies has become a significant measure for improving energy efficiency and reducing energy consumption in China's iron and steel industry^[25-27]. Technological improvements should be encouraged at all stages of steel production, such as pulverized coal injection into blast furnaces, coke dry quenching, and low-temperature sintering technologies^[28-30]. Energy-saving technologies based on the BF-BOF process are among the most studied emission reduction solutions^[31]. It is estimated that by adopting energy-saving technologies along the BF-BOF production pathway, energy consumption per ton of crude steel can be reduced by about 20%^[1] and carbon dioxide emissions can be decreased by 22%^[27].

Third, innovative technologies like carbon capture and storage (CCS) and direct reduced iron (DRI) are key to achieving carbon neutrality in China's iron and steel industry^[32]. Utilizing existing technologies can reduce emissions in China's iron and steel industry by 54%, but it is insufficient to achieve carbon neutrality^[17]. Combining traditional technologies with net-zero emission technologies, such as CCS and DRI, can fundamentally reduce carbon emissions and achieve an 80%-90% reduction, thereby fulfilling climate targets^[17,33]. The developing direct reduced iron-electric arc furnace (DRI-EAF) technology, which bypasses the coke oven and sintering process, has the advantages of a shorter process, less pollution, and lower energy consumption. It is also not affected by the shortage of coking coal resources, making it highly promising for reducing energy consumption and emissions^[34].

FINANCING CHALLENGES OF LOW-CARBON TRANSITION IN THE IRON AND STEEL SECTOR

The investment demand of low-carbon transition includes not only the initial costs of deploying mature technologies, as well as the costs of energy, raw materials, operations and maintenance, and financing, but also the research and development (R&D) expenses needed to develop new low-carbon technologies^[31,35,36]. On one hand, the market share of mature low-carbon technologies such as Scrap-EAF is currently limited,

and expanding their deployment requires substantial financial support^[37]. On the other hand, new low-carbon technologies such as CCS are often capital-intensive and in an immature stage of development, thus requiring substantial investments in R&D^[38].

The iron and steel industry is a typical capital-intensive sector facing long project cycles and high capital requirements in its green transition and upgrade. It often encounters challenges such as insufficient transformation momentum and financing constraints, with enterprises' own funds unable to meet the demands of green transition^[39]. Due to a lack of sufficient financial support, some emission reduction solutions that are technically feasible and effective in addressing climate change risks have stalled, with financing difficulties seen as a key obstacle to their progress^[40-42]. Additionally, different investments have varying risk-return characteristics, so investors may choose different investment methods based on differences in risk preferences, loss tolerance, and the tasks they undertake^[43-45]. In the early stages of low-carbon transition, commercially immature technologies face significant uncertainty, making investors reluctant to allocate resources to these high-risk areas^[10,46]. Therefore, there is a significant mismatch between the available sources of capital and the financial needs of the energy transition^[40,47].

Compared to high-carbon assets, the low-carbon technologies required for the transformation of the iron and steel industry are typically considered to carry higher investment risks under current climate policies, leading to increased financing costs^[8,38]. Moreover, low-carbon technologies are usually capital-intensive and require large investment amounts, reducing their competitiveness against fossil fuel technologies or existing high-energy-consuming technologies, thus facing a more challenging financing environment. It is estimated that nearly 3.5 trillion RMB will be needed for the iron and steel industry to reach peak carbon emissions, and achieving carbon neutrality will require an additional 19 trillion RMB^[48]. Moreover, advanced steel production processes like Scrap-EAF, DRI-EAF, and decarbonization technologies like CCS have high costs due to expensive construction and the lack of economies of scale. In 2022, the unit cost of producing crude steel through Scrap-EAF in China was about \$100/ton higher than that of BF-BOF^[49]. Furthermore, in the context of supply-side structural reform, the financing expenditures for steel companies are indirectly increased by policies limiting the financing of new capacity in the industry, with financing expenditures being 30-82 basis points higher compared to non-overcapacity industries^[50].

