清華大學 Tsinghua University

力拓 RioTinto

10th Anniversary Special Edition

China's Resources, Energy and Sustainable Development

Special Report on Carbon Neutrality Strategy for Metal Industry

2022

Tsinghua-Rio Tinto Joint Research Centre for Resources, Energy and Sustainable Development

December 2022

Preface I

The ever-more-frequency of extreme weather events around the globe alerts us that climate change is not only an immediate threat, but also a long-term and deep-seated challenge for humanity. The most recent IPCC Sixth Assessment Report highlights that global warming triggered by human activities is causing extensive rapid changes in the atmosphere, oceans, cryosphere and biosphere, and climate change is already causing enormous damage and increasingly irreversible losses in the ecosystem. To achieve societal-wide sustainable development, humanity must carry out self-revolution, and unite together to actively address climate change.

The Paris Agreement adopted by the Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) in 2015 established the goal of "Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels" by the end of this century, clearly defining the collective global response to climate change. The long-term vision and institutional arrangements for the global response to climate change and the general direction of

the future green and low-carbon transition have been outlined in the Paris Agreement. On September 22, 2020, President Xi Jinping solemnly announced at the 75th session of the UN General Assembly that China will scale up its Intended National Determined Contributions by adopting more vigorous policies and measures, while striving to peak CO_2 emissions by 2030, and to achieve carbon neutrality by 2060. This solemn commitment has greatly boosted global confidence in addressing climate change.

However, we should also recognize that China's industrial structure remains heavy, its energy structure largely relies on coal, its scientific and technological innovation capacity is insufficient, and there is only a short 30-year window from carbon peaking to neutrality, shorter than the average cycle of developed countries. Therefore, to achieve the "double carbon" goal brings huge challenges, we must implement systemic change in the economy and the society, and must balance between the four relationships of emission reduction and development, overview and specific, short and medium to long-term, government and market. It is necessary to recognize that there is a dialectical relationship between carbon peak and carbon neutrality: “If one is fast, the other will follow fast, if one is low then the other will be easy, if one is slow then the other will be challenging". Recognizing that it must be viewed as a whole from a connected systematic point of view and the establishment of a systemic and holistic view cannot be achieved without in-depth strategic and path-planning studies.

The energy system is the key to green and low-carbon transformation. According to the research of Tsinghua University's Institute of Climate Change and Sustainable Development, China needs to follow a long-term deep decarbonization transition path oriented by the 2°C and 1.5°C targets of the Paris Agreement. This means a fundamental change in our energy system from the current fossil energy share of about 85% gradually shifting to a non-fossil energy share of more than 80% by 2060. To this end, we should not only vigorously develop non-fossil energy, but also grasp the development of renewable energy and traditional fossil energy transition with a high degree of research and innovation.

At the same time, the industrial sector, including steel, cement and other energy-intensive industries, is the main target of the energy system. It is not only the main source of energy consumption but industrial production processes are also the main source of CO_2 emissions. According to the 2014 National Greenhouse Gas Inventory Report, it is projected that the total carbon emissions from the industrial sector in China amount to around 4.7 billion tons, accounting for 46% of the country's total CO_2 emissions. Evidently, the timing and peak scale of the industrial sector will play a significant role in the national carbon peaking, and the hard-to-abate industries and production processes will also directly affect the layout of achieving the carbon neutrality target, and the study of such a key sector is necessary and urgent.

In view of this, Tsinghua-Rio Tinto Joint Research Centre for Resources, Energy and Sustainable Development (The Joint Centre of Tsinghua-Rio Tinto) focuses on key issues in the low-carbon transition of industries such as steel and non-ferrous metals, to carry out continuous research work. This report is one of the Centre's series of reports, "*China's Resources, Energy and Sustainable Development*", released on the occasion of the Centre's 10th anniversary. The report focuses on carbon neutrality in the metal industry, and presents the research understanding from a multidisciplinary perspective on various issues such as policy action measures, capacity layout optimization, low-carbon technology assessment, and accounting method improvement in the steel and non-ferrous metals industries. This will help readers understand the important issue of metal carbon neutrality in resources, energy and sustainable development in the global climate change landscape, and thus provide references for relevant policy formulation and action, as well as a reference for policy formulation and implementation.

Due to the limitation of capacity, there will be some inaccuracies and even errors in the book, and we warmly welcome readers' feedback and criticism.

Zheng Li
President of the Institute of Climate Change and Sustainable Development
Tsinghua University

Preface II

Climate change is one of the biggest challenges facing society as a whole across the world. While there is broad consensus on the need to tackle climate change, there has yet to be sufficient action globally.

At Rio Tinto, we believe we should play an integral and essential part in the climate change solution. In 2021, we put the low carbon transition at the heart of our business strategy and are focused on three key areas:

- Producing materials essential for the low-carbon transition, including copper, low-carbon aluminium, battery minerals and high-quality iron ore.

- Reducing the carbon footprint of our operations by investing in low-carbon technologies such as renewable energy solutions including wind and solar.

- Partnering to reduce the carbon footprint of our value chains by increasing our R&D investment to speed up the development of products and technologies that will also enable our customers to decarbonise quicker.

We announced an ambitious plan to achieve a 15% reduction in scope 1 and 2 emissions by 2025, 50% reduction by 2030 and net zero by 2050. To deliver these targets, we will invest approximately $7.5 billion in capital between 2022 and 2030.

China's commitment to bring its carbon emissions to a peak by 2030 and to reach carbon neutrality by 2060 gave new impetus to the Paris Agreement and action on climate change more broadly. The iron and steel industry alone contributes around 8% of global greenhouse gas emissions, and 15% of China's total carbon emissions. To achieve net zero in China's metallurgical industry requires significant resources.

With the scale of investment and innovation required, none of us can achieve our climate change goals alone. Partnerships are critical. Rio Tinto is committed to working with our strategic partners in business, industry and academia, investing and leveraging our insights from across the value chain to achieve technological breakthroughs.

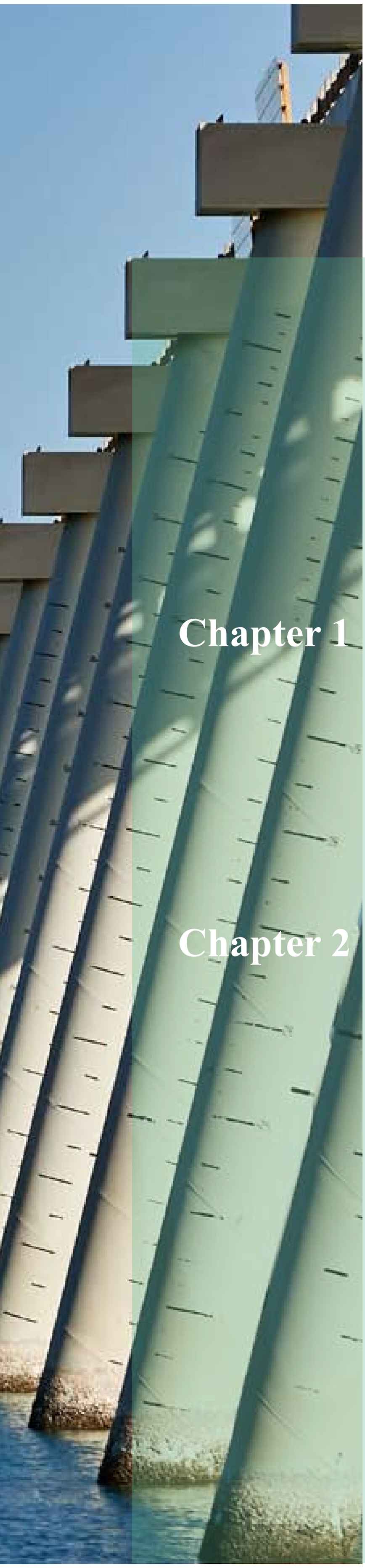
Ever since its establishment in 2012, the Tsinghua-Rio Tinto Joint Research Centre for Resources, Energy and Sustainable Development has been actively promoting cooperative research with institutions at home and abroad, aiming to contribute wisdom and solutions to the sustainable development of resources and energy in China and in the world. Over the past decade, Rio Tinto has been proud to support the research of the Centre to explore ways to respond to climate change, including improving environmental performance across the steel value chain.

As we celebrate the 10th anniversary of the establishment of the Centre, I hope we take this opportunity to deepen friendship and mutual trust, expand exchanges and cooperation, and combine our strengths to bring together solutions to help address the steel industry’s carbon footprint.

In commemoration of the 10th anniversary, the book is a compilation of the leading works by Tsinghua scholars on decarbonisation topics. Looking ahead, I wish the Centre even greater success in delivering impactful results informing both policy and industry, at home and abroad. I am confident the Centre will become a leading source of the knowledge and innovation that will help achieve China’s climate goals and solve the global challenges we all face.

Alf Barrios
Chief Commercial Officer and China Chairman
Rio Tinto


TROODOS SUN
LIMASSOL



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Abstract

The development and utilization of resources and energy are the building blocks that support the development of human society, but also are the main cause of human-induced ecological and environmental impacts. Confronted with the increasingly serious climate change globally, countries urgently need to join hands to promote a low-carbon transformation around the development and utilization of resources and energy, in order to achieve sustainable development of the global economy and society.

As a key country rich in resources and energy development and utilization, China has solemnly announced the development goal of "striving to peak CO_2 emissions by 2030, and to achieve carbon neutrality by 2060", which will have a strong impact on sustainable development of resources and energy. For example, it will promote large-scale development and utilization of renewable energy and the overall increase of electrification, and it will promote the development and application of extreme energy efficiency, recycling and major emission reduction technologies for metal production.

In view of the complex issues of resource, energy and sustainability, Tsinghua University, based on the Low Carbon Energy Laboratory, integrated the research resources of several faculties and established the Joint Centre of Tsinghua- Rio Tinto jointly with Rio Tinto in 2012, organizing interdisciplinary research teams to carry out research around resource, energy and sustainability. At present, the Centre has successfully completed the first two phases of research collaboration, and published the Chinese monograph *China's Resources, Energy and Sustainable Development* and the English monograph *China's Resources, Energy and Sustainable Development*:

2020. In the third phase, the Centre launched the flagship project"Carbon Neutrality in the Metal Industry", focusing on "metals" as a key element in the implementation of resource and energy systems. This year is the second year of the flagship project and the 10th anniversary of the establishment of the Centre, we are pleased to prepare a Special Report on Carbon Neutrality Strategy Study for the Metal Industry to review the development of the Centre and introduce the progress and research results of the Centre.

This report mainly consists of three parts. The first part is a review of the decade of the development history of The Joint Centre of Tsinghua-Rio Tinto, and on the basis of revisiting the mission and vision of the Centre, it summarizes the cooperation directions and main research results of the three cooperation phases respectively, and looks forward to the future development direction. The second part focuses on the flagship project in the third phase of collaboration, outlines the general layout of the flagship project and the progress of each special study. The third section summarizes the main achievements of the Centre under the flagship project, including key academic papers, science-based policy briefings and science-based industry perspectives.

This report was prepared by the Centre's project team, with the research and preparation process guided by the Centre's academic committee members, including Jiankun He, Zheng Li, Qiang Yao, Can Wang, Xiliang Zhang, and Zanji Wang, as well as the support of the Centre's Steering Committee members, many colleagues from Rio Tinto, and faculty and students from Tsinghua University.

Members of the Centre's Flagship Project Team for 2020-2021

Academic Committee Director: Zheng Li

Academic Committee Members: Xiliang Zhang Zanji Wang Qiang Yao Can Wang

Comprehensive Topic: Systematic Analysis of China's Iron and Steel Low-Carbon Development Strategy

Linwei Ma Shanshan Yang Honghua Yang Yuancheng Lin Ruipeng He Yuan Yuan

Topic 1: Regional Perspective of the Carbon Neutrality Strategy and Pathway for the Steel Industry

Shiyan Chang Bing Li Sining Ma Lina Zhang Haohua Deng Chao Yang

Topic 2: Demand Estimation and Plant-Level Low-carbon Transition Pathway towards Carbon Neutrality in China's Steel Industry

Wenjia Cai Xueqin Cui Zhao Liu Shihui Zhang Ruiyao Li Jin Li Canyang Xie

Topic 3: Low-Carbon Technologies in the Steel Industry: Identification, Evaluation and Application Prospects

Xunmin Ou Lei Ren Jianzhe Liu Zeyu Chen

Topic 4: Improvement in GHG Emission Accounting Methodology for Steel under Multiple Constraints

Jian Zhou Lingling Zhou Jie Zhang Junjun Shi

Topic 5: Steel Industry's Low Carbon Development: International Trends and National Policies

Jinxi Wu Xu Bai Nuo Ge Yongtao Wu

Topic 6: Study on the Potential of Online Detection Technology for Energy Saving and Emission Reduction in Steel Production

Zhe Wang Zongyu Hou Weiran Song Shangyong Zhao Jiacen Liu Weilun Gu Yuzhou Song Jianxun Ji

Topic 7: Carbon Neutral Pathway of Critical Non-Ferrous Metals for Energy Storage

Han Hao Shilong Du Hao Dou Yunfeng Deng Xin Sun Dengye Xun

Chapter 1: Centre's Decade Milestone

Vision

Striving to become one of the most influential domestic and global think tanks through informed insights and solutions to China's and the global sustainable development of resources and energy, contribute to the sustainable development of all humankind.

Mission

Organizing an inter-disciplinary research team with key relevant departments to conduct research in energy resources and sustainable development, actively promoting cooperative research opportunities with overseas and domestic institutions.

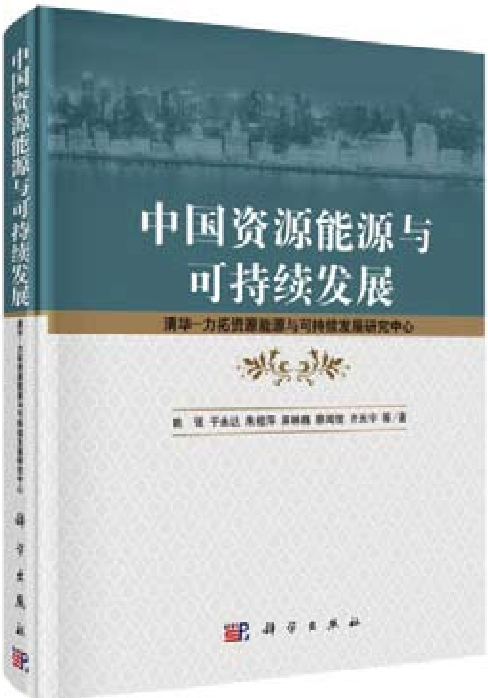
Tsinghua-Rio Tinto Joint Research Centre for Resources, Energy and Sustainable Development was established in 2012. It is a joint scientific research institution established by Tsinghua University and Rio Tinto. With a track of indepth and practical collaboration in the last two phases (2012-2017 and 2017-2020, respectively), the Centre is entering the third phase of 2020-2025, with 2022 marking the 10th anniversary since the establishment of the Centre.

The Centre's mission is to consolidate relevant departments across the university to conduct interdisciplinary research on energy resources and sustainable development, and actively promote joint research opportunities with domestic and international institutions, aiming to provide intelligent solutions to the sustainable development globally and in China in resources and energy. While striving to become one of the most influential think tanks in China and around the world, contributing to the sustainable development of all humankind.

First Phase of Cooperation (2012-2017)

1

1. The signing ceremony of the first phase of cooperation was held on July 2nd, 2012. Chen Jining, then President of Tsinghua University, signed the contract on behalf of Tsinghua University. The director of the Centre was Professor Qiang Yao, and the main team leaders consist of five professors, Zheng Li, Xiliang Zhang, Pengfei Du, Yongda Yu and Zanji Wang. Given the common interests of Tsinghua University and Rio Tinto in resources, energy and sustainability, in 2012, the joint research centre was established under the Tsinghua University Low-Carbon Energy Laboratory. Where an interdisciplinary research team incorporating five department within Tsinghua University, including the Department of Energy and Power Engineering, Department of Electrical Engineering, Institute of Nuclear and New Energy Technology, School of Environment, and School of Public Policy & Management, organizes and researches on key topics in energy, mineral resources and sustainable development globally, with a special focus on China.



《中国资源能源与可持续发展》各章执笔人

资源篇

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第 2 章　中国铁矿石发展战略的系统分析　麻林巍　李政　杨洁　沈学思　李伟起

第 3 章　铁矿石定价机制及其波动特征研究　尹峰　于永达

第 4 章　跨国矿业企业的战略研究　于永达

第 5 章　矿产金融问题研究　于永达

化石能源篇

第 6 章　中国煤炭分配图及煤炭消费增长的驱动因素分析　麻林巍　章景皓　李政　于飞飞　李伟起

第 7 章　中国煤炭清洁高效利用技术发展评价　李慧娜　杨倩　卓建坤　姚强

第 8 章　中国成品油定价政策研究　肖宁　于永达

第 9 章　二氧化碳捕集利用与封存技术评价　李慧娜　杨倩　卓建坤　姚强

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第 11 章　中国光伏产业发展现状及展望　鲁宗相　朱桂萍　王赞基

第 12 章　中国光伏业的国际智力回流问题研究　罗思平　于永达

第 13 章　中国智能电网发展现状及分布式电源并网的若干问题研究　朱桂萍　鲁宗相　王赞基

第 14 章　中国电动汽车发展现状及展望　鲁宗相　朱桂萍　王赞基

2. During which, the Centre conducted 12 commissioned research projects, published approximately 50 papers, and one multidisciplinary academic monograph *China's Resources, Energy and Sustainable Development*. With the support of Rio Tinto, the Centre also carried out a joint project with the China Metallurgical Industry Planning and Research Institute, allowing for extensive large-scale research and exchange with domestic steel industry and its corporates. In the first phase, the Centre trained three post-doctors, 23 Ph.D. students and 18 master students; and held more than ten academic exchange activities. The Centre invited then CEO of Rio Tinto as a guest speaker at Tsinghua University, and held one related international conference. Based on the research results, two policy proposals were submitted to the General Office of the CPC Central Committee and the General Office of the State Council of the People's Republic of China. 2

Second Phase of Cooperation (2017-2020)

1

1. The signing ceremony of the second phase of cooperation was held on November 24, 2017. The director of the Steering Committee and academic committee of the second phase is Professor Jiankun He, the director of the Centre is Professor Zheng Li, the executive director of the Centre is Linwei Ma, and the project leaders include Shiyan Chang, Jinxi Wu, Zongsang Lu, Guiping Zhu, Wenjia Cai, and Jian Zhou.

2

2. A Memorandum of Understanding (MOU) was signed between China Baowu Steel Group (hereafter Baosteel), Tsinghua University and Rio Tinto around future environmental cooperation on September 25, 2019. Strengthening disciplinary research in cross-disciplinary and project management. More than ten academic webinars were held annually with participation of ten professors' teams across seven different academic disciplines.

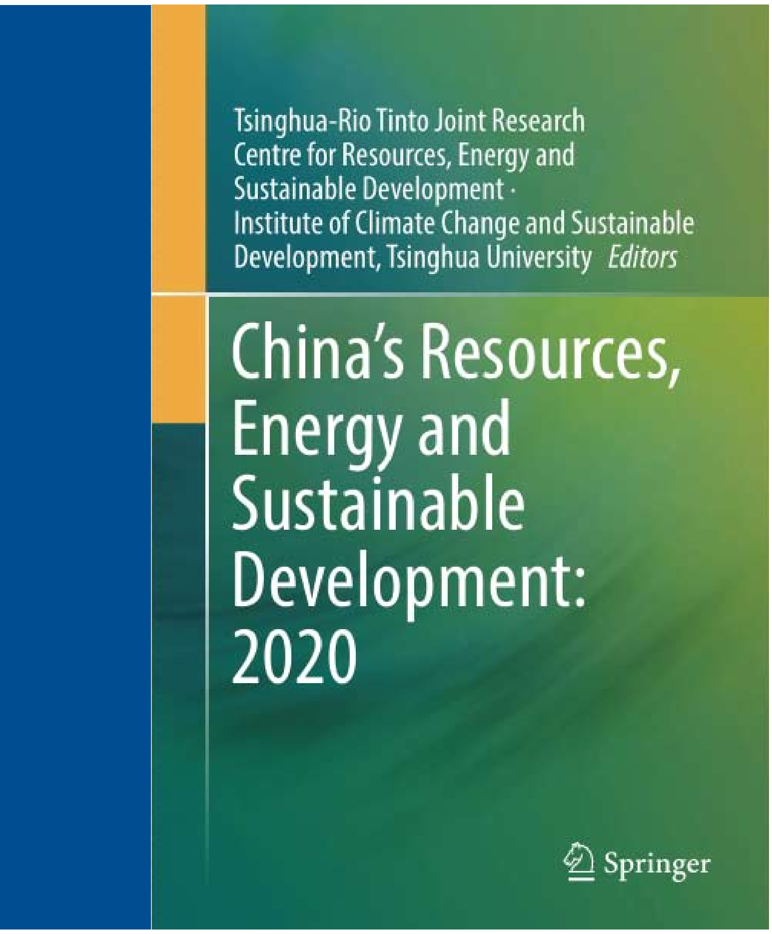
中心工作团队访问伦敦力拓总部
Visit RT's Headquarter in London Dec. 14, 2018

接待力拓先锋及访问先锋实验室
Receiving pioneers and visit Brisbane's Lab in 2019

力拓代表在清华演讲
RT's lectures in Tsinghua, Jun. 8, 2018 & Mar. 22, 2019

3

3. The Centre continued to strengthen bilateral exchanges and cooperation in the second phase of cooperation, with exchanges with and visits to Rio Tinto for more than ten times, and have also invited then CEO and then head of Corporate Relations of Rio Tinto, as guest lecturers at Tsinghua University. The second phase of cooperation focused closely in integrating academic research and industry practice.



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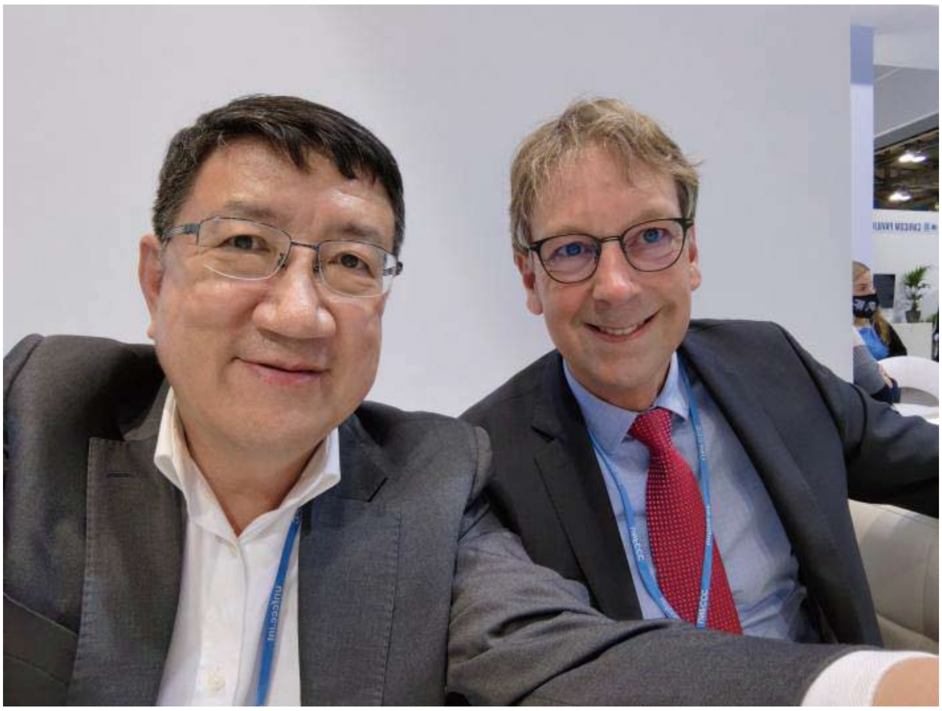
4

4. Under the results-oriented mechanism for annual project application and academic committee review, the Centre has achieved remarkable research results, with five policy proposals submitted and more than 20 academic papers published. The monograph, *China's Resources, Energy and Sustainable Development: 2020* was published in January, 2021. There are seven chapters on China's energy transition strategy in the context of addressing global climate change, low-carbon urbanization, urban carbon peaking, power system transition, water resources management, battery materials for electric vehicles and low carbon technologies for steel.

Third Phase of Cooperation (2020-2025)

1

1. On November 23, 2020, the Centre signed the third phase of cooperation, continuing and further strengthening the organizational and management structure, forming a management model with the Steering Committee leading the development of the Centre, and the Academic Committee and the Advisory Committee alongside providing professional guidance, establishing a working model with the Director of the Centre as the main responsible body, supported by a dedicated project lead and a research team across relevant departments. The Director of the Steering Committee and the Academic Committee of the Centre is Professor Zheng Li, the Director of the Centre is Associate Professor Linwei Ma, the Deputy Director is Ms. Christine Yuan from Rio Tinto, and the project leaders include Shiyan Chang, Wenjia Cai, Xunmin Ou, Jian Zhou, Jinxi Wu, Zhe Wang, Han Hao, Zongxiang Lu, Guiping Zhu, etc.



2

2. Jakob Stausholm, CEO of Rio Tinto, and Alf Barrios, Chief Commercial Officer and China Chairman of Rio Tinto, have participated in the meetings of the Centre's steering committee and advisory committee to guide the development of the Centre.

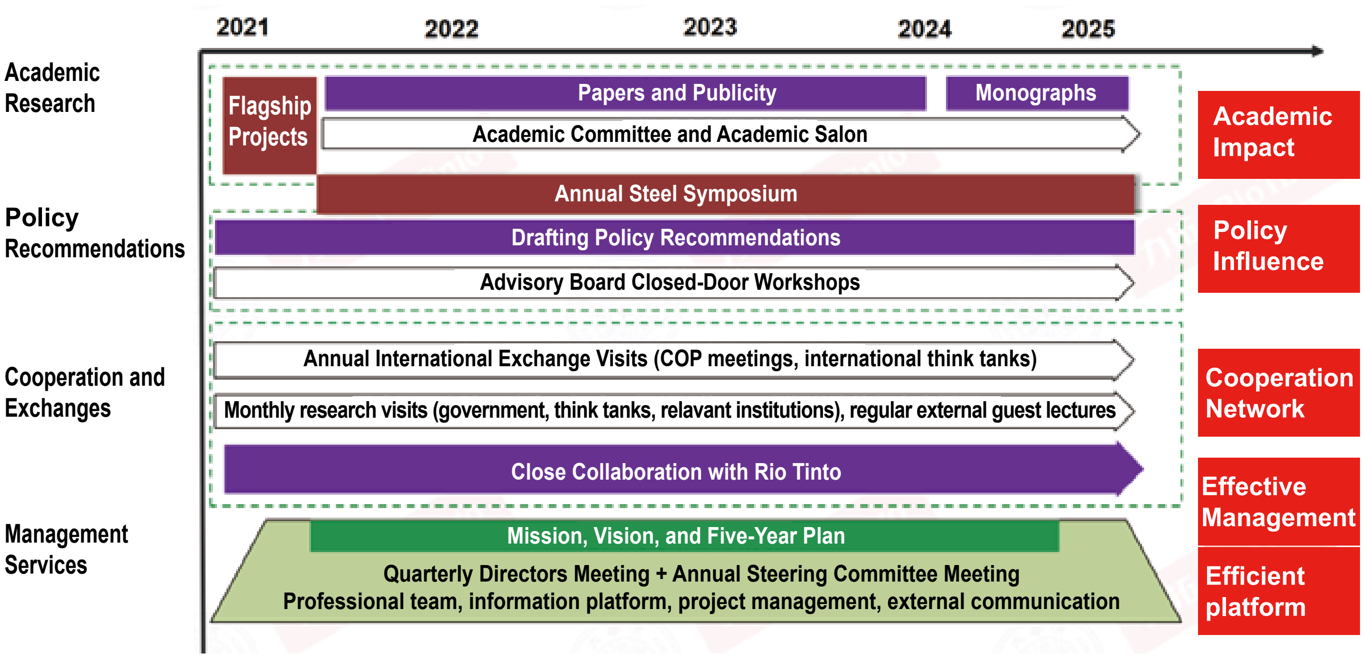
3

3. On December 17, 2020, Tsinghua University, Rio Tinto and China Baowu jointly held a symposium on China's Steel Industry Low Carbon Development in Beijing. This symposium is the next step in advancing the partnership formed between Rio Tinto, China Baowu and Tsinghua University in 2019 to develop and implement new methods to reduce carbon emissions and improve environmental performance across the steel value chain.

4

4. On December 15, 2021, the 2nd China’s Steel Industry Low-carbon Goal and Pathway Symposium, jointly organized by Tsinghua University, Rio Tinto, and China Baowu, was successfully held in Beijing. Based on the success of the first symposium held last year, the symposium aims to further congregate experts from academia and industry, share new ideas and solutions, discuss the pathways of China's steel green low-carbon transition, and help China achieve its carbon peak target and carbon neutral vision with practical actions.

Five-Year Plan of the Centre (2021-2025)



5

5. In 2021, as the starting year of the third phase of cooperation, the Centre further strengthened its strategic objectives and operational management, formulated a five-year action plan around the Centre's mission and vision, in the aspects of academic research, policy advice, cooperation and exchange, and management services, and has hired full-time researchers to facilitate all aspects of work in an orderly manner.

Chapter 2: Research Development of the Flagship Project "Carbon Neutrality in Metal Indusrty"

To promote the interdisciplinary research collaboration, The Joint Centre of Tsinghua-Rio Tinto organized professors from the five departments including the Department of Energy and Power Engineering, the Department of Automotive Engineering, the Department of Earth System Science, the School of Social Sciences, the Institute of Nuclear and New Energy Technology, the Institute of Energy, Environment and Economy of Tsinghua University and other institutions to conducting research on the steel industry chain from the international, regional, and corporate's perspectives, covering topics such as emission accounting and monitoring, low-carbon technology and other pressing topics. Eight research reports are summarized in this part to present the research progress of the flagship project "Carbon Neutrality in the Metal Industry".

Comprehensive Topic: Systematic Analysis of China's Iron and Steel Low-Carbon Development Strategy

1. Research Background

Steel is one of the most vital basic raw materials in today's society, widely adopted in various sectors of the national economy, such as construction, infrastructure and manufacturing. As the world's largest steel producer and consumer, China's crude steel production have ranked first in the world for 26 consecutive years since 1996, with crude steel production reaching 1.04 billion tons in 2021, accounting for 52.9% of the world's total output.

China's steel industry today is dominated by the blast furnace steelmaking process, resulting in its high dependence on resources such as iron ore and coal. The steel industry is the largest source of carbon emission in the manufacturing sector in China. In the short term, the steel industry is a typical resource- and energy-intensive industry, which will remain as a challenge for the carbon neutrality in China. As a result, the decarbonization of the steel industry will have a direct impact on the national carbon neutrality target, and the technological barriers of deep decarbonization in the steel industry will also make it one of the bottlenecks to achieve the goal of carbon neutrality. In order to achieve the goal of carbon peak and carbon neutrality in China, it is significant to accelerate the low-carbon transition of the steel industry. The development of the steel industry is related to economic development, social governance, the utilization of energy and resource. Thus, it's crucial to conduct a deep analysis of the key issues during the low-carbon transition, and systematically analyze the correlation of key factors in order to make a scientific plan of low-carbon development pathway.

2. Research Methods

To thoroughly analyze the low-carbon transition of steel industry, this study refers to the ESGO (Energy System - Sustainability - Governance - Operation) framework proposed by Ma et al. on energy transition,[1] further emphasizing and revealing the position and role of the metal system (M) in this framework, and proposes the M-ESGO analysis framework (as shown in Figure 2-1). This framework points out 5 key issues to analyze the steel low-carbon transition including:

1) Recognize the constraints of sustainability and how changes in the energy system affect carbon emissions (S-E process);

2) Identify key metal sectors that affect energy consumption and carbon emissions, and reveal the characteristics of the physical system (E-M process);

3) Understand the economic/market drivers of metal production and consumption (M-O process);

1. Zhang C., Yang, H., Zhao Y., Ma L., Larson E., Greig C. Realizing Ambitions: A framework for iteratively assessing and communicating national decarbonization progress. iScience. 2022; 25:103695.

4) Sort out available emission reduction technologies and measures for the market and decision makers, and put forward policy recommendations (O-G process);

5) Evaluate the effect of relevant policies on sustainability (G-S process).

Figure 2-1 The M-ESGO Framework

Guided by the M-ESGO framework, the specific research contents and methods of the comprehensive topic are as follows:

1) First, based on energy allocation and the carbon emission allocation methods, trace the flow of China's energy-related carbon emission from energy sources to final services, and then identify the metal sectors especially the steel industry is the main source of energy consumption and carbon emissions.

2) To further understand the physical characteristics of steel systems, the material flow analysis method is applied to trace the flow of steel in China from raw iron ore to end-use products . In order to identify the driving force of steel production and consumption, the extended input-output method is used to calculate the embodied steel of production activities in various economic sectors, further analyzing impact of national economic models on steel consumption;

3) After obtaining a comprehensive understanding on the characteristics of the steel physical system and the driving forces of its production and consumption, the next step is to sort out the low-carbon technologies and policy measures available for the steel industry. The framework of the technology roadmap methodology is used, combined with the literature review. Finally, evaluated key actions for the domestic and international steel industry low-carbon development from three dimensions including supply, demand and policy;

4) Based on the analysis mentioned above, provide feasible policy recommendations for the low-carbon development of China's steel industry.

3. Key findings and policy recommendations

(1) Traceability of China's energy and related carbon emission flows in 2020

In this study, we firstly draw the Sankey diagram of China's exergy allocation in 2020 based on the energy allocation method, as shown in Figure 2-2. The figure shows the primary energy consumption responsibility of each link in the energy system. The distribution of energy flow from left to right goes through five stages: energy sources, intermediate conversion, end-use conversion devices, passive systems, and final services. The color of each flow represents the type of energy, as shown in the legend on the right, while the width of each flow represents the amount of the energy consumption responsibility, in EJ (10^{18}J). The specific method and the detailed description of each stage can be found in the work of Yang et al. (2015) [2]. This study updates relevant data, which is mainly derived from the "2021 China Energy Statistics Yearbook" and " 2021 China Energy Data".

Based on Figure 2-2, the Sankey Diagram of China's Energy-Related Carbon Flow Allocation in 2020 is further plotted by introducing carbon emission factors, as shown in Figure 2-3. The

2. Yang H, Ma L, Li Z. A Method for Analyzing Energy-Related Carbon Emissions and the Structural Changes: A Case Study of China from 2005 to 2015. ENERGIES, 2020,13(8):2076.

framework of the Carbon flow allocation Sankey diagramFlow Allocation Sankey is basically consistent with that of the energy allocation Sankey diagram.Energy Allocation Sankey. The colors of different flows indicate the carbon responsibility from different energy types, as shown in the legend on the right side of the figure. The unit is ten million tons carbon element, and the drawing method is the same as above.

According to Figures 2-2 and 2-3, the characteristics of China's energy flow and energy-related carbon emissions in 2020 are concluded as follows:

1) Coal still dominates China's energy supply and consumption, accounting for 52.1% of primary energy supply, and up to 74.2% of energy-related carbon emissions;

2) From the perspective of the intermediate conversion, primary energy is mainly used as fuel and power generation, accounting for 44.6% and 41.7% respectively, and contributing 41.0% and 39.1% of energy-related carbon emissions, respectively.

3) From the perspective of passive systems, the factory system accounts for the largest energy consumption and carbon emissions, with 65% of energy consumption and 67.9% of total carbon emissions (6.27 billion tons of CO_2), of which the steel and chemical industries are the largest carbon emitters, accounting for 32.6% and 22.4% of the industrial carbon emissions in 2020, respectively, while the metal industry (steel and non-ferrous metals) accounts for 41.8%. The building system accounts for 24% of energy consumption and 20.9% of carbon emissions. While in the transportation system, the biggest contributor is cars (accounting for 42.8% of carbon emissions from transportation);

4) As for the final services, structural materials account for the key demand, taking up 52.6% of the energy consumption responsibility in 2020 and contributing 54.3% of the carbon emission (5.02 billion tons CO_2). Thermal comfort, sustenance, passenger transportation, freight transportation, lighting, hygiene and communication respectively account for 13.0%, 8.2%, 7.1%, 6.2%, 5.9%, 3.8% and 3.2% in the final service energy consumption.

It can be found that there is a strong demand for structural materials in China in 2020, which has led to huge energy consumption and carbon emissions in the metal sector, of which the steel industry is a key contributor. The steel sector accounts for 22.1% of total carbon emissions, including both direct and indirect emissions. Therefore, the low-carbon development of the steel industry is a major challenge for China to achieve carbon neutrality target.

(2) Relationship between China's steel production, steel consumption and economic development

This part aims to systematically reveal the relationship between China's steel production, steel consumption and economic development by establishing a wholistic view of steel flows from the steel production side to the steel consumption side. As shown in Figure 2-4, a Sankey diagram is introduced to show the iron flow in China's steel industry in 2018. On the left, the flow of steel in the steel production side is displayed, and on the right, the steel footprint on the steel material consumption side is displayed. The entire process from iron ore smelting, crude steel production, steel processing, to steel flow in the downstream economic sector, to final demand (gross fixed capital formation, final consumption, and net exports) is comprehensively displayed in the Sankey diagram. The colors of the flow represent different kinds of steel flows, the width of the flow represents the scale of steel flow, and the white vertical lines separate the different steel production and consumption processes.

By analyzing China's steel flow from consumption to production, from right to left in the Sankey diagram, several key understandings can be revealed as follows:

1) Investment rather than consumption dominated the use of steel in China, driving 75.1% of China's steel production in 2018, of which 50.4% was driven by the fixed capital formation in buildings and 24.3% in infrastructure.

2) Although the direct import and export volume of China's steel products was not large, a considerable part of the steel was embedded in iron-containing end-use products and exported, accounting for 13% of the total steel consumption, which was the second largest driver.

3) There was no direct steel consumption in the service industry, but it stimulated 6.8% of China's total steel consumption in the form of embodied steel.

4) The construction industry (including buildings and infrastructure) should be the current focus for improving material efficiency, as 58.6% of China's domestic steel production is for construction.

5) The large amounts of long-products consumed by construction lowered the overall loss fraction of steel fabrication in China (5.7%), but this did not mean advanced manufacturing efficiency, and the loss fraction of some steel products is still high (such as clad and coated products, which were 19.3%).

6) The historical development path and the limitation of scrap resources have made the BF-BOF route dominate China’s steel production (accounting for more than 90%). And the emissions per ton of steel (about 1.7 tons of CO_2/t crude steel) of this long-process steel production route are significantly higher than those of the "waste electric furnace" short-process production route (about 0.6 tons of CO_2/t crude steel[3]).

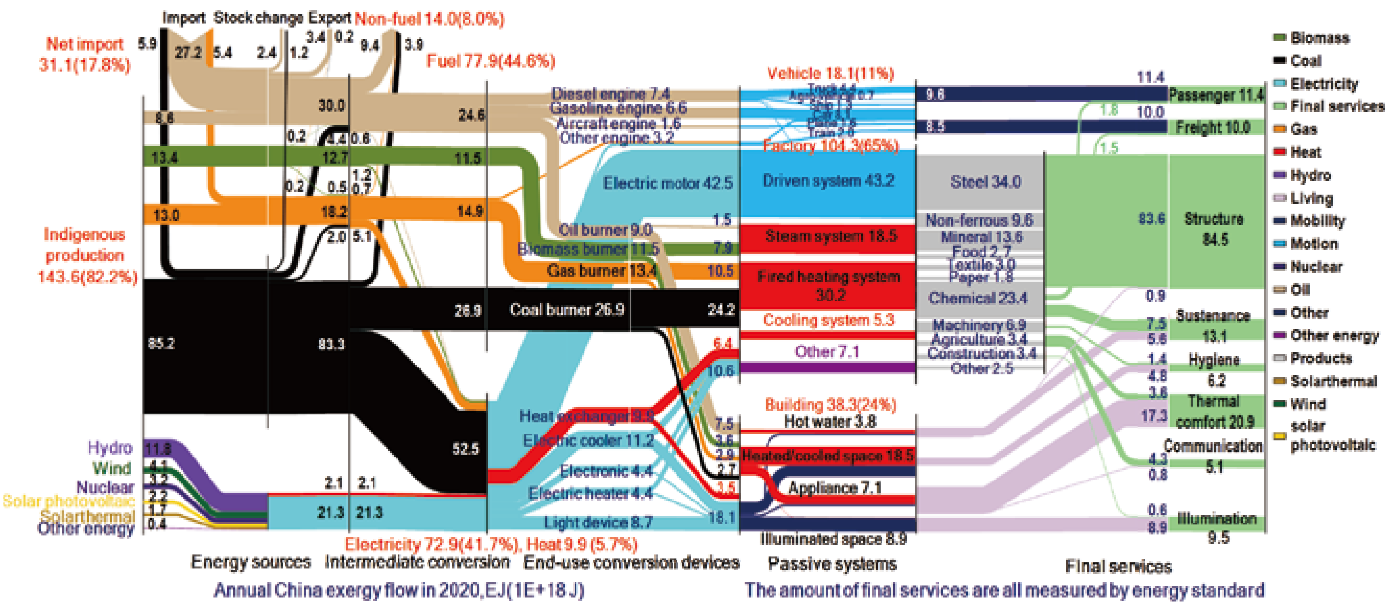


Figure 2-2 Sankey Diagram of Energy Distribution in China's Centire Stream in 2020 (unit: EJ)

3. Lin Y, Yang H, Ma L, et al. Low-Carbon Development for the Iron and Steel Industry in China and the World: Status Quo, Future Vision, and Key Actions. SUSTAINABILITY, 2021,13(22).

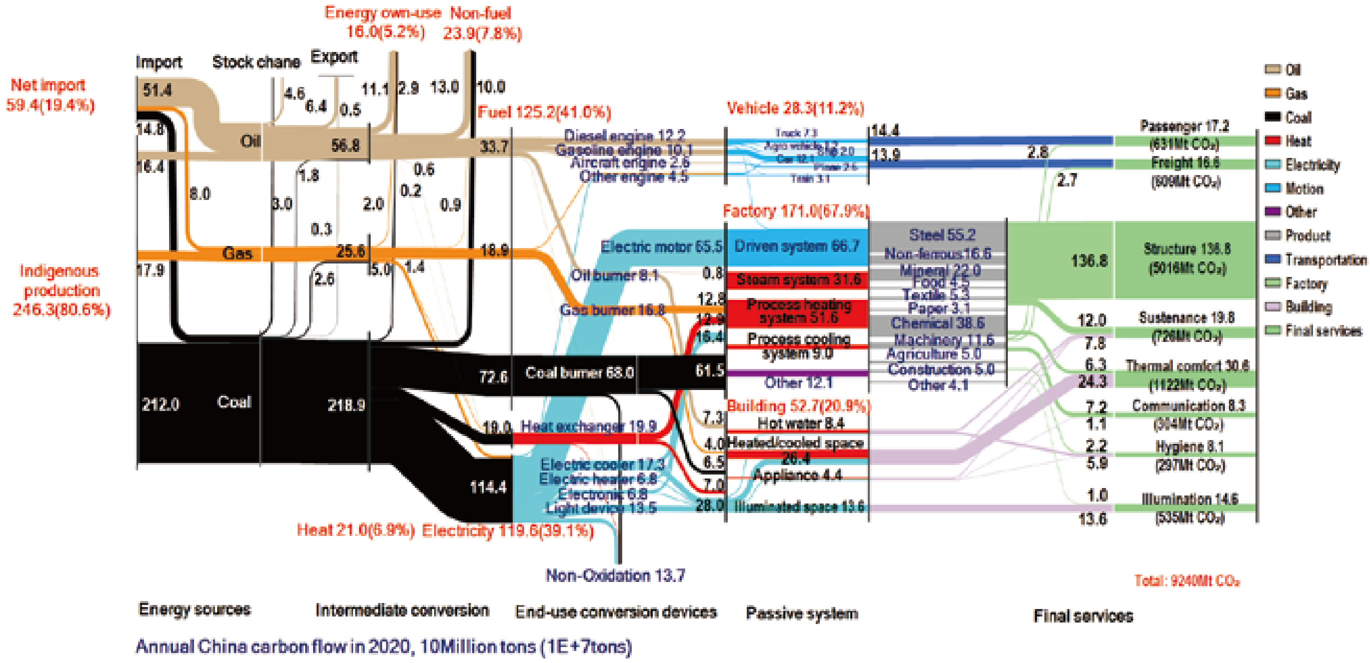


Figure 2-3 Sankey Diagram of the Distribution of Energy-related Carbon Flows in China in 2020 (unit: 10mil tons)

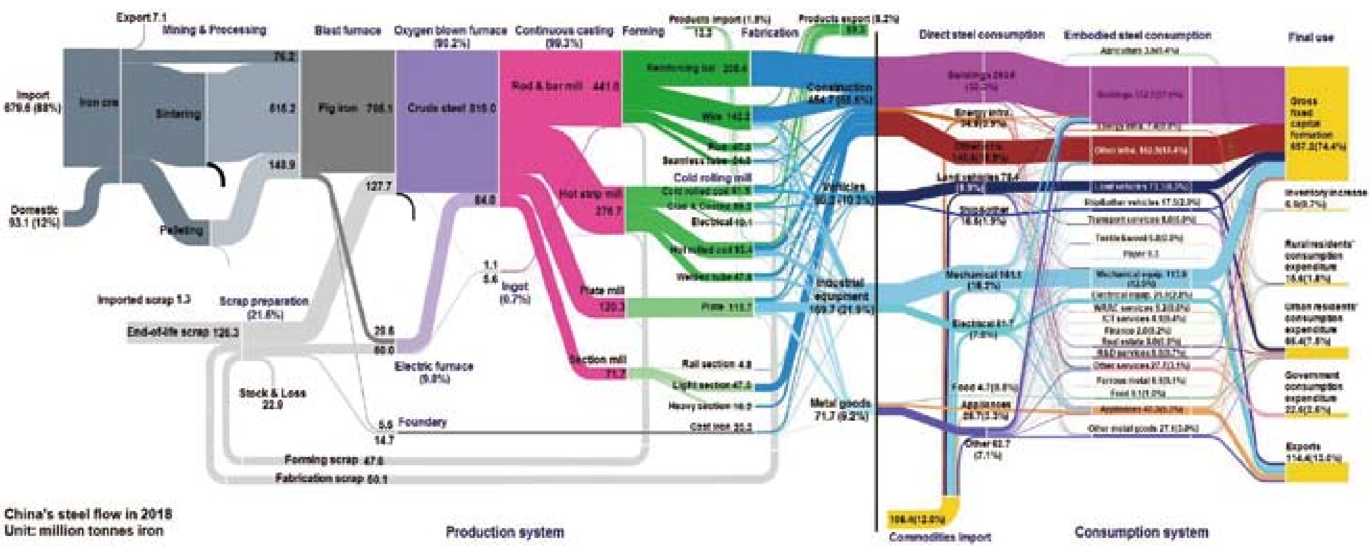


Figure 2-4 Steel Flow Sankey Diagram from Production Side to Consumption Side in China's Steel Industry, 2018

(3) A review of the global steel industry's low-carbon development technology roadmap

Over the past century, the increase in steel consumption has supported the development of economies around the world. Today, under the commitment of carbon neutrality, the low-carbon transition of the steel industry, a typical emission-intensive and hard-to-abate sector, has attracted much attention around the world. This part aims to provide an overview of the low-carbon development technology roadmap of several major steel-producing countries in the world (Table 2-1), to guide policymaking in China.

Table2-1 Overview of the Low-Carbon Development Technology Roadmap of the Steel Industry in the World's Major Steel-Producing Countries [3].

	Status Quo	Vision	Key Actions
Japan	The third largest steel-producing country; 15% of the country's CO_2 emissions	Aiming to realize carbon-neutrality by 2050	· Promotion of COURSE50 project and the ferro coke technologies plus CCUS in the blast furnace · Development of super innovative technologies such as hydro-based iron-making · Recovery of low- to medium-temperature waste heat · Use of biomass · Expanded use of scrap
Korea	The sixth largest steel-producing country; 20% of the country's CO_2 emissions	Following the NDC target of carbon neutrality by 2050	· Applying new, future technologies, like hydrogen and CCUS · Improving energy efficiency · Increasing the use of low-carbon fuels · Reducing F-gas from industrial processes · Bring forward circular economy

Germany	The seventh largest steel-producing country; 10% of the country's CO_2 emissions	Towards climate neutrality by 2050	· Using hydrogen replacing coke to reduce iron ore · Making further use of carbon within the industrial value network · Applying the carbon capture and storage for unavoidable emissions · Increasing the Scrap/EAF route production

The table above summarizes the low-carbon development technology roadmap of the steel industry in Japan, South Korea and Germany. It is evident that the current low-carbon development measures available for the steel industry can be mainly classified into the following four parts:

1. Fully improving energy efficiency. The improvement of energy efficiency is the fastest measure for the steel industry to obtain benefits in the short term, including technical improvement, process optimization, waste heat and waste energy recovery, intelligent management and control;

2. Accelerating the transition to electric furnace steelmaking. The CO_2 emission per ton crude steel in the electric furnace route is lower, if zero-carbon electricity can be accessed in the future, the steel industry is expected to achieve decarbonization;

3. Promoting the circular economy and promote the effective use of steel. In the future, with the development of the economy, the demand for steel will continue to increase, but the promotion of circular economy strategies can reduce steel production while meeting demand, thereby reducing carbon dioxide emissions. The main measures include more recycling of steel, longer lifetime of steel products, more intensive use of steel, lightweight design;

4. Developing innovative steelmaking technologies, such as hydrogen steelmaking and CCUS technology. These innovative steelmaking technologies are expected to achieve true and deep decarbonization of the steel industry, even zero-carbon steel. However, these technologies are still developed in the early stage, and require continuous R&D investment to promote the development.