Regarding the choice of financing methods, Myers and Majluf's pecking order theory suggests that firms should prioritize internal financing, followed by debt financing, and equity financing as a last resort^[51]. In the capital structure of China's iron and steel industry, debt financing outweighs equity financing^[52]. According to China Stock Market & Accounting Research (CSMAR) data, the asset-liability ratio of 23 publicly listed steel production companies in 2022 was 56.64%, with some companies' asset-liability ratios exceeding 70%. However, credit rationing assesses the relationship between risk and cost, and projects with excessive risk will not be financed through debt^[53]. Therefore, less mature technologies require a lower debt-to-equity ratio, indicating that the current capital structure of the iron and steel industry does not align with the needs of low-carbon transition^[10]. Moreover, insufficient financial policies have made it difficult for the steel industry to alter its existing capital structure, resulting in financing difficulties during its transformation process. Due to limited participation from entities offering green finance, the small number of specialized institutions providing green financial services, and the lack of diversified financing instruments, the development of financing to meet these needs remains inadequate. Additionally, inadequate information transparency and insufficient implementation of financial instrument standards further hinder progress^[54,55]. As a result, China's iron and steel industry has had limited involvement in green finance-related funding, making it difficult to effectively support the development of low-carbon technologies^[48].

FINANCING PATHS FOR THE LOW-CARBON TRANSITION OF THE IRON AND STEEL INDUSTRY

Traditional financial markets are insufficient to meet the financing needs for the transition of the iron and steel industry, so the support brought by green finance policies must be considered. As the primary driver of green finance, the government's involvement in green investment is crucial to the sustainability of companies' green development^[56]. Additionally, the stability of climate policies over time can better motivate stakeholders to invest early in low-carbon technologies^[57,58]. Numerous studies have found that green finance policies can increase financial institutions' investment in companies with better environmental performance^[56,59]. On one hand, this can help enterprises improve debt maturity mismatches^[60], reduce financing costs for green projects^[61], and provide more funds to conduct research and development, promoting green innovation^[62,63]. Notably, among industries that are both heavily polluting and financially constrained, green finance policies have a more pronounced effect in promoting green innovation^[64]. On the other hand, through debt financing constraints and equity financing constraints, green finance policies have also indirectly driven the transformation of heavily polluting enterprises^[55,65]. Currently, in China, the development of green finance largely relies on the government and banks to provide green credit, bonds, and other financial services to reduce financing costs and mitigate investment risks for green industries^[55]. It is noteworthy that, although the global green bond market is predominantly led by developed countries, China has emerged as the world's largest issuer of green bonds since 2022. In 2023, China issued USD 83.5 billion in green bonds, accounting for 14% of the global total, with Germany and the United States ranking second and third, respectively^[66,67]. Nonetheless, introducing international linkages, with attracting international investors, can enhance the compliance of Chinese green bond issuers^[65]. Furthermore, incorporating diversified financing channels like equity financing can alleviate the potential capital structure issues arising from green credit and green bonds, thereby reducing corporate debt pressure^[55].

Carbon pricing policies targeting high-pollution industries such as the iron and steel industry, including carbon tax or carbon market schemes, can channel funds toward companies with better environmental benefits through information transmission and capital redistribution^[68,69]. Emission trading schemes have been widely adopted in the European Union, the United States, Germany, China, and other regions^[70]. However, in 2024, the carbon market price in China was much lower than that in the European Union's carbon market^[70]. Promoting a steady increase in carbon prices will channel more funds to steel enterprises with good environmental performance^[71]. Carbon financial derivatives, such as carbon forwards, carbon futures, and carbon options, have further increased the activity of the carbon trading market^[72]. Additionally, a high-potential global steel sector emission reduction scheme indicated that revenue generated from these measures could offset the costs of the iron and steel industry's transformation, supporting the effectiveness of carbon revenue recycling^[73]. Moreover, the low-carbon research and development subsidies provided by the government, through the effect of research and learning, will effectively accelerate the cost reduction of low-carbon technologies in their early stages^[74,75], thereby minimizing the costs associated with large-scale deployment^[76]. Furthermore, project subsidies, tax credits, and the establishment of reasonable risk assessment metrics to overcome regulatory barriers are also key in fostering low-carbon innovation and development^[47]. These carbon finance policies not only reduce the risks associated with the steel industry's transition but also enhance investment returns^[77]. Specifically, on one hand, they lower the downside risks of low-carbon investments by simplifying project approvals, providing subsidies, investing in emission-reduction technology innovations, and utilizing equity financing to diversify funding channels. On the other hand, they increase the returns on low-carbon investments through mechanisms such as green certificates, carbon pricing, tax incentives, and concessional loans, while simultaneously reducing the profitability of high-carbon investments^[78-80].