(4) Policy recommendations for the low-carbon development of China's steel industry

In view of the main characteristics and existing problems of the steel industry, this part provides some suggestions on the low-carbon development of the steel industry in China:

1) Actively guide and control the steel demand. Steel demand is a fundamental issue in China, which is mainly driven by large-scale investment in fixed assets, including housing and infrastructure construction. Previously, most studies have underestimated China's steel demand. This results from the less attention on the fixed capital investment on steel demand. Therefore, the key to controlling steel demand is to guide and control the pace and speed of fixed asset investment, also the key to high-quality development. To avoid the waste of investment and curb over-construction, we must actively guide and control the steel demand, rather than passively respond.

2) Formulating the low-carbon development technology roadmap of China’s steel industry as soon as possible. In the near term, the most realistic means of low-carbon development of steel production is energy efficiency improvement, with acceptable costs and few negative effects. However, energy efficiency improvement should not be achieved by repeated construction (e.g. capacity replacement), otherwise it may not be enough to make ends meet. In the medium term, the most promising way is scrap recycling. Which requires the guide of the recycling of societal scrap, especially scrap embedded in long lifetime houses. This also requires the active use of scrap resources globally. In the long term, the decarbonization of the remaining steel production needs to be realized through major low-carbon technologies, such as hydrogen steelmaking, CCUS, and biomass substitution. However, at present, these technologies are not mature enough, and it is necessary to continue to invest in the research and development.

Overall, low-carbon development of the steel industry requires a series of strategies, including the demand-side that is strongly correlated with fixed asset investment, the supply-side that is closely related to technological development, and the scrap recycling that connect supply and demand. Low-carbon development of China’s steel industry is only plausible with the coordination of both supply and demand. Therefore, the current policy must effectively strengthen the coordination of the demand side and the development of a large circular economy that connects the supply and demand side. Otherwise, it is difficult to fundamentally and systematically solve problems if only focusing on the production-side, and it is difficult to achieve economic development and low-carbon development goals at the same time. In order to promote the implementation of the above measures, policy recommendations are made as follows:

1) Effectively strengthen the monitoring and management of investment and construction of fixed assets, and ensure that the steel can be effectively used and recovered. Give consideration to the introduction of indicators of related steel consumption or carbon emissions in fixed asset investment for statistical monitoring, such as the introduction of the indicator of steel consumption and steel stocks into economic indicators, the early introduction of carbon labels for steel products, etc., to avoid duplicate construction and over-construction;

2) Create an independent and comprehensive scrap recycling system as soon as possible. It is very important to grasp the recycling of scrap resources in the world and China as a strategic emerging industry and a major low-carbon industry, rather than as a traditional industry, and to give necessary support as soon as possible;

3) Support and encourage the steel industry to extensively carry out the research and development and the application of energy efficiency improvements and major low-carbon technologies. It should be combined with industry integration to promote the popularization of high standards of energy consumption and high research and development levels in the whole industry, resolve the co-existing issue of advanced and backward in low-carbon development, and coordinate scientific and technological policy support for technologies in different stages.

4. Research prospects

In the next phase of the study, further analysis on the influencing factors of carbon emissions in China's steel industry can be conducted. It is also expected to establish a model to dynamically analyze steel production, consumption and carbon emissions, and to assess the future impact of different mitigation measures. In addition, this study will further integrate the outcomes of other topics and provide policy recommendations. It is necessary to cooperate with the industry, promote the implementation of relevant policies and measures, and accelerate the application of research outcomes.

5. Members of the Research Team

NAME	TITLE/PROJECT ROLE	AFFILIATION
Linwei Ma	Tenure Associate Professor/ Director of the Centre	Department of Energy and Power Engineering/The Joint Centre of Tsinghua–Rio Tinto
Shanshan Yang	Senior Engineer, Head of Research	The Joint Centre of Tsinghua–Rio Tinto
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Yuan Yuan	PhD Student	Department of Energy and Power Engineering

Topic 1: Regional Perspective of the Carbon Neutrality Strategy and Pathway for the Steel Industry

1. Research Background

Regional and Industrial transition pathways have significant impacts on the achieving of carbon peaking and carbon neutrality targets nationally. The steel industry is not only an important pillar industry to support the development of the national economy, but also a major carbon emitter. The target of carbon peaking and carbon neutrality will reshape the overall development and spatial layout of the steel industry. At the same time, the spatial layout characteristics of the steel industry will also affect the regional decarbonization pathways, in turn affecting the national carbon neutrality pathways. Therefore, it is of great significance to study the strategy and pathways of the steel industry to achieve carbon neutrality from a regional perspective.

The spatial layout of the steel industry changed greatly in history, roughly grouping into three different stages. In the second half of the eighteenth century and the beginning of the nineteenth century, due to the high fuel consumption per unit of product, steel mills were mostly located in fuel production areas. In the second half of the nineteenth century and the beginning of the twentieth century, with the reduction of the proportion of coal and coke consumed in pig iron smelting and the increase in the mining of poor iron ore, the iron and steel industry clearly shifted towards the distribution of iron ore bases. Since the fifties and sixties of the twentieth century, the emergence of large (marine) transport ships has gradually reduced the cost of bulk commodity transportation, and the layout of the steel industry to the coast or to major consumption places has gradually become the mainstream trend. Under the overall goal of achieving carbon peaking and carbon neutrality, what factors will affect the spatial layout of China's steel industry? What will be the characteristics of the spatial layout of the steel industry? Based on this, how to better layout and optimize the allocation of regional resources, to better achieve the national carbon peak and carbon neutrality goal, is the main question that this study will explore.

2. Research Methods

In the study, the relevant policies of the regional layout of the steel industry were reviewed, critical factors affecting the spatial layout were identified, and the suitability assessment of key technologies in different provinces was conducted. On this basis, the overall trend of the regional layout of key technologies of the steel industry and the spatiotemporal evolution of energy consumption and carbon emission of the steel industry are simulated, which can provide scientific support to the decision-making of the steel industry toward the carbon peaking and carbon neutrality (Figure 2-5).

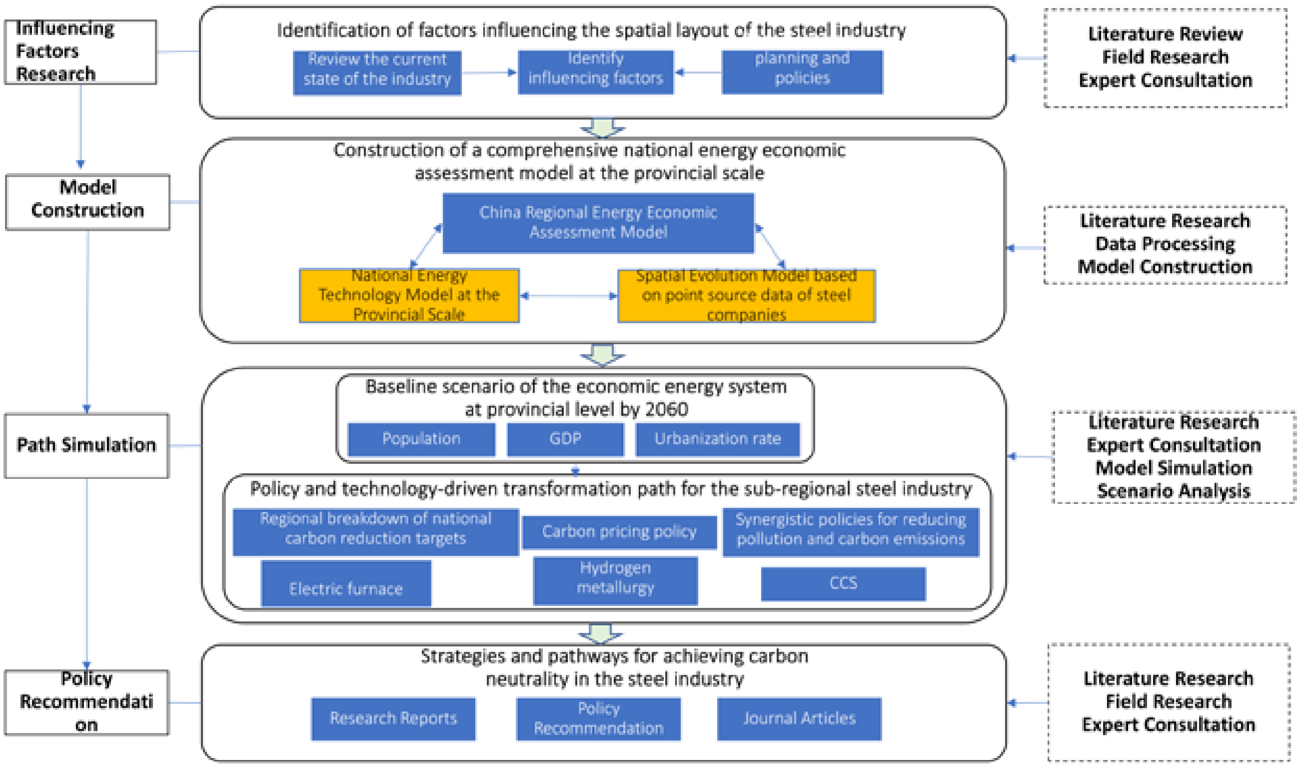

Figure 2-5 Research methods

3. Key findings and policy recommendations

(1) Policies related to the regional layout of the iron and steel industry

To align with high-quality economic and social development, the Ministry of Industry and Information Technology, the National Development and Reform Commission, and the Ministry of Ecology and Environment have issued a number of policies to guide the structural adjustment and industrial transfer of the steel industry (Table 2-2). These policies include restraint policies such as capacity replacement and environmental constraints, as well as incentive policies to guide industrial transfer and industrial restructuring. In general, the current policies encourage industry transfer to align with local conditions, including local environmental capacity, resource and energy endowments, industrial foundation, market size, and logistics capacity.

Table 2-2 Policies related to the layout of the steel industry

Area	Year	Department	Policy Title	Content
Production Capacity replacement	2021	Ministry of Industry and Information Technology	Steel Industry Capacity Replacement Implementation Measures	Clarify what kinds of iron and steel projects construction must implement capacity replacement; define the categories that can be used for capacity replacement; clarify the method of capacity approval
Industrial structure adjustment	2019	National Development and Reform Commission	Guidance Catalogue for Industrial Structure Adjustment (2019 version)	13 items for steel encouragement, 21 items for steel restriction, and 36 items for steel elimination
Industry transfer	2018	Ministry of Industry and Information Technology	Guidance Catalogue for Industrial Development and Technology Transfer (2018)	Propose guiding direction for the steel industry in the northeast, east, central, and west regions
	2021	Ministry of Industry and Information Technology, Ministry of Science and Technology and Ministry of Natural Resources	The Fourteenth Five-Year Plan for the Development of Raw Materials Industry	Guide the rational layout of the raw materials industry, optimize the layout of new production capacity, and promote the development of standardized clusters.

	2022	Ministry of Industry and Information Technology, Development and Reform Commission, Ministry of Ecology and Environment	Guidance on Promoting High Quality Development of Steel Industry	Encourage key regions to improve the phaseout standards. Encourage the regions that have the environmental capacity, energy consumption indicators, market demand, resources, and energy security to undertake the transfer of production capacity.
Environmental constraints	2019	Five ministries including the Ministry of Ecology and Environment, Development and Reform Commission, Ministry of Industry and Information Technology.	Opinions on Promoting the Implementation of Ultra-low Emission in the Iron and Steel Industry	Newly built (including relocated) steel projects nationwide should, in principle, reach ultra-low emission levels. For existing steel enterprises, by the end of 2025, the transformation of ultra-low emissions of steel enterprises in key regions will be achieved, and the country will strive to complete the transformation of more than 80% of its production capacity.
	2019	Ministry of Ecology and Environment	Notice on Good Assessment and Monitoring of Ultra-low Emission of Iron and Steel Enterprises	New requirements for the certification and acceptance of ultra-low emission levels.

	2019	Ministry of Ecology and Environment	Guidance on Strengthening Emergency Emission Reduction Measures in Response to Heavy Pollution Weather	Carry out performance grading of key industries and revise and improve them by year. Implementing the differentiated production suspension and restriction.
	2018	State Council	The Three-Year Action Plan to Win the Blue Sky Defense	The focus area was expanded from "2+26" cities in the region of Beijing-Tianjin- Hebei to the Yangtze River Delta and Fenwei Plain.
	2021	National Development and Reform Commission	Program to Improve the Control of Energy Consumption Intensity and the Total Volume	Further strengthen the guidance of double control of energy consumption
	2021	National Development and Reform Commission	Several Opinions on Strict Energy Efficiency Constraints to Promote Energy Conservation and Carbon Reduction in Key Areas	By 2025, through the implementation of energy-saving and carbon-reducing actions, the proportion of production capacity reaching the benchmark level in the iron and steel industry will exceed 30%. By 2030, the benchmark levels of energy efficiency will be further improved.
	2022	National Development and Reform Commission	Implementation Guide for Energy-saving and Carbon-reducing Transformation and Upgrading in Key Areas of High Energy-Consuming Industries (2022 Edition)	Proposed specific goals and directions for energy-saving and carbon-reducing transformation and upgrading.

(2) Main Factors Affecting Steel Industry Spatial Layout

To achieve carbon neutrality, in addition to reducing the demand of the steel product, carbon neutrality can also be achieved through process reengineering, fuel substitution and other methods. The spatial layout of the steel industry is closely related to the choice of carbon neutrality path of steel. Six factors affecting the spatial layout of the steel industry have been analyzed in detail below.

1) Industrial foundation

China has formed a steel industry layout with Beijing-Tianjin-Hebei, Yangtze River Delta and Northeast China as the main hotspots of steel enterprises. Hebei, Jiangsu, and Shandong are the top three provinces in China's steel production, with a total crude steel output of 450 million tons in 2020, accounting for 42% of the country's total output (Figure 2-8a). From the perspective of iron ore resource sources (Figure 2-8b) and industrial chain maturity, these provinces have a good industrial foundation and will remain the main regions for China's steel industry layout in the future.

According to some predictive studies, China's crude steel production will likely drop from the current one billion tons to 300-600 million tons by 2060, a decrease of 40% to 70%. It indicated that many Chinese steel plants will retire early in the future. Therefore, where the steel mills will retire early will become a major concern. From the perspective of the technical level, the penetration of leading-level equipment is lower in Hebei, Jiangsu, and Shandong provinces than the national average, given the large base (Figure 2-6, Figure 2-7). Thus, it is expected that under stricter energy consumption and carbon emission policies, the scale of capacity decommissioning in these provinces will be larger.

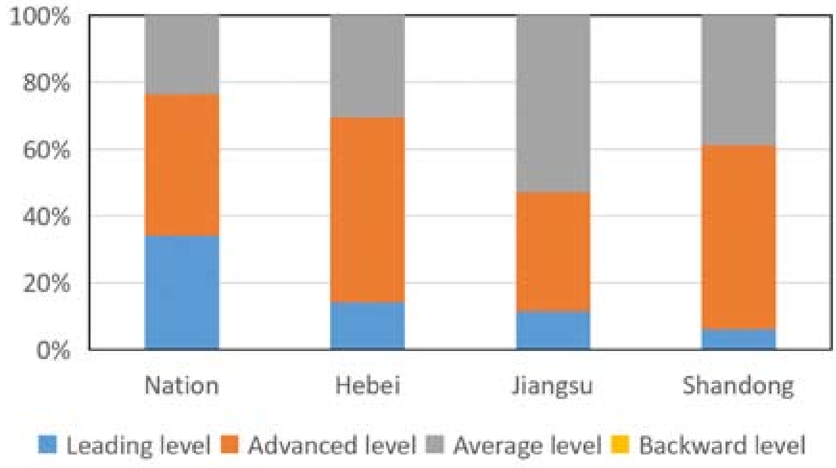

Figure 2-6 Capacity of Ironmaking Blast Furnaces in Enterprises by technology level

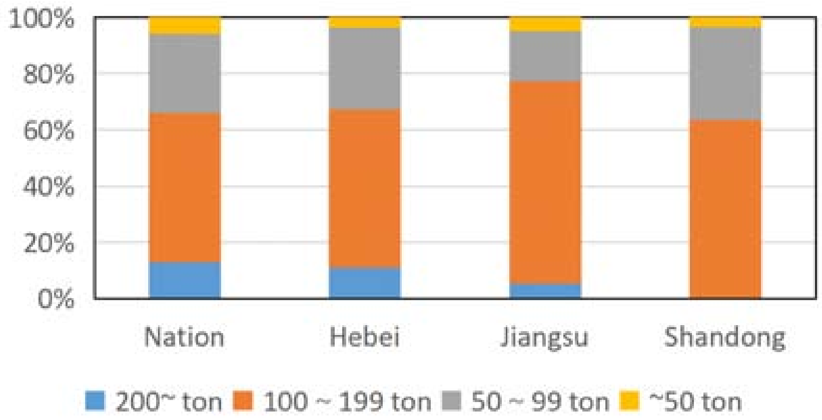

Figure 2-7 Capacity of Converters by scale

2) Scrap steel resources

At present, China's steel industry is dominated by blast furnace technology, accounting for about 90%. To achieve the goal of carbon neutrality, China's steel industry needs to carry out process optimization and innovation. Compared with "long-process" steelmaking, the energy consumption and carbon emissions of "short-process" steelmaking can be significantly reduced. Data show that electric furnace steel accounts for 70% in the United States, and 25% in Japan, while China's electric furnace steel accounts for only 10%. At present, China's electric furnace steelmaking capacity is mainly distributed in Jiangsu, Guangdong, Shandong, Hubei, Yunnan, Fujian, Sichuan and other provinces, with the electric arc furnace production capacity in long-process enterprises as the mainstay. The development of China's electric furnace steel will go through three stages: First, the initial stage of bottoming out, by 2025, the proportion of electric furnace steel in China will account for 15%-20% in steel production; The second is the stage of rapid growth, by 2035, China's electric furnace steel will increase from 20% to 30%; Third, the stage of adapting and balancing, electric furnace steel continues to adapt to the market, resources, environment, technology, power and other conditions at that time, gradually reaching a new balance, by 2050, the proportion of electric furnace steel will likely increase to 40% or higher. The main raw material of electric furnace steelmaking is scrap steel resources, and the layout of scrap steel resources will greatly affect the production layout of electric furnace steel in China.

Scrap resources include self-produced scrap, processed scrap, depreciated scrap and net imported scrap. Self-produced scrap is mainly concentrated in the main steel-producing areas; processing scrap is mainly found in the developed areas of the machinery manufacturing industry; depreciated scrap is concentrated in economically developed areas. Considering the import of recycled steel raw materials, the coastal areas have advantages. At present, more than 80% of the country's scrap steel resources are distributed in Northeast China (Liaoning), North China (Beijing, Tianjin, Hebei, Shanxi), East China (Shanghai, Jiangsu, Shandong, Zhejiang), Central China (Henan, Hubei), Sichuan, Guangdong and other provinces and cities with relatively concentrated and densely populated industrial and mining enterprises (Figure 2-8c).

3) Green electricity and green hydrogen resources

The current energy cost accounts for about 20% -40% of the total cost of steel production (World Steel Association, 2021)[1], and the energy cost is mainly in coke production. With the promotion of electric furnace steelmaking and hydrogen metallurgy technology in the future, energy costs will be mainly reflected in the cost of electricity or hydrogen energy consumption, so the distribution of green power and green hydrogen resources in the medium and long term will have a greater impact on the distribution of the newly built steel plants. The new electric furnace steelmaking capacity will likely be

1. World Steel Association. 2021. Energy use in the steel industry. https://worldsteel.org/wp-content/uploads/Fact-sheet-Energy-use-in-the-steel-industry.pdf.

more distributed in the area where the large renewable energy generation base is located. According to Wang et al. (2022)[2] and the National Energy Administration (2020)[3] , China's onshore wind power resources are mainly distributed in Inner Mongolia, Heilongjiang, and Xinjiang; Offshore wind power resources are mainly distributed in Guangdong, Zhejiang, and Shandong; Centralized photovoltaic resources are mainly distributed in Xinjiang, Inner Mongolia, and Qinghai; and Hydropower resources are mainly distributed in Sichuan and Yunnan (Figure 2-8d, Figure 2-8e).

Hydrogen metallurgy is an important and revolutionary technology for the steel industry to achieve carbon neutrality. It is expected that after 2030, China's hydrogen-direct reduced iron-electric furnace steelmaking technology will begin to be promoted and applied on a large scale, and the proportion of hydrogen-based steel may reach 16% in 2050[4], and by 2060, the proportion of hydrogen-based steel may reach 25%-50%[5,6]. At present, China's hydrogen energy industry is mainly concentrated in the Yangtze River Delta, Guangdong-Hong Kong-Macao Greater Bay Area, Beijing-Tianjin-Hebei and other regions, the production mode is mainly fossil fuels (especially coal) hydrogen production, and the hydrogen energy currently used in the steel industry is mainly from coke oven hydrogen production. In the future, with the further strengthening of carbon emission reduction target constraints, the large-scale promotion of hydrogen metallurgy technology may be carried out simultaneously with the large-scale application of renewable energy hydrogen production. According to Huang and Liu (2020)[7], Inner Mongolia, Xinjiang, Shandong, Hebei, Gansu, and other provinces will be the regions with the most potential for renewable energy

2. Wang, Y. and Q. Chao, et al. 2022. Assessment of wind and photovoltaic power potential in China. Carbon Neutrality 1 (1).

3. Department of New and Renewable Energy, National Energy Administration Energy Research Institute, National Development and Reform Commission. 2020. Renewable Energy Databook 2020

4. Zhang Zhen, Du Xianjun. 2021. Study on carbon reduction economy of hydrogen metallurgy under the carbon neutral target. Price Theory and Practice. 65-68.

5. IEA.2021. An energy sector roadmap to carbon neutrality in China. https://www.iea.org/reports/an-energysector-roadmap-to-carbon-neutrality-in-china.

6. Institute of Climate Change and Sustainable Development, Tsinghua University. 2022.Comprehensive Report on China's 2035 and Medium-and Long-term Low-carbon Development Strategy towards Carbon Neutrality.

7. Huang, Y. S. and S. J. Liu. 2020. Chinese Green Hydrogen Production Potential Development: A Provincial Case Study. IEEE ACCESS 8: 171968-171976.

hydrogen production; At the same time, considering the technological advances of offshore wind, the potential of renewable energy hydrogen production in some eastern coastal regions such as Guangdong, Jiangsu, Shanghai, and Shandong will likely increase significantly by 2030.

4) Carbon storage potential

By 2060, the majority of the remaining long-process steel smelting equipment will need to be equipped with carbon capture and storage devices, and the long-process steelmaking capacity of the steel industry will be more concentrated in areas with carbon sequestration capacity. According to the analysis results of Wei et al. (2021)[8], based on the source-sink matching method, low-cost crude steel enterprises are mainly distributed in and near the Bohai Bay, Junggar District, Jianghan, Ordos and other basins (Figure 2-8f). Where there is a concentrated number of crude steels with a high CO_2 emission and suitable conditions for storage (storage capacity and injection).

5) Market demand

Steel demand is closely related to industries such as construction, machinery, automobiles, energy, home appliances and shipbuilding, and largely echoing the process of industrialization and urbanization of different regions. The production layout of China's steel industry has long shown the characteristics of "north heavy and south light" (Figure 2-8g), and a large number of domestic steel products are sold from the north to the south. At present, large steel enterprises such as Angang Iron and Steel, Bengang and Shougang in Northeast and North China regard East China and Zhongnan as key domestic steel sales areas (China Iron and Steel Association, 2021[9]).

Looking forward to 2035, China will basically achieve socialist modernization, urbanization rate will reach a new high, basically achieve new industrialization and urbanization, under the "carbon peak, carbon neutrality" goal constraints for various industries, steel consumption will go into a downward range. By 2060, affected by product iteration, non-metallic material substitution, and other factors, China's traditional steel industry will undergo unpredictable changes, steel

8. Wei et al. 2021. CCUS Assessment of carbon reduction potential of crude steel production in China. Chinese Environmental Science,41 (12): 5866-5874

9. China Iron and Steel Association. 2021. China Steel Industry Development Report. Beijing: Metallurgical Industry Press.

consumption will be significantly lower than 2035, and it is expected that crude steel consumption will drop to about 350 to 800 million tons in 2060[10].

6) Environment capacity

Environmental factors such as air quality are the main factors affecting the layout of China's steel industry in the near and medium term, and will continue to play an important role in the future. China's steel industry is densely distributed in the Beijing-Tianjin-Hebei and Yangtze River Delta regions, which are also the most polluted areas in China. Steel companies in these regions are facing more stringent pressure on backward steel production capacity.

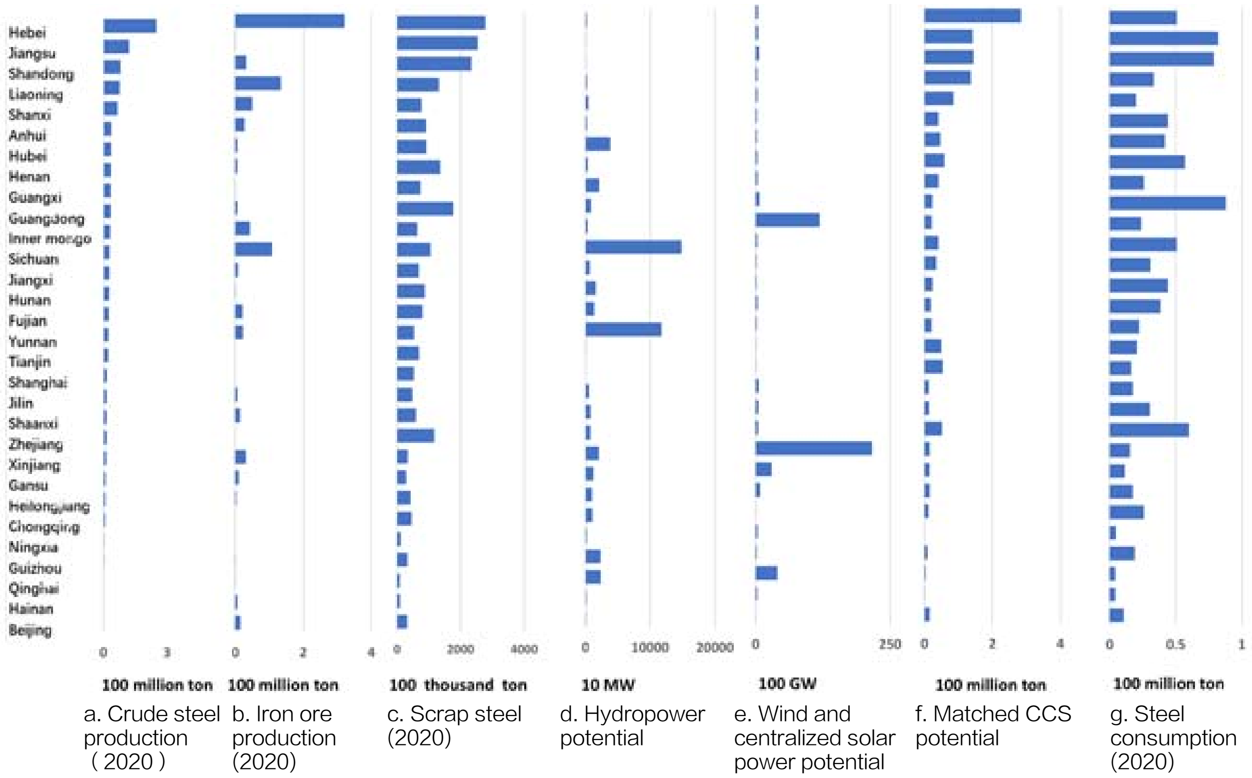

Figure 2-8 Main influencing factors by province[11]

10. LI J., XIE C., CAI W., WANG C. 2022. Low Carbon Development Pathway of China's Iron and Steel Industry under the Vision of Carbon Neutrality—Consensus and Uncertainty. Chinese Journal of Environmental Management, 14(01): 48-53.

11. Source: Steel production is quoted from the National Bureau of Statistics; Iron ore production is quoted from China Business Intelligence Network; Steel consumption and scrap resource generation are provided by the authors of the paper; Renewable electricity development potential includes hydropower, wind power and photovoltaics, which quoted from the National Energy Administration (2020) and Wang et al. (2022); Matched CCS potential quoted from Wei et al (2021).

(3) Projection of the trend of the regional layout of the steel industry

A suitability assessment was conducted based on TOPSIS (Technique for Order Preference by Similarity to an Ideal Solution) method. It is found that the Hebei and Shandong will face a relatively strict withdrawal scale in steel production capacity. The capacity may be transferred from these overly concentrated areas in the form of electric furnace short process and hydrogen metallurgy to the southwest, northwest and south China coastal areas. It is projected that by 2060, the dominant technology will be electric furnace steelmaking and hydrogen metallurgy in northwest China, and that will be electric furnace steelmaking in southwest China. CCS technology will account for a relatively high proportion in the eastern and northeast regions (Figure 2-9).

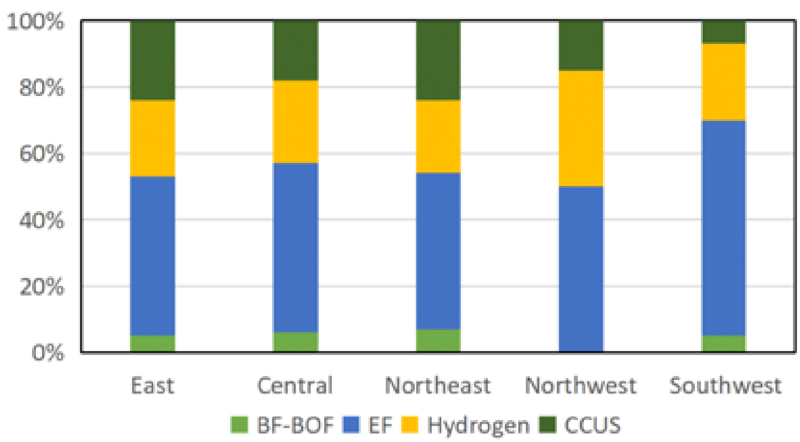

Figure 2-9 Proportion of steel industry technology in 2060 by region

(4) Policy recommendations

First, the state guides the industrial layout of the steel industry in an orderly manner based on the industrial foundation, scrap steel resources, green power and green hydrogen energy guarantee, carbon storage potential, market demand, and environmental capacity.

Second, each region formulates a low-carbon transformation path for the steel industry considering its own characteristics and local conditions. The eastern region should strengthen the reduction of the steel industry and take multiple measures to promote the low-carbon transformation of the steel industry through process reengineering, fuel substitution, and raw material substitution. The central region is limited to regional market capacity and resource and energy support, and the steel industry is laid out in accordance with the market-oriented trend. Relying on their own renewable energy resources and carbon sequestration potential, the southwest and northwest regions give priority to undertaking the transfer of production capacity in other regions in the form of electric furnace steelmaking and hydrogen metallurgy to meet the regional market demand.

Third, encourage cross-regional steel capacity replacement, and the cross-regional capacity replacement policy is tilted towards electric furnace steelmaking, hydrogen metallurgy, and steel production with CCS projects.

4. Research Prospects

Further resource and technology evaluation of low-carbon steel transformation in the subregion needs to be carried out, including the sub-regional scrap steel resources and the sub-regional application potential of low-carbon/carbon-negative technologies such as electric furnace steelmaking, hydrogen metallurgy, and CCS. In terms of CCS evaluation of the steel industry, considering the layout of China's inland carbon sequestration potential and the steel industry, there will be a mismatch in the spatial distribution in some regions (for example, Guangdong has limited inland carbon sequestration potential, while the steel industry is more developed), which will strengthen the evaluation of offshore carbon sequestration potential in the eastern coastal areas. In order to further refine the composition of low-carbon/carbon-negative technologies and energy consumption in the steel industry in the subregion.

5. Members of the Research Team

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Topic 2: Demand Estimation and Plant-Level Low-carbon Transition Pathway towards Carbon Neutrality in China's Steel Industry

1. Research Background

In the context of China's carbon peaking and carbon neutrality pledge, the common consensus among academia and industry is that the steel industry should undertake deep decarbonization to synergistically achieve the setout climate and environmental goals. For the carbon peaking, the characteristics and external policy landscape of the steel industry both require controlled production capacity. Looking at the internal characteristics, China's future steel demand generally sees a downward trend, with many studies suggest that China's crude steel production will peak by 2025 and then enter a phase of steady decline; second, the production process mainly based on long-process blast furnaces (BF) gradually upgrade to advanced processes such as short-process electric furnaces (EF) and hydrogen steelmaking; third, the average operating life of existing facilities are relatively short, policies are needed to promote their early retirement. In order to achieve economic transition, environmental protection and low carbon goals, China has issued a series of policy documents since 2013 requiring the steel industry to reduce excess and backward production capacity.

Therefore, it is necessary to promote the early retirement of carbon-intensive capacities in the steel industry through policy measures. However, the existing studies have paid less attention to the issue of integrating efficiency and equity factors into a scientifically-designed retirement strategy of carbon-intensive capacity. The capacity retirement strategy needs to pay attention to both its potential environmental benefits to maximize the policy benefits and the economic and employment impacts of capacity retirement on each province to achieve an equitable low-carbon transition in the steel industry among regions.

2. Research Methods

This study aims to propose a retirement strategy for the carbon-intensive capacities (meaning BFs) while balancing policy effectiveness and impacts on regional equity, combining top-down demand forecasting with bottom-up comprehensive performance assessment of BF capacity to identify the scale and roadmap of the retirement in a carbon-neutral scenario. The specific research contents and methods of this topic are as follows (as shown in Figure 2-10).

1) Predict the actual demand for steel in China based on stock-based and consumption-side dynamic material flow analysis, including: the scale of capacity, the amount of available scrap resources and recycling rate, and the share of EF steel production from 2020 to 2060.

2) Build a holistic database of Chinese iron and steel production facilities by matching multiple data sources, validation and accounting, and calculate the "Carbon-Water-Health" Comprehensive Performance Index (CPI) of BFs based on their carbon emissions, water consumption and air pollutant emissions with different index weights.

3) Combining the two above, we propose a performance-based retirement strategy for BF capacity in China's iron and steel industry during the 14th Five-Year Plan period based on CPI rankings.

4) Considering an equitable distribution of inter-provincial capacity retirement burden, after allocating proportion of the retirement capacity to each province, the trade-off between environmental benefits and distributional impacts of capacity retirement is explored, followed with a proposed optimized capacity retirement strategy to improve benefits and equity.

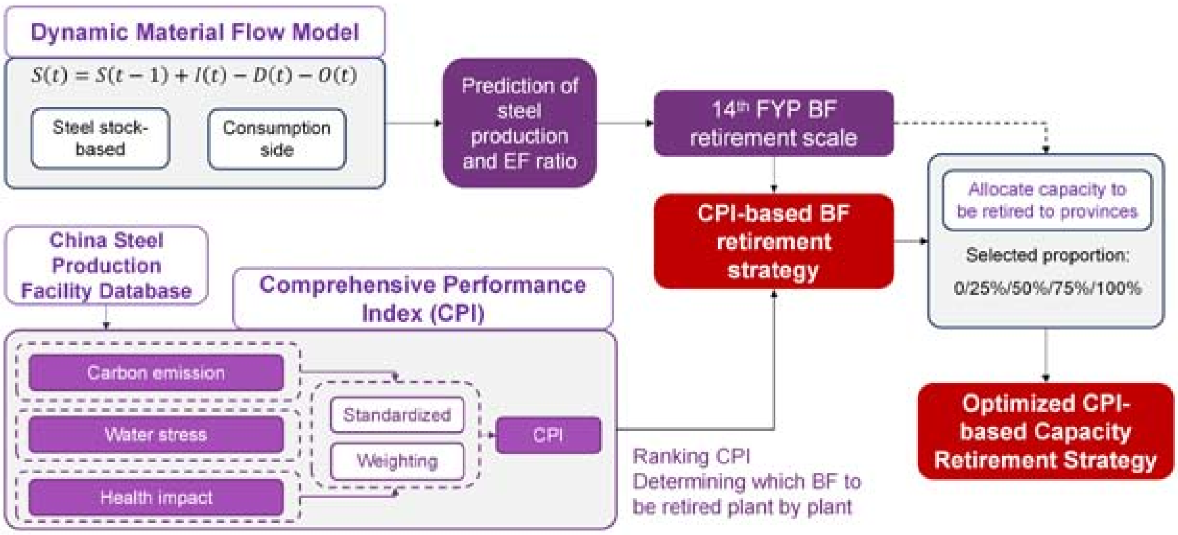

Figure 2-10 Topic 2 Research Roadmap

3. Key Findings and Policy Recommendations

(1) Capacity distribution and environmental performance of China's steel **industry**

Figure 2-11 shows the regional distribution and environmental impact of the current capacity (BF and EF) in China's steel industry. As seen from the figure, the current steel capacity is concentrated in northern China provinces such as Hebei, Tianjin and Shandong. The SO2, NOx, PM, CO_2 emissions and water consumption per unit of crude steel output vary widely, with the ranges of 0.12-1.04kg SO2/ton steel, 0.26-1.64kg NOx/ton steel, 0.08-1.39kg PM/ton steel, 1.01-2.95t CO_2/ton steel and 1.03-5.87t water/ton steel, respectively.

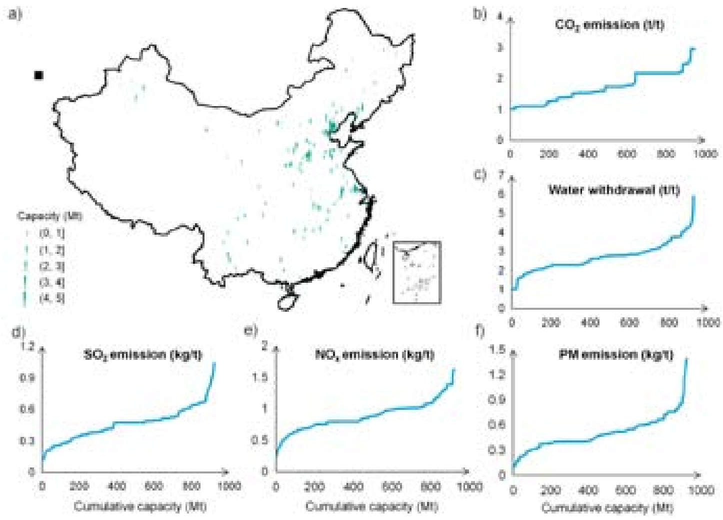

Figure 2-11 Regional Distribution and Environmental Impact of Active Capacity

Figure 2-12 shows the CPI of BFs considering carbon-water-health impacts. As shown in the figure, the BFs with poor performance (i.e., higher in the CPI) are mainly located in western and northern China provinces, and the BFs with good integrated performance (i.e., lower in the CPI) are often found in southern China provinces.

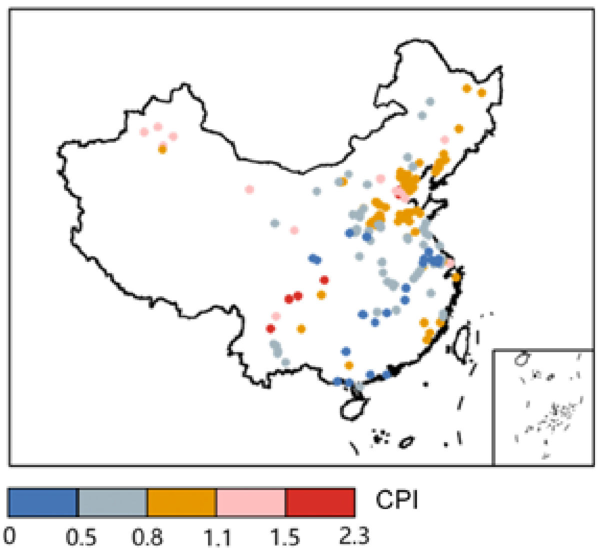

Figure 2-12 China BF Comprehensive Performance Index (Carbon-Water-Health Weighting Equally)

1) China's Crude Steel Demand and the Proportion of Electric Furnace Steel between 2020-2060

China's crude steel demand and production will see continuous decline, while the proportion of EFs will see continuous increase. Crude steel production will gradually decline from 1,064 million tons in 2020 to 977, 730 and 612 million tons by 2030, 2050 and 2060, respectively. While the proportion of EF steel will gradually rise from 10.3% in 2020 to 19.9%, 41% and 53.2% by 2030, 2050 and 2060 (as shown in Figure 2- 13 shown).

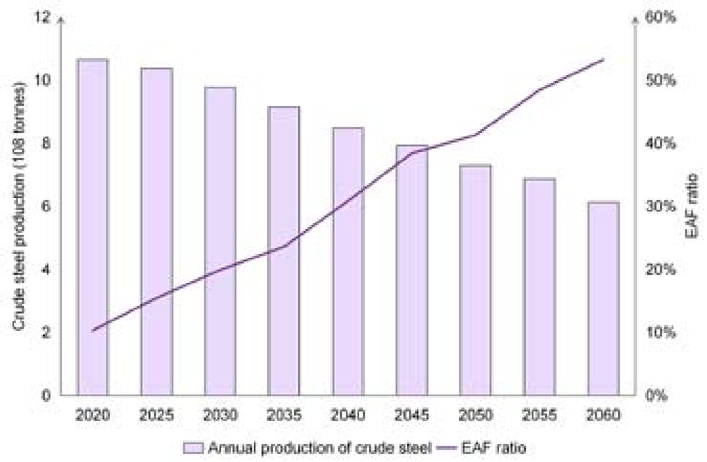

Figure 2-13 China's Crude Steel Production and Electric Furnace Steel Ratio Forecast from 2020 to 2060

2) Comprehensive Performance Index-based Retirement Strategy for China's Steel Blast Furnace Capacity and its Impacts during the 14th Five-Year Plan Period

Considering different scenarios of existing capacity retirement and replacement, China needs to retire 98-286 million tons of BF capacity (192 million tons on average) in the 14th Five-Year Plan period. Under the scenario of retiring 192 million tons of BF capacity, the CPI-based retirement strategy indicates that BF capacity to be retired is concentrated in Hebei (82.48 million tons), Tianjin (24.27 million tons), Shanghai (20.9 million tons), Sichuan (18.28 million tons), Shandong (16.2 million tons), and Xinjiang (14.75 million tons) Provinces (as shown in Figure 2-14).

BF capacity early retirement will result in multifaceted benefits including carbon emission reduction, air pollutant emission reduction and health co-benefits, and water stress relief. However, different retirement strategies vary in environmental benefits. Traditional capacity retirement

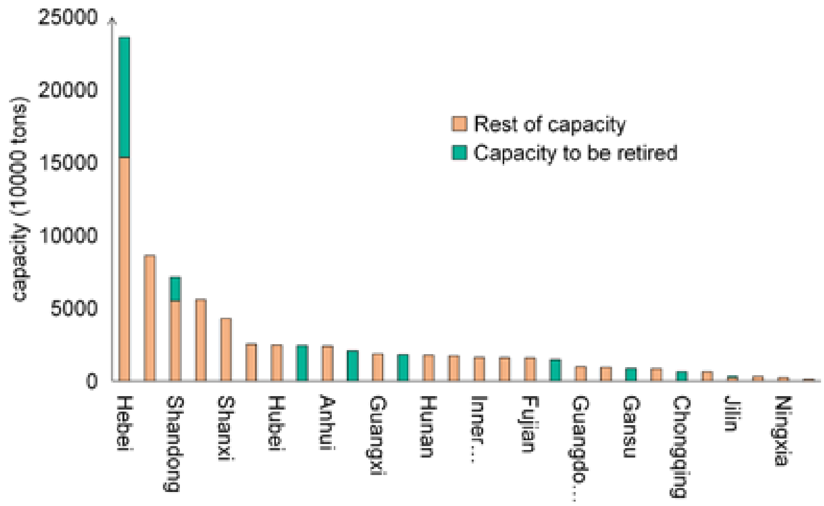

Figure 2-14 The Scale of BF Capacity Retirement by Province under Comprehensive Performance Index-based Strategy

strategies are generally based on either the year of operation (i.e., prioritizing the retirement of those with longer years of operation) or the size of capacity (i.e., prioritizing the retirement of those with smaller capacity). In this study, we calculate the scale of capacity retirement and environmental benefits under the above two traditional strategies and compare them with the proposed CPI-based strategy. The results show that the environmental benefits of the CPI-based strategy are generally better than the traditional operating year-based or capacity-based retirement strategy, given the retirement scale, as shown in Figure 2-15.

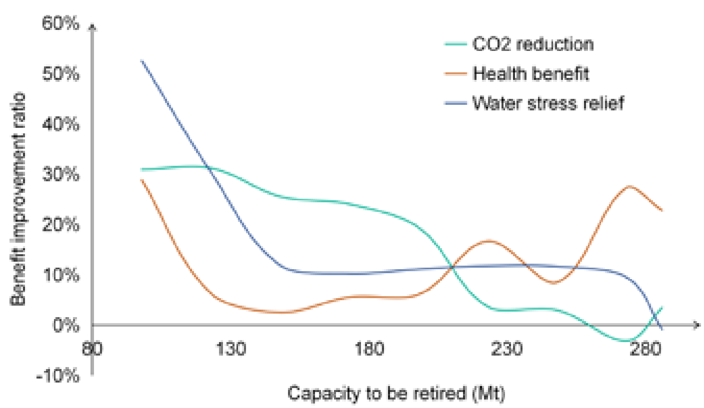

Figure 2-15 Improvement in Carbon-Water-Health Benefits for Different Retirement Scale under CPI-based Retirement Strategy Against Traditional Strategies

3) Incorporating Provincial Equity into the Optimization of BF Capacity Retirement Strategy

Although the CPI-based capacity retirement strategy is very likely to outperform the traditional strategies in terms of environmental benefits, the strategy allocates a significant proportion of capacity to be retired to a few provinces, exacerbating inter-provincial equity in terms of capacity retirement responsibilities compared with the traditional schemes. Figure 2-16 shows the "Gini Coefficient"[7] of capacity retirement under the three retirement strategies, and the results show that the Gini Coefficient of the CPI-based strategy is higher than those of the traditional strategies given the retirement scale.

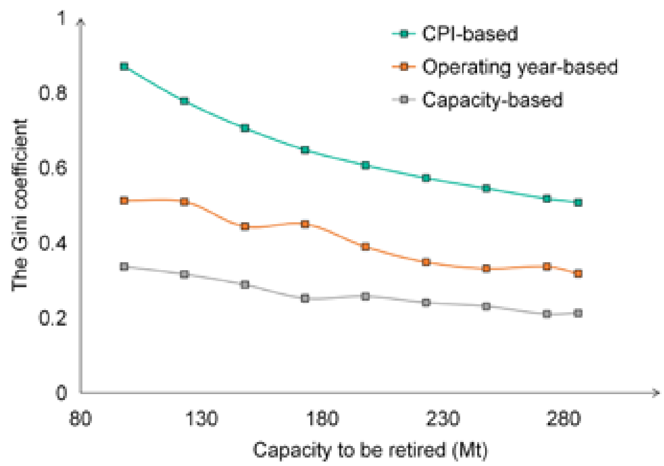

Figure 2-16 Inter-Provincial Inequity (Expressed as Gini Coefficients) in Capacity Retirement for the Three Retirement Strategies at Different Scales

In order to improve the inter-provincial equity, we propose that a certain proportion of the total capacity to be retired can be allocated to each province (proportionally to its total capacity), applying the CPI-based strategy, while the rest of the capacity to be retired is still selected nationwide. The results are shown in Figure 2-17. When the proportion exceeds 50%, the improved

7. Gini coefficient (range: 0-1) was originally used to quantitatively depict the equity of income or wealth distribution. The higher the Gini Coefficient value, the unfairer the income or wealth distribution. In this study, the "Gini coefficient" of BF retirement is used to evaluate the equity of the distribution of capacity retirement among provinces i.e. The higher the Gini Coefficient value, the unfairer the distribution of capacity retirement among provinces.

scheme outperforms the traditional strategies and original CPI-based strategy (i.e. proportion=0) in terms of both environmental benefits and inter-provincial equity, and can achieve a win-win situation of both benefits and equity, as shown in the gray area of Figure 2-17.