The financing needs for the low-carbon transition involve various investors and financial institutions and the funding mix required for technology development changes with the technology life cycle. Therefore, appropriate financing at different stages of the “financing lifecycle” is essential to facilitate the necessary speed of technology diffusion^[81]. To effectively mobilize the needed capital, it is crucial to map the investment needs of technology to the appropriate sources of funding^[45]. Public funds often finance mission-oriented R&D projects, which can give rise to entirely new industries^[82]. As technology matures and risk becomes more manageable, uncertainty decreases, allowing for the use of cheaper sources of capital to fund more mature projects^[40]. In this process, effectively mobilizing and directing public and private capital into climate-related projects is crucial^[83]. Green finance policies can signal the market, attracting more private capital into green investment sectors through direct or indirect financing^[77,84]. At the same time, the nature of investors changes as private capital's willingness to invest grows. The capital structure shifts from government-led investments to the involvement of venture capitalists, and then to investments from insurance companies, banks, pension funds, and even international financing channels^[44,85]. During this process, policy frameworks evolve as well^[86], shifting from funding R&D and deployment to establishing project certification standards, relevant regulations, and scientific performance evaluation mechanisms, thereby ensuring the efficient use of transformation funds^[87,88]. This transition enables the development of technology from policy-driven to market-driven, completing the process where public capital mobilizes private investment. See [Table 1](#) for an overview of key policy instruments and their definitions. Future research can further explore how to better align financial needs with technological development and investigate more effective policy measures to promote the widespread adoption of low-carbon technologies, thereby accelerating the iron and steel industry's low-carbon transition and providing strong support for China's carbon neutrality goals.

In summary, based on an overview of emission reduction technological pathways for China's iron and steel industry, we analyze the financing challenges faced in the low-carbon transition, including significant funding gaps and mismatches between capital structure and technological development. To address these issues, we emphasize the government's leading role in financing the low-carbon transition and highlight the roles of policies such as green credit, carbon pricing, and R&D subsidies in promoting low-carbon technology development and reducing financing costs to advance the iron and steel industry's low-carbon development. Similar to other studies analyzing transition financing, we summarize the impacts of various financial instruments. However, we further propose specific financing strategies tailored to the unique technological and financing challenges of China's iron and steel industry. Additionally, we underscore the need for close integration of financial policies with technological development and the importance of flexible policy adjustments throughout the “financing lifecycle” to maximize the role of financial policies in facilitating the industry's transition. There is still room for improvement in the design and implementation details of existing carbon finance policies. Furthermore, balancing the long-term stability of policies with fiscal expenditure pressures represents a direction for further research. Meanwhile, the adaptability and fairness of carbon finance policies among enterprises of different sizes deserve attention, in order to explore more flexible policy tools, enhance policy precision and execution effectiveness, and strive to cover emission reductions across all industries. Additionally, it is also noteworthy how policy instruments can be leveraged to mobilize and guide private capital participation, realize the market-oriented development of low-carbon technologies, and promote efficient capital allocation and synergies through public-private partnership models.

Table 1. Policy instruments and their definitions

Policy	Definition
Green bonds	Bonds that provide funding for projects that meet environmental-friendly standards ^[55]
Carbon pricing	Measures to curb greenhouse gas emissions by charging for carbon dioxide emissions or providing incentives for emission reductions ^[89]
Carbon derivatives	Derivative financial instruments based on carbon emission rights. Common types of carbon derivatives include futures, options, and swaps ^[90]
Carbon revenue recycling	The recycling of revenues raised by governments through carbon pricing policies, including reductions in VAT, corporate and household income taxes, increased social security and welfare for low-income families, one-time transfer payments, investments in green project R&D and construction, etc. ^[91-94]
R&D subsidies	Financial support for research and development of projects, such as grants ^[95]
Concessional finance	Below-market-rates access to green finance ^[96]

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Authors' contributions

Made substantial contributions to the conception and design of the writing and revision: Liu, J.
Performed the collection of literature and writing: Jiang, X.

Availability of data and materials

Not applicable.

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Conflicts of interest

Both authors declared that there are no conflicts of interest.

Ethical approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

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