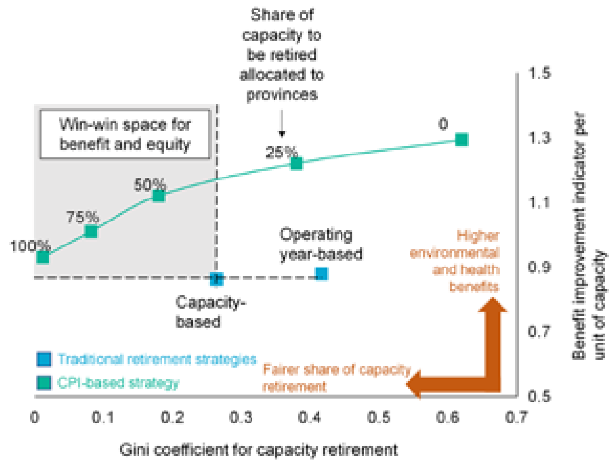

Figure 2-17 Improvement in Environmental Benefits and Equity Given a Proportion of Capacity to be Proportionally Allocated to Each Province (green line and dots) under the CPI-based Strategy (192 Million Tons Capacity to be Retired)

4) Policy Recommendations for Low-Carbon Transition of China's Steel Industry

First, promote the optimization of BF capacity and promote the deployment of EF to synergistically strengthen pollution and carbon emission reduction and enhance the overall benefits of early carbon peaking in China's steel industry. Since the twenty-first century, China's rapid social and economic development has triggered significant increase in steel demand in construction, transportation and machinery sectors, giving rise to the expansion of a large number of steel enterprises, resulting in excess production capacity, this has seriously undermined the sustainable development of the steel industry. In response, China has introduced a series of initiatives to phase out excess capacity, by eliminating a number of technically inferior and emission-intensive capacity in order to raise the capacity utilization rate to a healthy level. However, recent years have seen a slow-down in China's urbanization, per capita steel stock increase, and steel demand increase. In addition, China's BF-dominated steel production structure remains pollution, energy and carbon-intensive. The cleaner, energy-efficient and low-carbon EF capacity accounts for only 10%, far below that of developed regions and countries such as Europe and the United States. Main limiting factor is the limited supply of scrap resources, but as China enters a slower development stage and optimizes the scrap recycling system, the supply of scrap resources will increase. In order to synergistically achieve pollution control and climate targets, it is necessary for China to introduce combined incentive-based and mandatory measures to promote the adjustment of BF capacity and the development of EF capacity. Specifically, China should strictly limit the growth of BF capacity, actively replace BF with EF, and promulgate a policy package including carbon market coverage expansion to the steel industry and transition from energy consumption control to carbon emission control.

Secondly, support the innovation and R&D of deep decarbonization technologies such as hydrogen metallurgy, CCS and biochar steelmaking, and analyze the spatial layout of deep decarbonization technologies. The current decarbonization actions for China's steel industry are mainly focused on capacity management, energy efficiency improvement and EF development. However, towards the long-term goal of carbon neutrality, achieving near-zero emissions in the steel industry still requires the large-scale application of deep decarbonization technologies such as hydrogen metallurgy, CCUS and biochar steelmaking. Therefore, it is necessary to advance the innovation and deployment of these technologies. On the one hand, encourage the R&D and piloting of key technologies through incentive policy instruments to promote collaborative innovation between industry and academia and strengthen the role of enterprises in technology innovation. On the other hand, conduct systematic analysis of the multidimensional socioeconomic, ecological and environmental impacts of the large-scale application of different deep decarbonization technologies, taking into account the spatial heterogeneity of resource endowment, in order to identify the prioritized areas for the deployment of decarbonization technologies in the iron and steel industry and promote disruptive decarbonization technologies from pilot demonstrations to large-scale application.

4. Research Outlook

In the next phase of research, we propose to conduct study on the optimal regional layout of steel production capacity based on carbon and environmental constraints. Specifically, in the context of carbon neutrality, disruptive zero-carbon steelmaking technologies see a wide range of application prospects, providing new momentum to the development of the steel industry. Include hydrogen-based steelmaking, CCUS, and biochar steelmaking. However, the development of these technologies depends on key spatial elements such as wind and solar potential, land and biomass resources, and carbon capture and storage locations. Future steel capacity replacement and construction should incorporate the above factors, so as to optimize the spatial layout picture of China's steel industry.

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Topic 3: Low-Carbon Technologies in the Steel Industry: Identification, Evaluation and Application Prospects

1. Research Background

1) Carbon emission reduction in the steel industry is crucial to achieving the "double carbon" goal.

As an energy-intensive industry, the steel industry is a major contributor to greenhouse gas emissions, and the "carbon reduction" or even "de-carbonization" of the industry is crucial to achieving the "double carbon" goal.

2) The steel industry needs to thoroughly explore low and zero carbon technology pathways.

The current technological innovation in China's steel industry to promote the realization of "double carbon" goal is confronted with three challenges: the difficult to reverse long-established coal-coke production method in the steel industry in the short term; the significant reduction in energy consumption in China's steel industry, leaving little room for further improvement; the policy of restricting production capacity in China's steel industry makes it difficult to meet the requirements of high-quality economic development.

3) There is an urgent need to judge the maturity, application potential and effectiveness of the technology selected.

Technological innovation often comes with risks, and steel companies must carefully evaluate and weigh various technology options from a full industry chain perspective. For policy makers, develop a deep understanding into steel carbon-neutral related technologies to form a concise and comprehensive development picture will help in formulating policies that meet the needs of the industry.

Therefore, it is necessary to evaluate the maturity of low-carbon technologies, analyze the effects of their application, and use it to design a roadmap for technological innovation development.

2. Research Methods

The key research revolves around is the evaluation of major emission reduction technology innovations in each link of the whole steel industry chain, corresponding to the following research ideas: first, identifying the major technology innovation options in the steel industry by means of literature research and enterprise research; second, assessing the maturity of low-carbon technologies and the performance of carbon reduction costs and green premiums by combining the academic progress and industry status quo; Thirdly, establish life cycle analysis database for the steel industry and build relevant analysis model to assess the feasibility and benefits of each technology application.

As shown in Figure 2-18, the following studies were conducted based on the existing hydrogen energy life cycle analysis and steel carbon reduction technology research:

1) Identify technologically innovative solutions and track enterprises' technological progresses.

This part mainly adopts the methods of literature research and enterprise research. On the one hand, fully identifying and summarizing the existing technical solutions in the steel industry (mainly hydrogen metallurgy and CCUS), focuses on investigating various technical parameters and organizing and analyzing data and information; on the other hand, follow up and establish the technical progress of major international and domestic steel enterprises (e.g. ArcelorMittal, Baowu, etc.) and steel abatement technology supply companies (e.g. Tenova-HYL, MIDREX).

2) Build life cycle analysis database and model for technology assessment.

This section focuses on the metallurgical database required to analyze the smelting process by relying on the whole life cycle analysis method and establishing a matching life cycle analysis model for steel metallurgy to measure and analyze the carbon footprint of different technology routes. The metallurgical database includes the consumption and generation of main materials, auxiliary materials, by-products and their end-use status and the substituted raw materials as well as their own life-cycle energy consumption status, as well as the detailed framework of smelting equipment/processes and process fuel types and consumption.

3) Conducting cluster analysis of enterprises and abatement technologies, analyzing technology application and scenarios.

This section combines the results of steel industry research and technology evaluation, based on plant-level data mining and combing, and further conducting clustering analysis of enterprises/ technologies; Then, design and evaluate the technology strategy from the perspective of the enterprise, and identify the advantage utilization scenarios of each technology from the perspective of technology.

4) In-depth integration of China's status-quo, establish technology development roadmap, and formulate policy recommendations.

Based on the first three parts of the study, we will consider the socio-economic development of China, the status-quo of steel enterprises as well as the technology assessment results, consider the risk of industry development and the cost of low carbon technology application, and formulate a technology development roadmap for the industry.

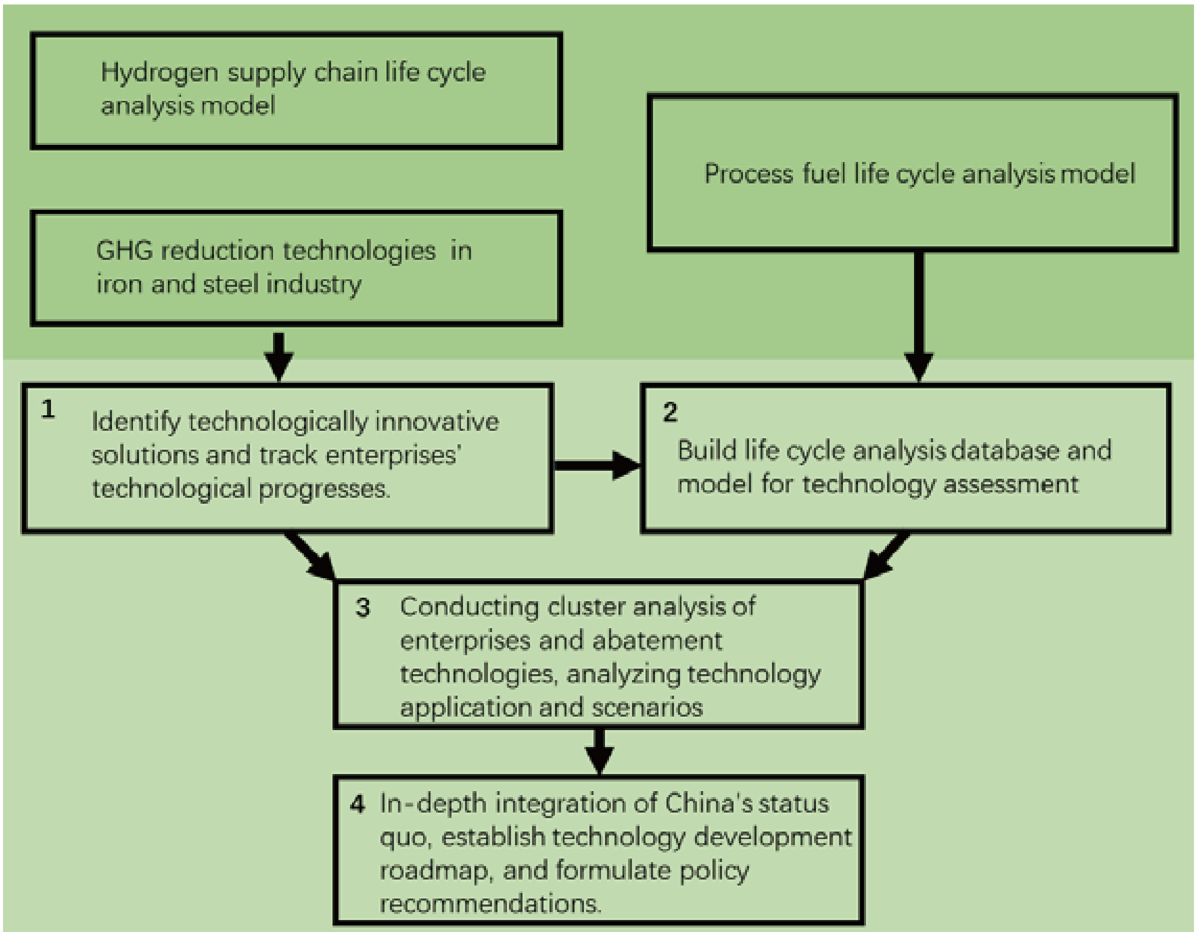

Figure 2-18 Content Framework and Technology Roadmap

3. Key Findings and Policy Recommendations

1) Life cycle carbon emission analysis of different processes of steel production

As shown in Figure 2-19, the GHG emissions of conventional steelmaking technologies (blast furnace-converter, blast furnace-converter hydrogenated, scrap/iron electric arc furnace, pure scrap electric arc furnace), hydrogenated/pure hydrogen direct reduced iron (DRI) technologies and fossil fuel DRI (coke oven gas-based DRI, coal-based DRI, Natural gas DRI designed by MIDREX, natural gas DRI designed by ENEFARM) that can be used as a transition technology were analyzed for GHG emissions.

The hydrogenation/pure hydrogen direct reduction iron technology is subdivided into three technology subcategories: all-hydrogen smelting (using hydrogen as reductant and fuel), partial hydrogen smelting (using hydrogen as reductant only), and natural gas DRI hydrogenation.

The results of the whole life cycle analysis show that the main greenhouse gases (containing CO_2, N_2O and CH_4) emitted by the pure hydrogen DRI route are comparable to the current scrap-electric arc furnace route, and that DRI as an intermediate product has the potential to be inter-substituted with scrap in electric furnaces. However, if the required reaction heat for the pure hydrogen DRI route is supplied by fossil fuels, the full life-cycle carbon emissions of this route are similar to those of the fossil fuel DRI route.

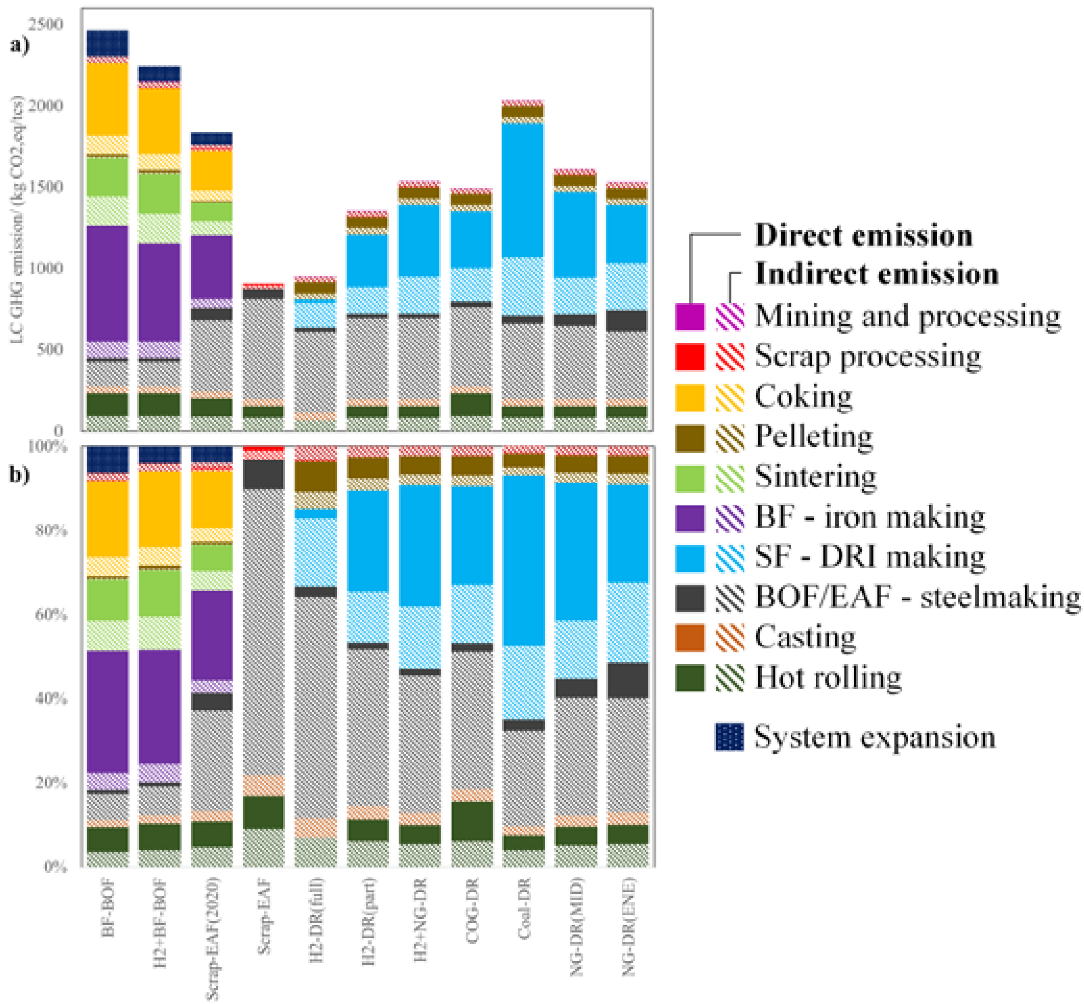

Figure 2-19 Life cycle GHG emission results (a) Emissions (b) Share of emissions by stage

2) Analysis of the prospects and impacts of hydrogen metallurgy through scenarios

Scenarios with different levels of future scrap recycling are set up to analyze the potential of hydrogen energy steelmaking technology to reduce emissions in the Chinese steel industry. Preliminary results show that the interaction between future scrap recycling and steel demand will determine the development potential of DRI. In a combined scenario where scrap recycling is more desirable and crude steel demand will decline, the amount of crude steel produced by ironmaking using direct reduction technology in China is expected to reach a level of 100 to 200 million tons in the decade from 2050 to 2060.

3) It is recommended that the deployment of key common technologies for low-carbon development in the steel industry should be accelerated in the research and development process.

It is recommended to increase investment in research and development of basic, forward-looking and key common technologies. Targeted and focused organizations should be promoted to facilitate the research and development of low-carbon and zero-carbon ironmaking technologies and industrialization application work.

Especially for the disruptive and revolutionary process technology represented by hydrogen metallurgy and carbon utilization technology represented by CCUS, carrying out systematic research on the whole process and the whole industry chain around the basic theory, process route, equipment manufacturing and system integration is needed to overcome the technical barriers in low-carbon steel production.

4. Research Outlook

In the next phase, both micro-detailed and macro-comprehensive studies will be conducted on the cost of abatement and green premium of low-carbon technologies for steel.

Micro focus on individual technology lines, macro focus on industry-wide technology strategy, including research on technology penetration, investment scale, technological progress, etc.

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Topic 4: Improvement in GHG Emission Accounting Methodology for Steel under Multiple Constraints

1. Research Background

China's steel producers face the multiple challenge of preparing for accounting methodologies such as MRV for domestic carbon market pilots and national carbon markets and other international carbon emissions accounting methods. As of the end of April of 2022, six steel industry tailored accounting requirements (methodologies, guidelines, etc.) have been issued by various Chinese government bodies. In the meantime, the EU carbon market and the EU carbon border adjustment mechanism have also issued accounting requirements for the steel industry. This topic aims to analyze the domestic carbon market and international carbon accounting requirements for the steel industry, and suggest directions for future improvements in the steel guidelines.

2. Research Methods

Research will be conducted on the GHG accounting methodologies for the steel industry in the carbon market, sorting out issues and trends. With additional research on the EU carbon market, the progress of the EU carbon border adjustment mechanism and the requirements of accounting for steel producers. Investigating the production process and process characteristics of major steel producers in China, implementing interactive and visual computing procedures through the LEAP (Long Term Energy Alternative Planning System) model to improve the capacity building of carbon emission accounting for steel producers in China.

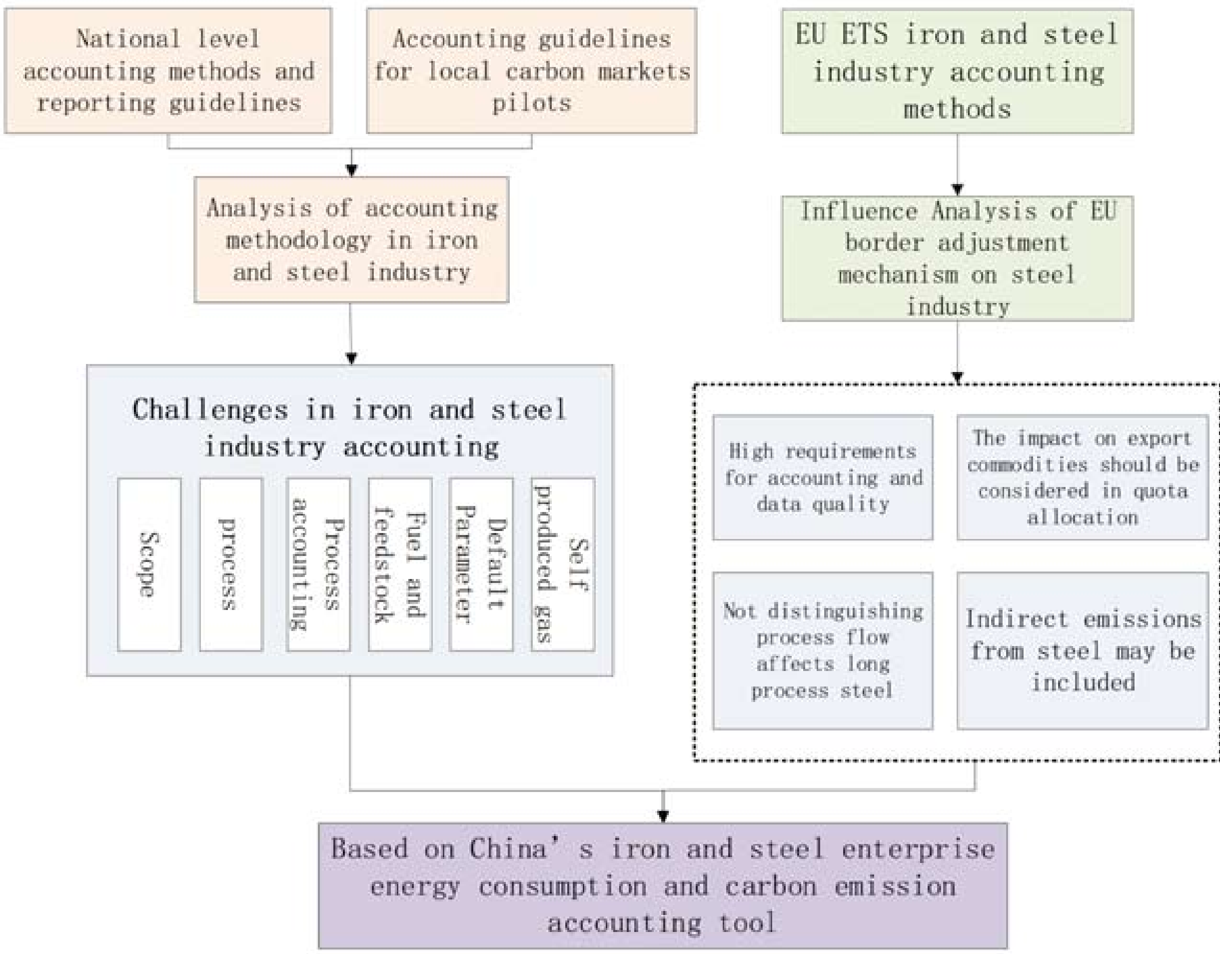


Figure 2-20 Technology Roadmap

3. Key Findings and Policy Recommendations

1) Comparative Analysis of Domestic Steel Industry Accounting Requirements

China’s steel industry carbon emission accounting requirements analyzed in this study include: the "GHG Emission Accounting Methodology and Reporting Guidelines for China's Iron and Steel Producers" issued by the National Development and Reform Commission and the national standard "Requirements of the GHG emission Accounting and Reporting-Part 5: Iron and Steel Production Enterprise"; the annual publication "Supplementary Data Sheet on GHG Emission Reporting for Iron and Steel Producers" (hereinafter referred to as the respective annual "Supplementary Data Sheet") issued by the Ministry of Ecology and Environment; the accounting guidelines for local carbon markets pilots, "Methodology for Accounting and Reporting Greenhouse Gas Emissions in the Iron and Steel Industry in Shanghai (Trial Implementation)" and "Guidelines for Reporting Carbon Dioxide Emission Information for Iron and Steel Enterprises in Guangdong Province (revised in 2022)".

This section provides a comparative analysis of the above accounting methodologies, leading to the following conclusions:

Relatively uniform steel production accounting methods. The emission factor method and the material balance method are commonly used. The emission factor method is generally used for fossil fuel combustion and net purchased electricity and heat emissions, while the material balance method is generally used for carbon containing raw material input and output.

There are existing theoretical and practical basis for emissions accounting by steel processes. Each guideline specifies the processes to be considered for iron and steel production, with the Shanghai guideline, Guangdong guideline and supplementary data sheets all requiring data in according to certain process priorities (with slightly different requirements).

Inter-process accounting issues. There are inter-process inputs and outputs in iron and steel production (such as inter-process supply of high coke converter gas), which are not clarified or not covered in the individual guidelines; the supplemental data sheet for 2019 and the sheets for the previous years both calculate all primary and secondary energy purchases and transfers for the process, while the supplemental data sheet for 2020 only considers primary energy.

Gradual refining of the accounting methodologies. 2019 supplemental data sheet asks for the steelmaking process, and 2020 requires the converter steelmaking process (smelting, refining, continuous casting) and the electric furnace steelmaking process (smelting, refining, continuous casting), taking into account a wider variety of steel production, but also increasing the difficulty of filing accordingly.

2) Challenges in the Accounting Process of the Iron and Steel Industry

By collecting and categorizing the issues raised by companies in their submissions, the main challenges confronting steel producers in accounting include:

(1) Accounting scope. Although the current accounting guidelines point out the processes involved, they do not fully define the steel production enterprises and related processes, and there is uncertainty in the determination of the industry attributes of the enterprises concerned.

(2) Accounting process issues. Specifically refers to the process of filling out the supplemental data sheets for the steel industry, whether the calcination of limestone in steel enterprises is counted as an auxiliary process, and etc. The definition of each process is not yet clear in the guideline, especially the definition of other auxiliary processes, there remains differences in various guides.

(3) Sub-process accounting problem. Mainly refers to the measurement of energy consumption of long process steel enterprises without sub-processes, and how to account for carbon emissions of these sub-processes. With the gradual refinement of process accounting classification, further investigation is needed for the current accounting accuracy.

(4) Accounting for fossil fuels as carbon-containing raw materials. The belonging of reducing agent such as bituminous coal or coke in emission sources, and the method used for accounting for such emissions has a relatively commonly accepted method, which is calculated according to fossil fuel emissions, and emission factor method of accounting, but the reasonableness of the treatment and the consistency with the existing enterprise statistics needs further confirmation.

(5) The problem of inadequate default parameters. Enterprises using other carbon containing solid, liquid and gaseous fuels such as charcoal cannot be accounted for, and the use of default parameters is unclear. According to the research enterprises that use a variety of other solid fuels, as well as other gas, liquid fuel use, further research is needed on the use of other fossil fuels in iron and steel production enterprises, if necessary, supplement the application of more fossil fuel default parameters.

(6) The problem of comparability of gas supply within enterprises. It is a common phenomenon that the self-produced gas is supplied to other processes in steel production within an enterprise. According to the "2020 Supplementary Data Sheet" filling requirements, the mutual supply between processes of the same enterprise is not considered, and the gas supplied to the priority of the outgoing enterprise is deducted, which will result in the weak comparability of steel production enterprises containing different process lengths. For instance, the emission intensity of the same process varies greatly, and there are positive and negative emissions, thus accounting results cannot be compared vertically and cannot reflect the actual emissions and intensity of a process.

3) EU Carbon Market Accounting Methods and Requirements for the Iron and Steel Industry

The EU Carbon Market (EU ETS) has established requirements for accounting and reporting based on Directive 2003/87/EC (Regulation 2018/2066 (MRR)). The body of the MRR sets out the common requirements for accounting and reporting, and the special accounting requirements for facilities in different sectors are set out in an annex, which specifies the scope of inclusion and accounting principles for facilities in each sector.

EU Carbon Market Accounting Guidelines. There are two types of accounting methods specified in the MRR, namely calculation-based methods and measurement-based methods. The MRR does not provide separate guidelines for each industry, but rather specifies the general methods in the main text, and then details the specific accounting methods for each industry’s process and facility levels in the annexes, including the specific monitoring scope, accounting methods, and data priorities.

Accounting for the iron and steel sector in the EU carbon market. Directive 2003/87/EC and Regulation (EU) 2019/331 specify the scope and conditions of production facilities in the steel industry, also specifying the products to be included and the corresponding quota allocation benchmarks, respectively. Facility operators in the steel sector may account for source streams using either the standard or (and) the mass balance method, with data selection priorities based primarily on the type of facility and the accounting method used.

The EU carbon market allocates and trades quotas for the products of each process. According to the content of Annex 1 of Regulation (EU) 2019/331, the products involved in the steel production process included in the EU carbon market trading include coke output from the coking process, sintered ore output from the sintering process, iron output from the blast furnace, carbon steel from the electric furnace, high-alloy steel from the electric furnace, iron castings, limestone, dolomite and sintered dolomite from the lime firing process.

4) Impact of the EU Carbon Border Adjustment Mechanism on the Steel Industry

On July 14, 2021, the European Commission released a package of regulatory proposals as part of "Fit for 55" to help achieve the European Green Deal's "55% net reduction target by 2030," which includes the EU's Proposal for a Carbon Border Adjustment Mechanism (CBAM).

Currently, the industries to be incorporated in CBAM include steel, aluminum, cement, electricity, and fertilizers, with steel products covered by customs tariff codes 72 (except 7202 ferroalloys and 7204 scrap), 7301-7309. With 2023 to 2025 as a transition period, non-EU producers will need to report direct and indirect emissions, and from 2026 onwards, importers will need to declare and purchase CBAM permits to cover GHG emissions associated with the production of imported steel products. This will initially apply only to direct emissions, but may be extended over time to indirect emissions (i.e. emissions associated with electricity production, as well as heat and cooling consumed in the production of steel). The CBAM permits to be purchased would only need to cover the portion of emissions that exceed the free ETS allowances received by EU steel producers, and could be reduced by the equivalent carbon price already paid by non-EU steel producers in their home carbon markets. In particular, free ETS allowances for EU steel producers will be phased out from 2026 to 2035 (reduced by 10% per year to zero by 2035). Responsibility for compliance with the CBAM rests with steel importers (not non-EU producers, unless they are the same entity). The penalty regime under CBAM (which mirrors that under the ETS) also applies only to importers. However, non-EU producers need to be aware of other potential sources of liability for non-compliance (e.g. under customer contracts).

The EU Regulation on the Establishment of a Carbon Border Adjustment System (CBAS) provides detailed regulations on the products included in the mechanism, the implementation cycle, the operation mechanism, and the method of calculating carbon emissions. Among them, the corresponding accounting methods are proposed for simple and complex commodities respectively.

Accounting for simple commodities. Simple commodities are products that require only raw material and fuel inputs in the production process that do not have implicit emissions. The key to the actual implied emissions of a simple commodity produced in a given facility is the recognition of the attributable emissions of a commodity, which refers to the portion of the facility's direct emissions during the reporting period that are attributable to the process of producing that commodity.

Accounting for complex commodities. Complex commodities are commodities other than simple commodities. The actual implied emissions of complex commodities produced in a given facility are recognized by including the implied emissions of input materials consumed in the production process in addition to the imputed emissions considered for simple commodities.

The main impacts of CBAM on China’s steel industry include:

(1) Higher accounting requirement for emissions accounting and data quality at the facility level

From the perspective of accounting methods, the accounting mechanism of CBAM focuses on calculating the implied emissions of commodities, and currently focuses on direct emissions, but will also include indirect emissions caused by the consumption of electricity, heat and cold in the future in due course, especially for the accounting of emissions of complex products, which need to account for the implied emissions of all materials of commodities. The specific accounting methods and scope of inclusion are mainly based on the relevant EU ETS regulations, so the requirements for emissions accounting and data quality at the facility level are high.

(2) Consideration for potential future impact on export commodities in the confirmation of the quota allocation scheme

The draft CBAM proposes that the CBAM permits to be paid by importers are related to the free allowances available to steel producers in the EU carbon market and the purchase of allowances in the relevant carbon market in the country where the imported commodity is produced. The importer would only be required to pay for the portion of the commodity that exceeds the free quota in the EU carbon market, and the importer would also be able to deduct the equivalent quota if the producer of the imported commodity has purchased it in its own carbon market. However, the EU carbon market stipulates that the free quotas issued to steel companies will be reduced annually, and no more free quotas will be issued for post 2035.

At present, although China's steel industry has been confirmed to be included in the national carbon market, it has not been fully launched, the carbon market's carbon reduction drivers for steel companies are still unknown, and the quota allocation scheme has not been clearly defined. The allocation of quotas in China's carbon market and the carbon price fluctuations it causes may directly affect the purchase of CBAM permits, so the potential future impact on export commodities should also be fully considered in the formulation process.

(3) CBAM does not take into account the impact of process differentiation of products on China's steel long process production methods

Majority of China's current steel exports to the EU consists of products using long processes, which involve more complex production processes, with higher carbon emissions intensity, but CBAM does not consider the process to differentiate between products, only the carbon emissions used to make the product, which may have a potential impact on the selection of technical routes and processes of China's steel enterprises.

(4) Impact of possible future inclusion of indirect emissions in CMAM on energy choices in China's steel industry

In addition, China still relies to some extent on thermal power generation, and as a high energy-consuming industry, indirect emissions caused by electricity consumption in the production process of steel companies are usually high. The European Commission, on the other hand, proposes to include purchased electricity and indirect emissions from electricity in the scope of taxation. The advanced progress of CBAM to include indirect emissions implied by products may be expected, and may also introduce a propulsive effect on the energy choice for the steel industry.

5) Development of an accounting tool based on the current status of energy consumption and carbon emissions of major steel enterprises in China

This study collected a total of about 50 sample data from each of the three processes of blast furnace ironmaking, converter steelmaking and electric furnace steelmaking enterprises of steel enterprises in 2020 through questionnaire research. The sample enterprises have a total of 177 million tons of long process steel production and 0.028 billion tons of short process steel production, totaling 205 million ton of steel, accounting for nearly 20% of China's total crude steel production in 2020.

(1) Blast Furnace Ironmaking

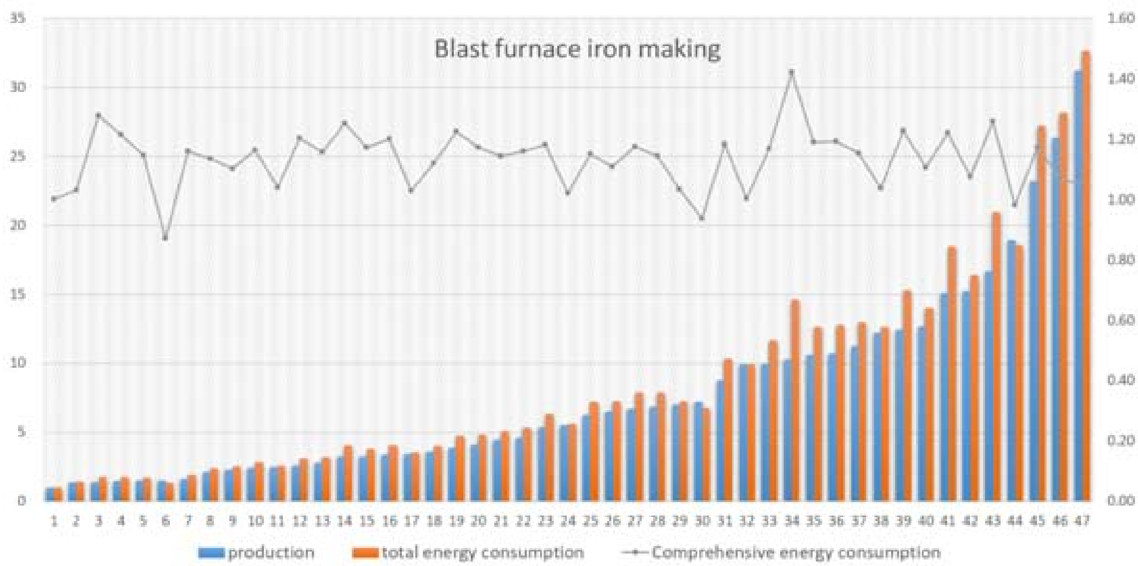


Figure 2-21 Energy consumption and energy efficiency of blast furnace ironmaking process (data are normalized, same as below)

The concentration of industry is low. The sample data single blast furnace pig iron production between 0.4 -13 million ton, the average pig iron production per blast furnace is about 3.2 million tons, higher than the national average, the sample is mostly concentrated in China's larger-scale iron-making enterprises.

The comprehensive energy consumption is generally high. Only two enterprises in the sample had energy consumption levels below the national benchmark level (435 kgce/t), and if the energy consumption of exported blast furnace gas is deducted, a total of four enterprises were below the national benchmark level requirement.

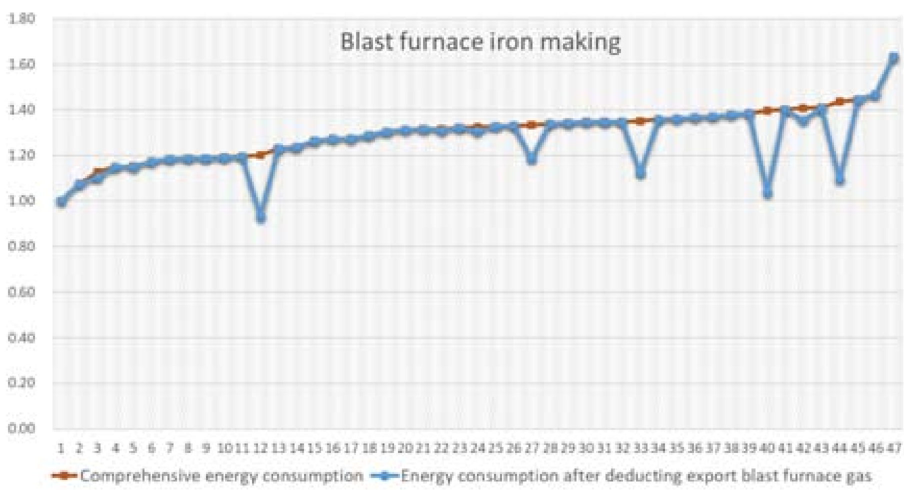


Figure 2-22 Energy efficiency level of blast furnace iron-making process

(2) Converter Steelmaking

Large differences in production capacity between enterprises. The crude steel production of individual enterprises in the sample data ranged from 140,000 to 14 million tons, with an average production of about 4.2 million tons per enterprise and large capacity differences between enterprises.

Comprehensive energy consumption is generally higher than the benchmark level. If the energy consumption of exported blast furnace gas is deducted, a total of six enterprises are below the national benchmark level, while the energy consumption of other steel producers is higher than the national benchmark level.

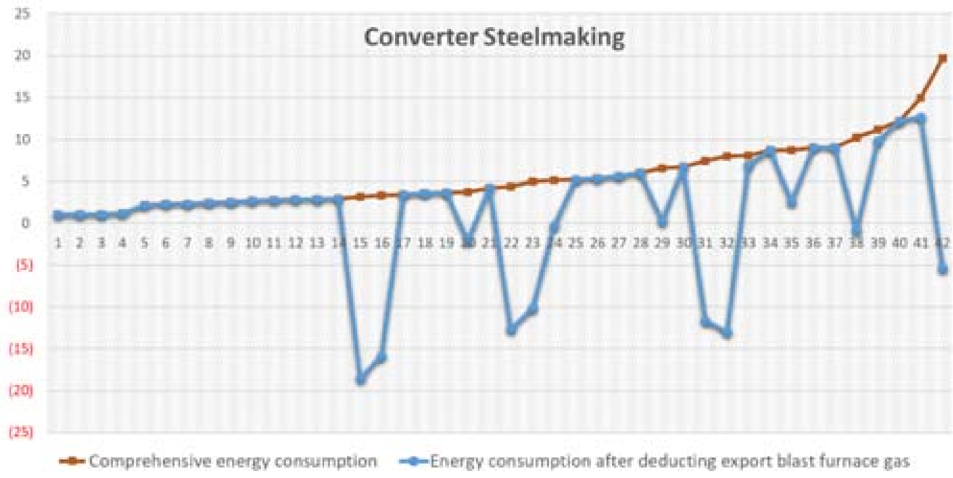
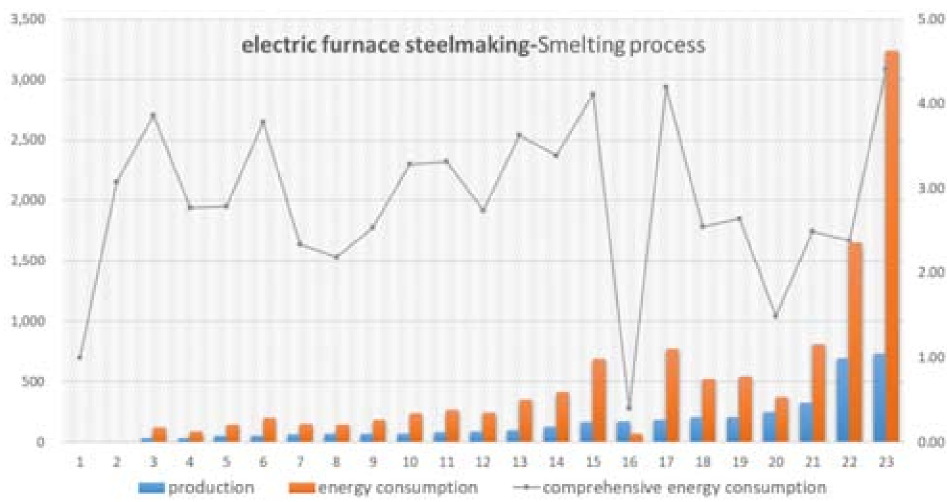
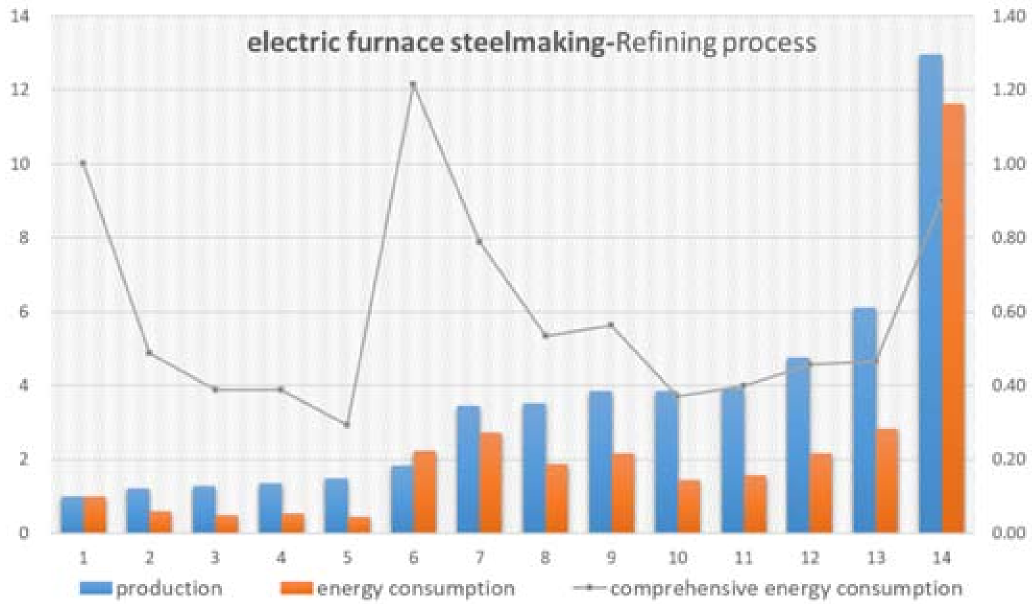


Figure 2-23 Energy Efficiency Level of Converter Steelmaking Process

(3) Electric furnace steelmaking

Despite the large differences in production capacity among enterprises, the comprehensive energy consumption level of the sample enterprises is generally low, with 22 of the 23 enterprises consuming less than the national benchmark level per unit of product and 17 less than the benchmark standard in the national standard. Among the three sub-processes of electric furnace steelmaking, the energy consumption level of the smelting process is higher than that of the refining process and higher than that of the continuous casting process, and the smelting process is the key control process in short process steelmaking enterprises.





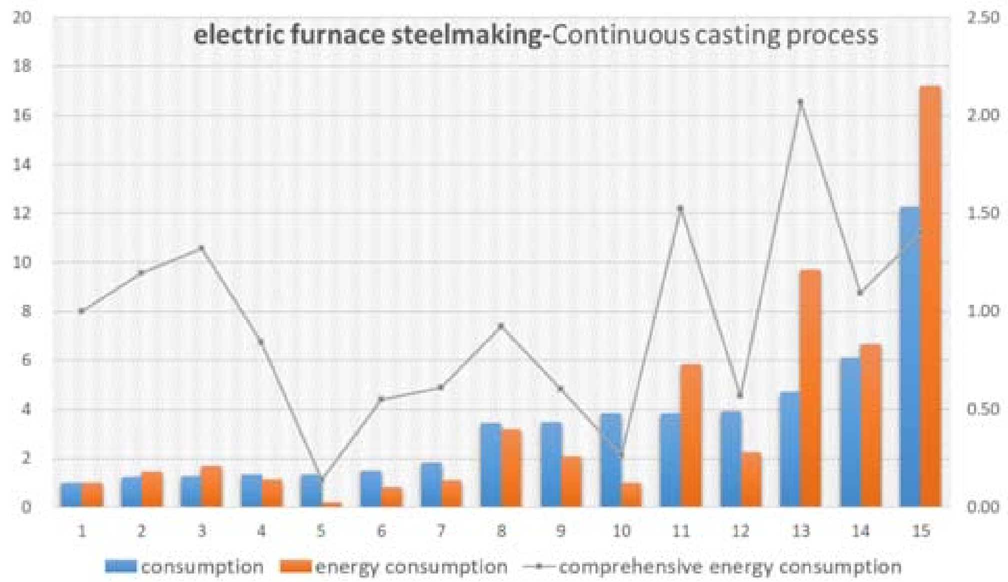


Figure 2-24 Energy consumption and energy efficiency of electric furnace steelmaking process

(4) LEAP model to build visual applets

In this study, all sample data of iron and steel enterprises are entered into LEAP model, and the model processes for data classification, data analysis and calculation of energy consumption and carbon emission, etc. Currently, the model has the following functions:

1) Year of data: 2020;

2) Number of samples covered: 141;

3) Steel enterprises sub-processes: blast furnace ironmaking, converter steelmaking, electric furnace steelmaking;

4) Energy consumption variety in each process: including washed coal, bituminous coal, anthracite coal, natural gas, diesel, coke, electricity, heat and coke oven gas, blast furnace gas and converter gas;

5) Model calculation of total energy consumption, energy intensity and energy structure analysis for each sample;

6) The model calculates the total carbon emission, carbon intensity level and carbon emission structure analysis for each sample.

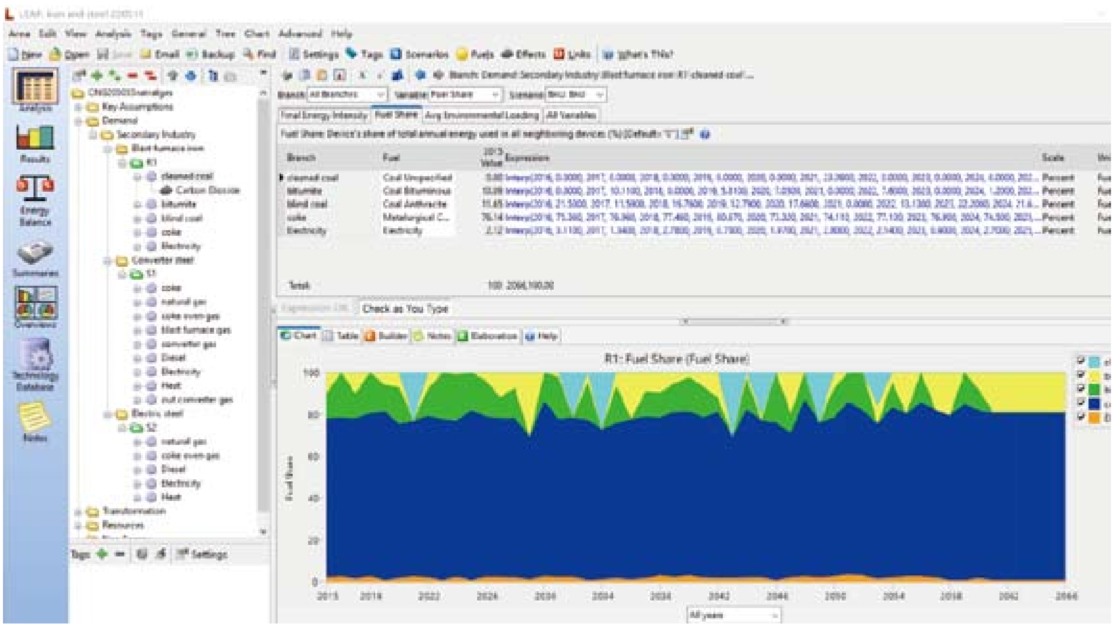


Figure 2-25 LEAP Model Outline Structure Overview

(5) Policy Recommendation

On the basis of accurate accounting of carbon emissions of steel enterprises, industry management gradually refined through a step-by-step approach. In the medium to near term, the main task is to service ETS, the iron and steel industry will be included in the ETS after the 14th Five-Year Plan, promote detailed accounting method, while focusing on the key ETS challenges. In the medium and long term, expand to incorporate it into the carbon emission peak and carbon neutrality planning, with expansion to local government, industry, enterprise level.

In the middle and near future, the focus of the work is to improve the methodology of carbon emission accounting for the steel industry in the national carbon market.

(1) Clear definitions and reduce ambiguity. This includes clear definitions of steel enterprises, emission sources and processes.

(2) Uniform accounting and expanded application. Drawing on the EU ETS practice of calculating emissions separately for each process, and with reference to the requirements of Shanghai and Guangdong Province for accounting by process, potential consideration for revision of the guidelines could include the general calculation methods for fossil fuel combustion emissions, carbon input and output emissions (if involved), and net purchased electricity and heat emissions; the quota allocation scheme should consider adopting the calculation methods by process, and all processes should apply the guidelines. The calculation method can be applied to each process. In this way, the accounting guidelines can be general and concise, independent of the length of the steel enterprise's processes and the processes to be included, thus achieving "semi-decoupling".

The impact of the EU Carbon Border Adjustment Mechanism (CBAM) accounting methodology should be taken into account in the improvement of carbon accounting methodology for the steel production industry.

Based on the characteristics of CBAM accounting method, China's steel enterprises should consolidate the data foundation as early as possible and pay attention to carbon data management, especially the whole life cycle carbon footprint management system of raw materials and the emission accounting system by facilities and processes. Iron and steel, as the raw material side, may need to provide carbon data to downstream users even if they do not export directly to the EU. In order to further respond to the needs of global importers, carbon emission data disclosure and full life-cycle evaluation need to be normalized. In addition, in terms of carbon emission accounting standards, standards and accounting systems for steel production processes and life cycle carbon footprints of steel products should also be developed in due course.

Strengthen the capacity building of iron and steel enterprises.

Based on the LEAP model, steel enterprises can develop static and dynamic application scenarios based on the process level. On the one hand, the model can be dynamic to obtain multi-year sample data and analyze the overall trend of production capacity, energy consumption and carbon emission in the steel industry; on the other hand, the current model can be used as a basis to map out the medium and long-term carbon peaking and carbon neutral roadmap for steel enterprises through multi-scenario analysis, combined with the overall national energy efficiency constraints, industrial upgrading and other related policies.

4. Research Outlook

Follow-up research work can be carried out in the following areas: improvement of the LEAP-based simulation model for steel carbon emission accounting and refinement of key technologies. At the industry level, consider the impact of carbon price factors influencing the choice of key technologies on the carbon neutral pathway in the steel industry.

5. Members of the Research Team

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Topic 5:
Steel Industry's Low Carbon Development: International Trends and National Policies

1. Research Background

Since 1996, China has been the world's largest producer of crude steel. Over the past two decades, China's steel production has grown rapidly and has become a major source of growth in world steel production, reaching 53% of total world steel production in 2021, compared to 9% in 1990. The dramatic increase in Chinese steel production has supported China's rapid industrialization, massive urbanization and large exports of manufacturing products. Currently, the steel industry is one of the four most energy-intensive and carbon-emitting industries in China. Therefore, the strategy, goals and pathways for the low carbon development of China's steel industry will largely affect the achievement of China's and the world's carbon peaking and carbon neutrality goals.

Looking at the stage of development, Europe, America, Japan and other developed countries have completed the industrialization and urbanization process, the period of intensive infrastructure construction, high steel demand has passed, steel supply and demand showed a steady decline. Meanwhile, these countries are actively identifying new technological pathways, and strong control measures to promote the low-carbon development of the steel industry.

Therefore, a comparative analysis of the low-carbon development experiences of developed countries such as Europe, Japan, and the United States in the steel industry, especially low-carbon technologies, processes, development strategies, and policy measures, is of great significance in promoting the low-carbon development of China's steel industry. Based on the above considerations, this study compares the international trends of low-carbon development in the steel industry, and focuses on the world's second largest steel production and marketing group, the European Union, to analyze its technology and related policy tools to promote the low-carbon development of the steel industry, with a view to providing policy reference for the low-carbon development of China's steel industry.

2. Research Methodology

This topic mainly adopts literature and policy text analysis, industry big data collection and collation, typical enterprise technology path case study, and industry expert research interviews to conduct research.

In the study, the official statistical databases of the EU and the Chinese Iron and Steel Association were used to focus on the analysis of steel production, energy consumption, technology routes, carbon emissions, new technology development and promotion, and policy measures in the EU and other countries since 2000, and a systematic comparative analysis with the situation of the Chinese steel industry was carried out, resulting in a series of findings and several policy recommendations. The flow and technical route of the research work are shown in Figure 2-26.

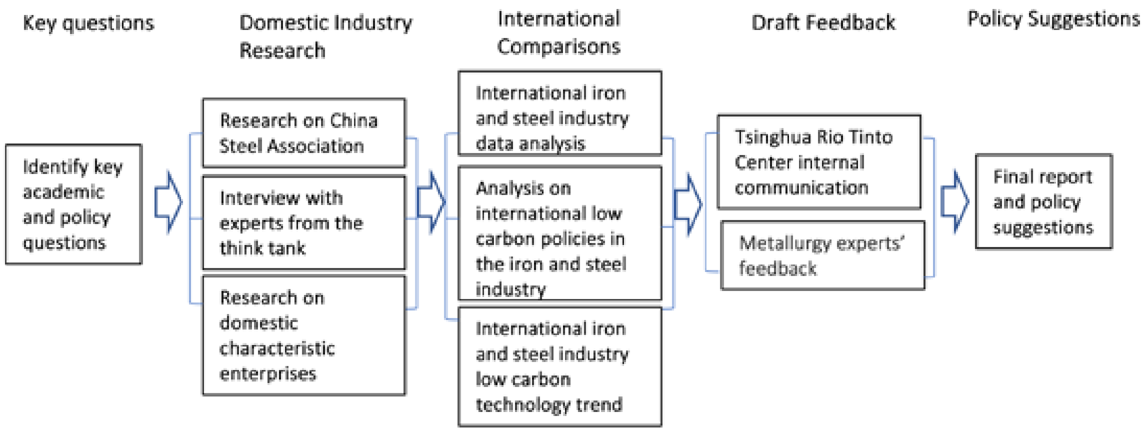


Figure 2-26 Research Technology Roadmap

3. Key Findings and Policy Recommendations

(1) Major findings

1. China is a major contributor to global steel production growth, producing more than half of the world's steel.

Global crude steel production has grown rapidly over the period 1990-2021, especially since 2000. Among them, China's crude steel production has grown at the fastest rate, becoming the world's largest crude steel producer since 1996 and remaining so until now, with the increase in Chinese steel production constituting the major part of the increase in world steel production over the last two decades. Chinese crude steel production started to reach more than half of the global crude steel production in 2017 and reaches 53% in 2021. As the second largest steel producing group - the EU crude steel production has generally shown a declining trend during the same period, the US and Japan crude steel production has not changed much since 2000, it is worth noting that India's crude steel production has grown rapidly in recent years and has overtaken the US and Japan to become the second largest steel producing country after the EU, with Indian steel production reaching 118 million tons in 2021.

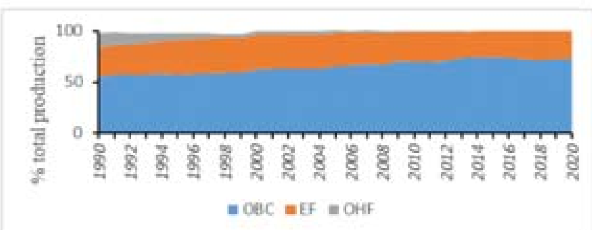
In 1990, China's urbanization rate was only 26%, while in 2020 it has increased to over 63%, surpassing the world average. In 1990, China's urban population was only 300 million, while in

2020 it will be over 900 million, with 600 million peasants moving into cities in 30 years. At the same time, China is rapidly becoming the country with the largest manufacturing output and the largest export of goods in the world. Rapid urbanization, industrialization and internationalization all require huge steel production capacity to support.

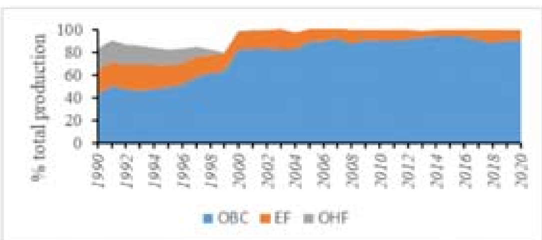
2. Oxygen converter steelmaking accounts for majority portion of China's steel production, while electric furnace steelmaking accounts for a relatively small proportion.

In terms of global crude steel production, the crude steel production process is mainly based on the oxygen converter method, and the crude steel production using this method reaches more than 60% of the total global production. This is followed by the electric furnace steelmaking method, while the share of the blast furnace steelmaking method has been decreasing year by year, falling to less than 1% since 2012. From a country perspective, China and Japan are dominated by the oxygen converter method, while the U.S. and India have a large share of both oxygen converter and electric furnace steelmaking, but are gradually shifting to electric furnace steelmaking and becoming the most important production process. This shows that the electrification of crude steel production in China and Japan is low.

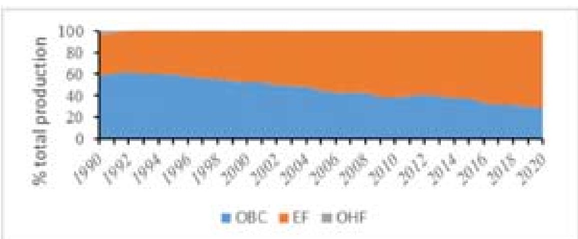
This long production process determines the relatively high carbon emissions per unit of steel production in China. The high use of this process is related to the lack of scrap supply in China, the price of iron ore, and the technological dependence of the Chinese steel industry.



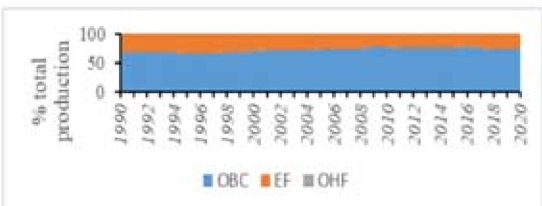
1. Global crude steel production process



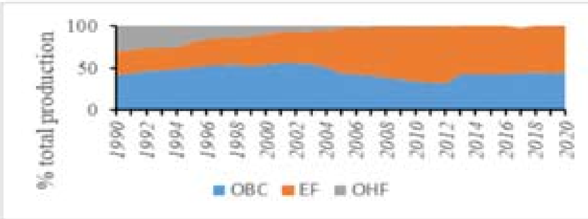
2. China crude steel production process



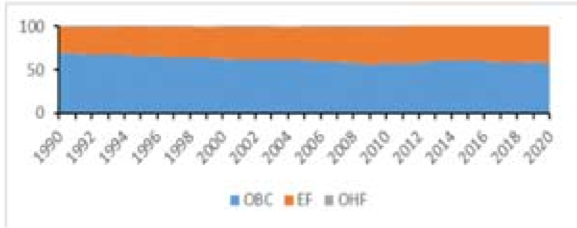
3. US crude steel production process



4. Japan crude steel production process



5. India crude steel production process



6. EU crude steel production process

Figure 2-27 Comparison of steel process structures in major countries worldwide

Note: OBC - oxygen-blown converter; EF - electric furnace; OHF - open hearth furnace.

3. China's steel consumption is dominated by domestic consumption, while EU steel product mainly relies on import and export.

China is the world's largest steel consumer, both in terms of crude steel equivalent and finished steel consumption, reaching more than half of the global total. 2021, China imports 27 million tons of steel and exports 66 million tons of steel. Compared to the huge steel production, the proportion of both import and export of steel in China is small, and it can be said that China's steel production mainly supplies its own demand. From the perspective of import and export of steel products by country, the EU ranks first in terms of both import and export volume.

4. In recent years, the total energy consumption and carbon emission of EU steel and the energy intensity and carbon intensity of Chinese steel have been decreasing continuously, and the energy intensity and carbon intensity of EU steel are significantly lower than those of China.

Energy consumption for steel production in the EU has generally shown a decreasing trend over the last 20 years. Among them, German energy consumption for steel production is the highest among the EU countries, which is related to Germany being the largest steel producer in the EU. From the perspective of countries within the EU, the energy consumption of steel production in all EU countries has been on a decreasing trend since 2000.

Since 2014, China's steel production has been increasing and total energy consumption has shown a steady decline and rebound again. In terms of energy intensity, the energy intensity of

China's steel industry has continued to decline significantly, from 1.60 tons of standard coal/ton of steel in 2000 to 0.66 tons of standard coal/ton of steel in 2019, making very significant progress. However, compared to the EU, the energy intensity of China's steel industry is still too high, currently equal to about three times the EU average (0.23 tons of standard coal/ton of steel).

The carbon emission results from the steel industry show that carbon emissions from China's steel industry have increased rapidly since 2000, but the total carbon emissions from China's steel industry have stabilized since 2014, mainly due to the rapid decline in carbon intensity of China's steel industry, from 3.11 tons of CO_2 emitted from tons of steel in 1997 to 1.86 tons of CO_2 in 2019. However, compared with the EU's emission intensity factor of 0.725 tons of CO_2, the carbon intensity of China's steel industry is still too high, 2.56 times higher than that of the EU, which indicates that there is still much room for progress in the low-carbon development of China's steel industry.

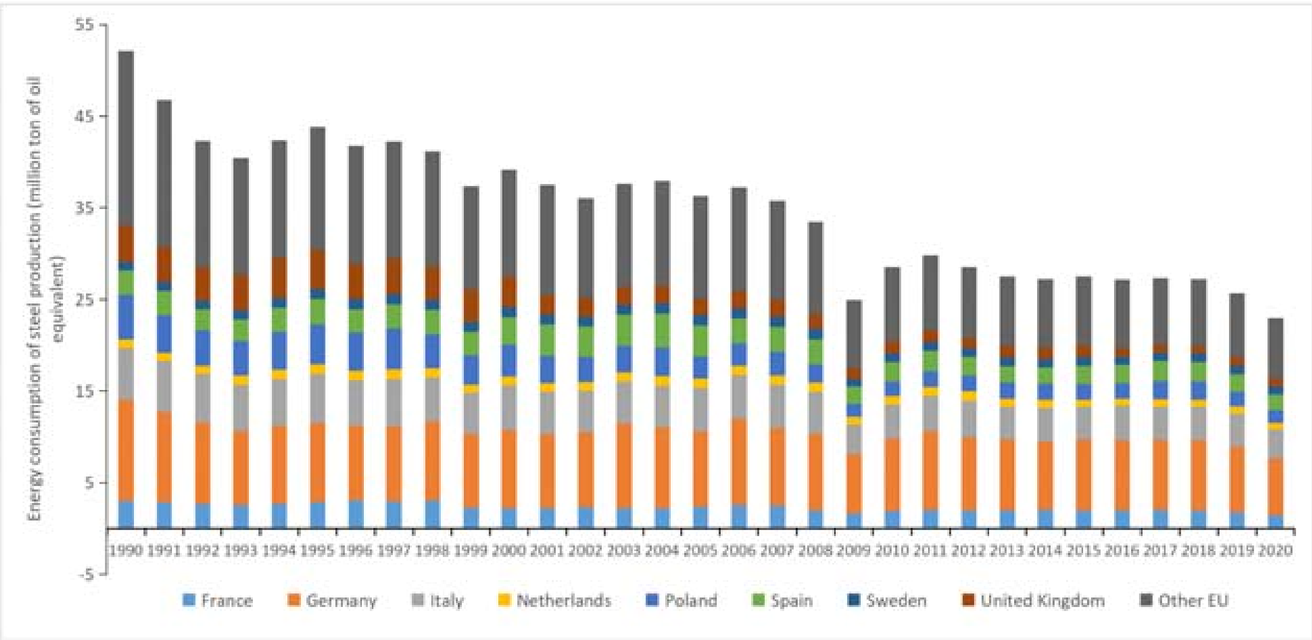


Figure 2-28 Total Energy Consumption of Steel in EU Countries

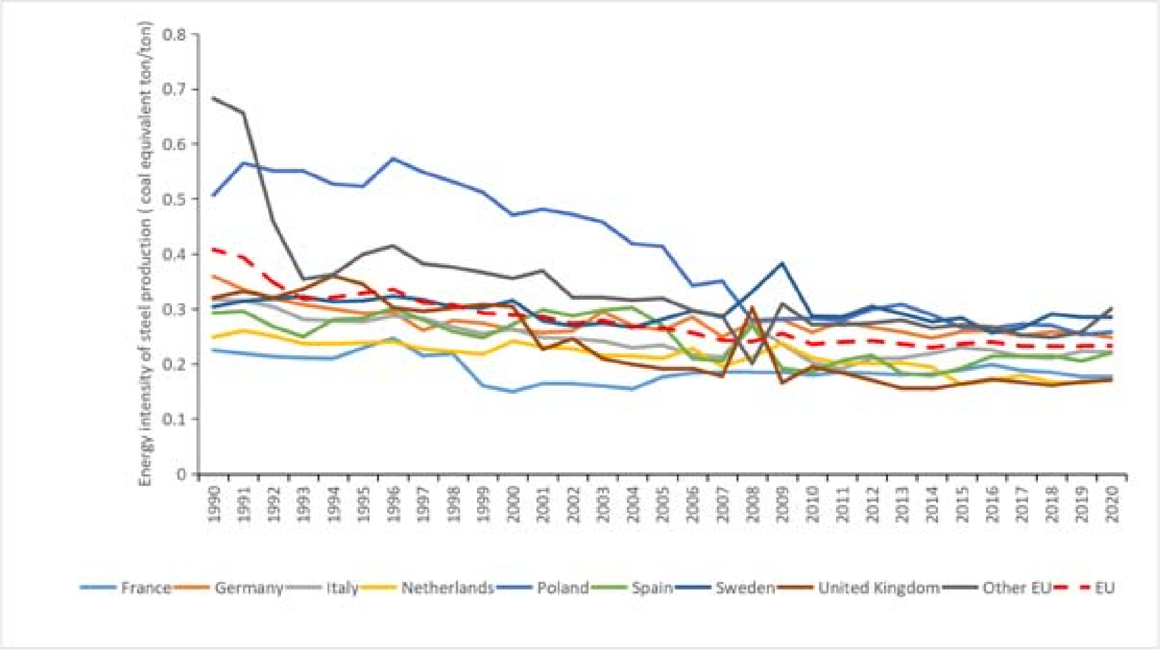


Figure 2-29 Energy Intensity of Steel Production in EU Countries

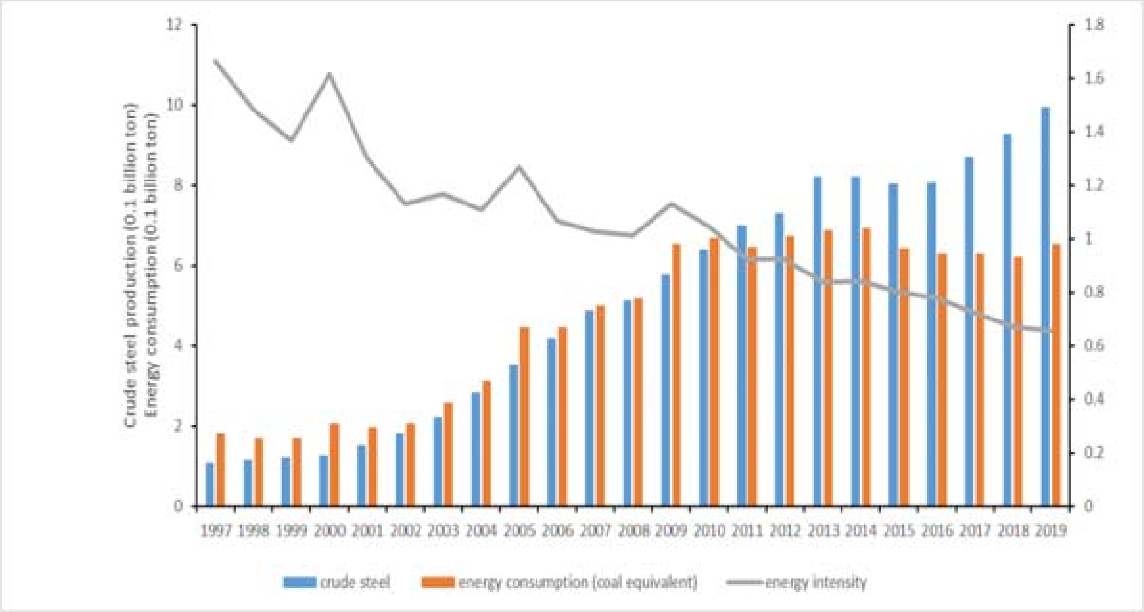


Figure 2-30 Total Energy Consumption and Energy Intensity of Steel Production in China

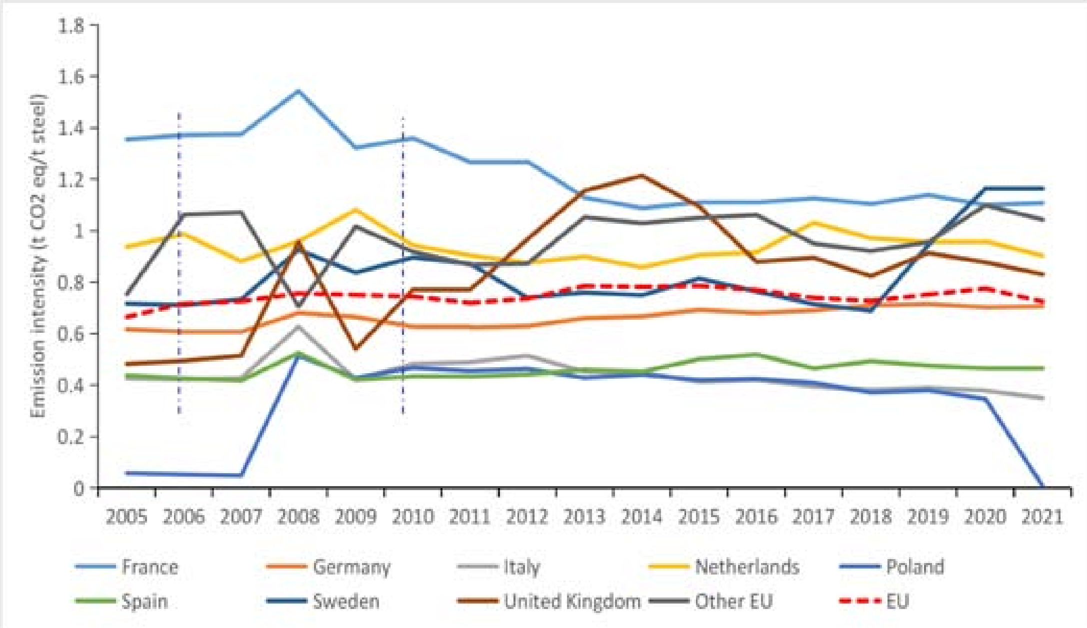


Figure 2-31 Carbon Emission Intensity of the Steel Industry in EU Countries

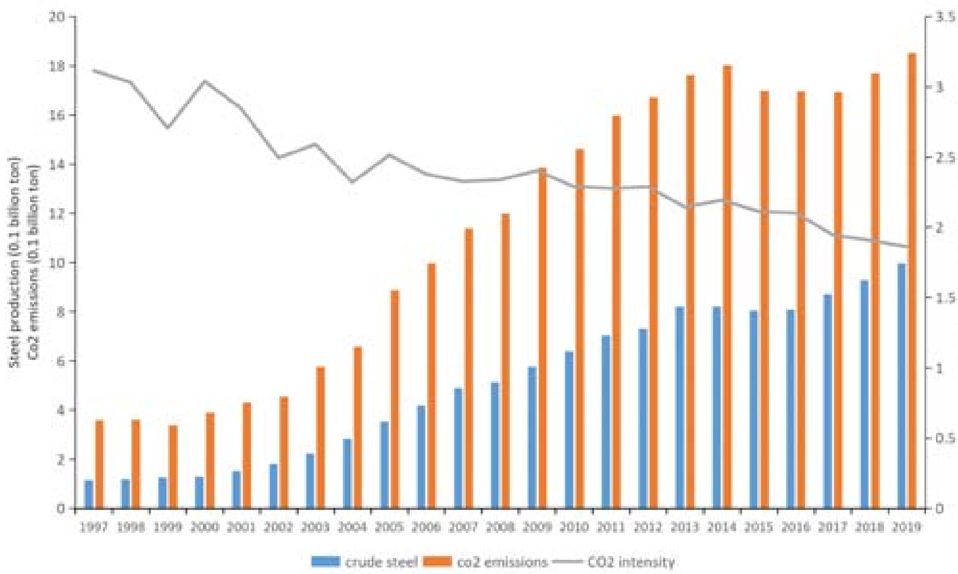


Figure 2-32 Carbon Emissions and Emission Intensity of China's Steel Industry

5. Trends of low carbon policies and technological innovation in the EU steel industry.

The EU's policies for low carbon development in the steel industry can be divided into several aspects, such as binding policies for carbon emission reduction, policies to promote technological innovation, and policies for financial support.

In terms of binding policies to control carbon emissions, the EU passed the Carbon Border Adjustment Mechanism (CBAM) bill, a policy that would impose tariffs on carbon emissions embedded in imported goods and include five industries, including steel, among the first industries to be implemented, thereby reducing carbon leakage. In addition, the EU has adopted the Carbon Emissions Trading System State Aid Guidelines in recent years, hoping to stop some EU companies with high carbon emissions from circumventing EU policy by shifting production to countries with limited climate emissions targets.

To balance the cost disadvantage of green steel products (green steel), the EU has adopted both supply-side pricing (e.g., CCFD) and demand-side market creation (e.g., carbon labelling) to promote the production costs of "green steel" in the EU that are competitive with those of conventional steel, thus effectively guaranteeing the low-carbon technology's return on investment.

In terms of promoting technological innovation and diffusion, the EU places special emphasis on the promotion of Best Available Technologies (BAT) and the promotion of technological upgrading in terms of smart carbon use (e.g., use of CCS, CCU technologies) and direct carbon avoidance (e.g., use of clean energy alternatives). In addition to the promotion of "green hydrogen" steelmaking, the EU also vigorously promotes the use of direct reduction iron and steelmaking technology (DRI), and strongly advocates the transformation of steel production to electrification, calling for more enterprises to use the electric arc furnace method for steel production, increasing the proportion of scrap in steel production, shortening the process and reducing carbon emissions. In addition, the EU has also increased investment in breakthrough technologies for carbon reduction to promote the improvement of the technology level of the whole industry.

In addition, the EU is also ahead of the world in promoting the development of green finance and making full use of the carbon market to promote emission reduction, and its institutional mechanism and practical experience are worth learning from.

The European Union carbon market (EU ETS) is the world's earliest and most mature leader in the development and largest scale of carbon trading. Since its inception in 2005, the EU ETS has been covering high-emission industries such as steel and cement. The EU ETS strictly enforces the principle of Cap and Trade, and the total amount of carbon emission allowances covered by the EU ETS accounts for about 40% of the total carbon emissions in the EU. Currently, the EU ETS has entered the fourth stage of development, which requires a 2.2% reduction in the total number of allowances per year. At the same time, a low-carbon financing fund will be established for the industrial and power sectors.

What is particularly worth learning is that EU ETS implements a strict monitoring and assessment system, which requires enterprises to be fully verified by independent and certified verification agencies every year in accordance with the principles of completeness, consistency, comparability, transparency and accuracy, and the EU requires member states to conduct annual assessments of enterprises based on third-party verification reports, and enterprises that exceed their emissions are subject to a penalty of 100 euros per ton, while the defaulting enterprises are required to make up the excess carbon emission allowances of the current year in the following year.

(2) Policy recommendations

Based on the above analysis, this study puts forward the following policy recommendations to promote the low-carbon development of China's steel industry.

1. Steel production process requires structural adjustment. Extensive development on short process direct reduction ironmaking-steelmaking technology is needed, to gradually shift from the blast furnace-converter steelmaking method of production to direct reduction method. While paying attention to the transformation from blast furnace converter steelmaking to scrap electric arc furnace steelmaking, improve the rate of steel electrification. Increase the recycling of scrap steel and improve the utilization rate of scrap steel.

2. New technology development and utilization. Increase investment in R&D of low-carbon technologies for steel and accelerate the development of breakthrough technologies. Increase the promotion and use of the best available technologies in low-carbon steel production, reduce the environmental impact of all processes in production as much as possible, and vigorously eliminate backward production capacity. Promote clean energy development, especially vigorously develop green hydrogen energy.

3. Take advantage of the synergetic effect of low-carbon policies. Influence the cost of green steel production through financial subsidies and emission permit rationing to change its cost disadvantage and increase the proportion of "green steel" production. Improve the institutional mechanism for the operation of the carbon market and fully utilizing the existing carbon market in discovering prices, promoting transactions and facilitating technological innovation. Vigorously promote the construction of a national green financial system to provide financial support for green transformation and technological breakthroughs in the steel industry.

4. Develop a flexible carbon regulation mechanism. Impose a carbon adjustment tax on imports, as well as domestic carbon-intensive steel and iron products, to reduce carbon leakage.

4. Research Outlook and Next Steps

1. Analyze the impact of the Russia-Ukraine war on the decarbonization goals, behaviors and strategies of the EU and global steel industry.

2. Further analysis on the effect of carbon neutrality policy implementation and future policy trends in the steel industry in Europe, America and Japan. For example, the implementation effect of Carbon Boarder Adjustment Mechanism (CBAM), the operation effect of carbon trading market, etc.

3. Continue to track and analyze the new decarbonization technologies and their industrialization status in the steel industry in Europe, America and Japan.

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Topic 6: Study on the Potential of Online Detection Technology for Energy Saving and Emission Reduction in Steel Production

1. Research Background

The steel industry is one of the largest carbon emitting industries. Green and low-carbon development is a key theme that will be highlighted in future steel industry development. Some important policy guidance documents, such as the Guidance on Promoting the High-quality Development of the Steel Industry and the Implementation Plan for the Carbon Dioxide Peaking of Steel Industry, require the steel industry's high-quality, green and low-carbon development. Under the carbon peaking and carbon neutrality goals, the steel industry will usher in a new round of structural optimization with the key focus in energy saving and carbon reduction.

Steel production consists of multiple processes of iron making, steel making and steel rolling. Online detection technology can realize fast online detection of raw material quality, intermediate product and final product quality, so as to provide real-time element composition information for optimization control of each chain, further provide technical support for integrated planning and scheduling of multiple chains, dynamic collaboration of cross processes, and orderly operation of the whole process.

Currently available online detection technologies include Prompt Gamma Neutron Activation Analysis (PGNAA), Laser-Induced Breakdown Spectroscopy (LIBS), Infrared Spectroscopy (IR), X-Ray Fluorescence Spectroscopy (XRF), Tunable Laser Absorption Spectroscopy (TDLAS), Raman Spectroscopy (RS), Hyperspectral Imaging Technology (HSI), Ultrasonic Flaw Detection Technology, and etc. Due to the different detection principles adopted by various technologies, their detection indexes, equipment systems, environmental adaptability, and other features vary, and the maturity of each technology differ as well. Although some technologies have industrial pilot applications, there is no unified evaluation standard for environmental safety and detection reliability. Especially under the target guidance of "carbon peaking, carbon neutrality", the carbon reduction potential of various online emission reduction technologies has not been evaluated. It is necessary to systematically evaluate the detection performance and energy saving and emission reduction potential of various detection technologies according to the actual application scenarios and detection needs, so as to optimize the configuration plan of online detection.

2. Research Methods

Based on the production process of iron and steel smelting, we will investigate the status of detection technology in each process, and evaluate the carbon reduction potential of each chain. We will summarize the basic principle, technical characteristics, equipment cost and other information of existing online detection technologies, and evaluate the potential of energy conservation and emission reduction of various online detection technologies in the steel industry. According to the detection requirements of each chain, the online detection technology will be matched, and the configuration proposal of each online detection technology in the iron and steel industry will be proposed. Research framework of energy saving and emission reduction potential of online detection technology in steel production is shown in Figure 2-33.

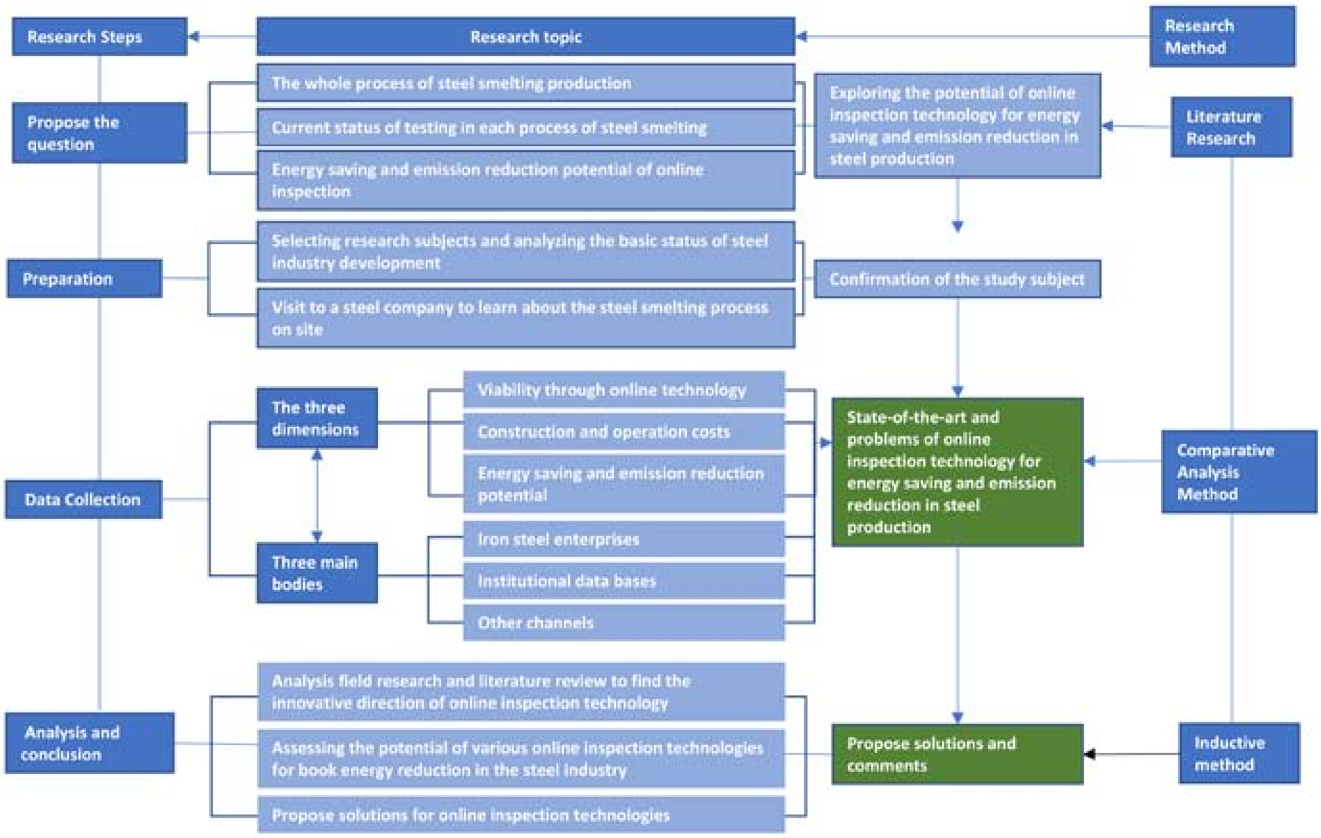

Figure 2-33 Overview of the study of energy saving and emission reduction potential of online inspection technology in steel production

Firstly, through literature review, we will understand the main process flow of the steel industry, the main objectives and key technical indicators of each process. Reviewing the existing publications and technical reports, we can understand the basic principles, system equipment components, technical advantages and defects of various online detection technologies, such as infrared spectroscopy, Raman spectroscopy, XRF, LIBS, TDLAS, PGNAA and other related detection technologies. Secondly, we will survey the entire life process of steel production on-the-spot, observe the environmental conditions of each online detection scenario, especially focus on the constraints of online detection system implementation. Further, by means of expert interviews and seminars, the target parameters of detection in each process will be identified, evaluating the energy saving and emission reduction potential of various online detection technologies, then recommending online detection configuration in specific application scenarios; Finally, by summarizing and analyzing the principles, characteristics, applicable scenarios and costs of detection technology, and considering the feasibility, economic benefits, instrument costs and assembly difficulties of online detection implementation, the optimal matching scheme will be obtained.

3. Key Findings and Policy Recommendations

The steel industry production process mainly includes a wide-ranging industrial system consisting of mining, sintering, coking, iron making, steel making, steel rolling and the corresponding ferroalloys, refractory materials, carbon products and many other production sectors. The steel industry is characterized by a large industrial scale and a long production process, requires many processes from ore mining to the final processing of products.

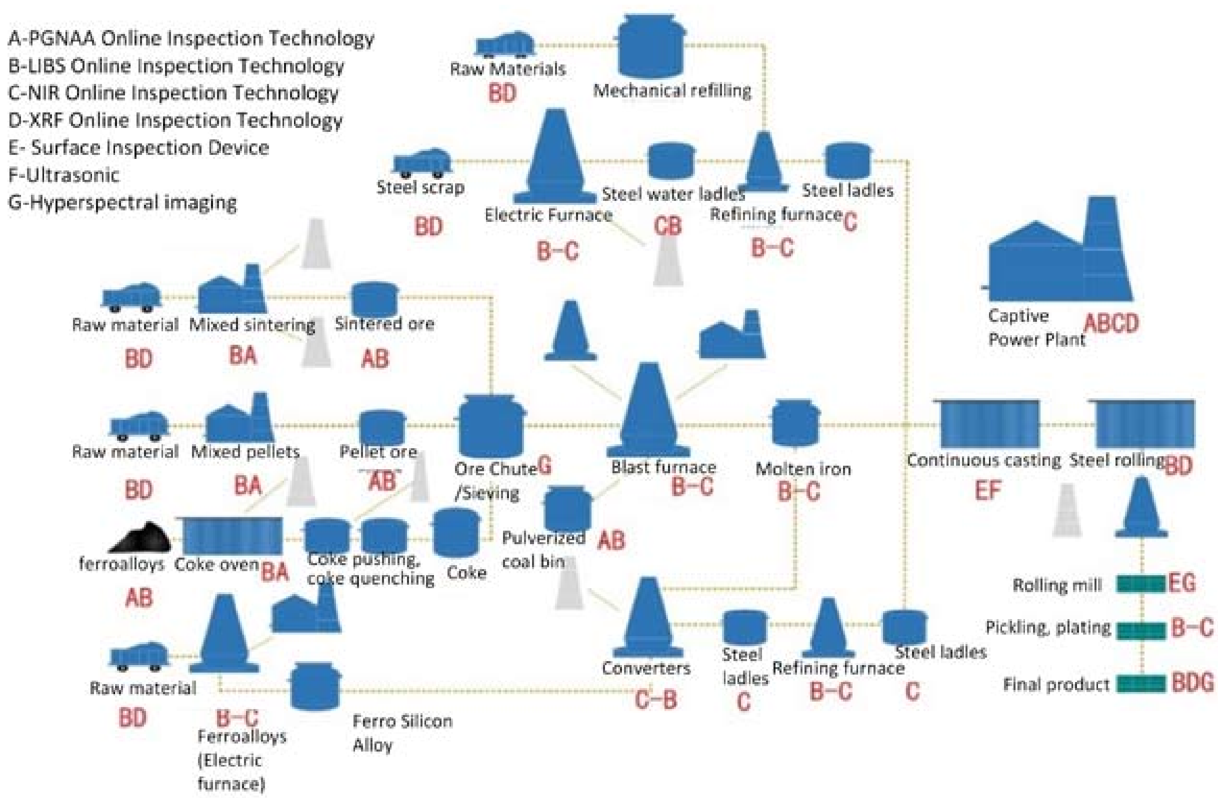

Figure 2-34 Suggested matching of online detection technology for steel smelting processes

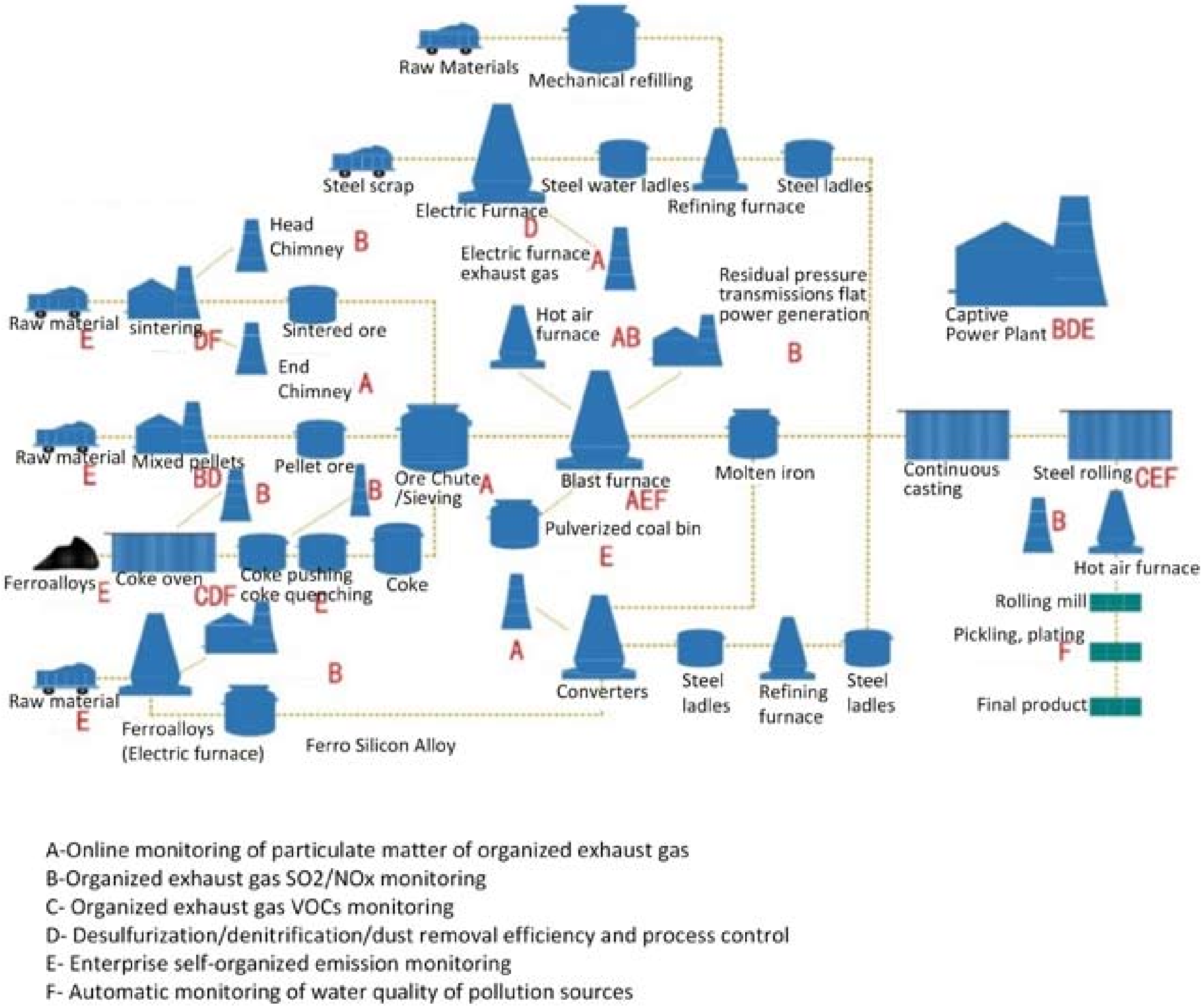

Figure 2-35 Suggested matching of online detection technology of wastewater and air pollutants

Key findings: At present, the composition detection technologies applied in steel production (pilot operation or being explored and developed) are mainly X-ray diffraction (XRD), infrared carbon and sulfur analysis, ICP spectrometry, X-ray fluorescence analysis. For some important processes, such as sintering, most of the steel enterprises mainly adopt manual sampling and testing methods to detect the composition of sintered ore, and use the test results as the basis to adjust the on-site production. The main problems are: (1) Human management, operation habits, randomness, etc. that affect the sampling and sample preparation of raw materials, resulting in certain degree of deviation in the test results; (2) The representativeness of measurement is poor. The measurement results can only represent a portion of samples, but cannot reflect all material; (3) The measurement process is time-consuming, which leads to the sintering quality being seriously affected. Online detection and analysis in the production process can provide real-time measurement, monitoring, optimizing the production process and ensuring product quality. According to the online detection requirements of the production process in the iron and steel industry, some suggestions on online detection technology matching are proposed, as shown in Figure 2-34 and Figure 2-35.

The online detection technology matching recommendations are categorized into five main areas:

(A) Raw material detection. Analyzing the quality of raw materials, compared with the material quality standards, so as to determine whether they are qualified.

(1) Iron-containing raw materials. Quality monitoring based on online composition detection of iron content. Technical level of concentration accounts for 70%, blast furnace operation accounts for 10%, modern management level accounts for 10%, equipment operation accounts for 5%, and external factors account for 5% on the ironmaking index. Therefore, the key to reducing the ironmaking fuel consumption is to increase the iron content grade in the furnace.

(2) Coal quality. Quality monitoring based on online composition detection (moisture, ash, sulfur, heating value, ash content).

(3) Coke quality. Quality monitoring based on online composition detection (moisture, ash, sulfur, calorific value, ash content)

(B) Sintering-pellet detection . Sinter pellets are the raw materials of the blast furnace. Generally, the ore powder transported from the mine cannot be directly put into the blast furnace. Because the permeability of the ore powder is poor, it is easy to cause the blast furnace to collapse. The size of the sinter is large and the strength is relatively high, so it can ensure the smooth operation of the blast furnace. It is an important chain in the steel production process, which is to mix iron ore powder, anthracite, lime and other raw materials in a certain proportion.

(1) Intelligent batching of raw material mixing. Online detecting the Fe and Si level in mixed raw material, so as to intelligently control the stabilization level of Fe and Si content.

(2) Intelligent batching for sintering. Intelligent batching based on online composition detection, applicable to sintering plant, to improve the alkalinity R stability rate of sintered ore.

(3) Intelligent batching for pelletizing. Intelligent batching based on online composition detection, applicable to pellet plant, to improve Fe, SiO2 stabilization rate of pellet ore.

(4) Intelligent batching for coking. Intelligent batching based on online composition detection, applicable to coking plant, to improve the stability rate of coal powder composition.

(5) Sintered-pellet ore quality online monitoring. Quality monitoring based on online composition detection, applicable to quality monitoring of sintered ore product.

(C) Blast furnace detection. As the main method of modern ironmaking, blast furnace ironmaking is an important process in steel production. The ironmaking process is to load iron containing raw materials (sinter, pellet or iron ore), fuel (coke, pulverized coal, and etc.) and other auxiliary raw materials (limestone, dolomite, manganese ore, and etc.) into the blast furnace at a certain proportion from the top of the high speed furnace, and blow hot air into the blast furnace from the lower part of the blast furnace along the tuyere around the furnace to facilitate coke combustion (some blast furnaces also inject pulverized coal, heavy oil, natural gas and other auxiliary fuels).

(1) Intelligent batching for coal injection. Based on online composition detection, to improve coal powder composition stability rate, applicable to coal spraying plant.

(2) Intelligent batching for blast furnace. Intelligent batching based on online composition detection, applicable to blast furnace workshop, to improve the stability rate of blast furnace slag alkalinity.

(3) Online detection of molten iron quality. Molten iron detection includes molten iron temperature and molten iron composition (silicon, phosphorus, sulfur, manganese, and etc.), which is an important parameter to characterize product quality, energy consumption level and furnace temperature status.

(D) Steel product detection. Steel product detection is mainly used to test the physical characteristics and chemical composition of the product to meet the quality requirements and reduce the rate of inferior products from the factory.

(1) Continuous casting defects, such as surface cracks, iron oxide, scars, and vibration lines. Casting billet surface quality inspection, including corner cracks, horizontal cracks, longitudinal cracks, and star cracks, using image inspection method for intelligent identification; internal quality inspection, including internal cracks, central porosity, shrinkage, and segregation.

(a) Flaw detection by ultrasonic. When the ultrasound reaches the defective metal, the transmission of the ultrasound is significantly different, so as to produce the corresponding "sound shadow".

(b) Flaw detection by radiation, such as X-rays, γ-rays and neutron rays, etc. Different substances have different absorption capacity of rays. When rays pass the cast billet, ray will project the defects, which will show different intensity of the rays, which allow us to determine the shape and location of defects in the cast billet.

(2) Rolling steel online detection. Medium-thick plate tying machine (testing requirements: residual stress), hot strip mill (testing requirements: ferrite phase change), cold rolling mill (testing requirements: hardness, surface roughness, r value), stainless steel plate (grain size), electrical steel plate (grain size, iron loss), galvanized steel plate (coating composition).

(E) Pollutant detection. The steel industry is one of the main sources of pollutants emission. The steel smelting process involves exhaust gas, wastewater and slag pollutants. The online detection mainly includes water pollution, gas and slag pollution detection. The concerned compositions mainly include heavy metals, petroleum and harmful gases and other analytical objects.

Iron ore powder is the basic raw material for the production of iron and steel, so it is particularly important to control the grade of iron ore powder. At present, there are mainly two methods for the detection of iron ore powder, which are the traditional chemical titration method and XRF detection method. The chemical titration method of detection is time consuming, complex and requires a high level of operation. The performance of XRF depends on the granularity, composition, structure of the sample, and it is difficult to accurately detect light elements.

If the iron grade of sintered ore decreases by 1%, the coke ratio of blast furnace will increase by 2% and the production output will decrease by 3%. If the FeO of sintered ore changes by 1%, it will affect the coke ratio of blast furnace by 1%~5% and the production output by 1%~5%. FeO also affects the reducibility and soft fusion performance of sintered ore. If the alkalinity of sintered is below 1.2, every change of 0.10 will affect the coke ratio of blast furnace and the production output by 3%~3.5%. The strength of sintered ore has a certain influence on blast furnace smelting. If the degree of strength is not adequate, the powder ore will be more prone to break into particle less than 5mm, and a 1% change in powder ore content affects the blast furnace coke ratio by 0.5% and the blast furnace output by 0.5%~1.0%. Every 5% increase in the low temperature reduction strength of sintered ore reduces the utilization rate of CO in gas by 0.5%, decreases the output by 1.5% and increases the coke ratio by 1.6%, so the measurement of sintered ore is vital for the process. Therefore, quality testing of sinter ore is especially crucial.

At present, blast furnace smelting iron composition detection is mainly conducted by a series of processes such as manual sampling - cooling - sample making, and then sent to the laboratory for X-ray fluorescence spectroscopy analysis, which takes about 20 to 100 minutes. It cannot guide the production process in real time, which greatly affects the production efficiency, and cause energy waste.

Therefore, In situ on-line rapid detection of ore grade, sinter and metal produced by blast furnace is a key problem to be solved by iron and steel enterprises. As shown in Figure 2-36, The main online detection suggested to be carried out in the near future includes: (1) iron ore detection, which can be used for in situ and online rapid analysis of iron grade of raw materials, fine materials and tailings; (2) Sintering intelligent batching, which is based on online composition detection, is applicable to sintering plant to improve sinter alkalinity R stability rate and other parameters; (3) On line detection of melted metal quality of blast furnace, including temperature and composition (Si, C, P, S, Mn, etc.), so as to control and improve product quality, reduce energy consumption. It is suggested to promote the implementation of relevant demonstration projects as soon as possible.

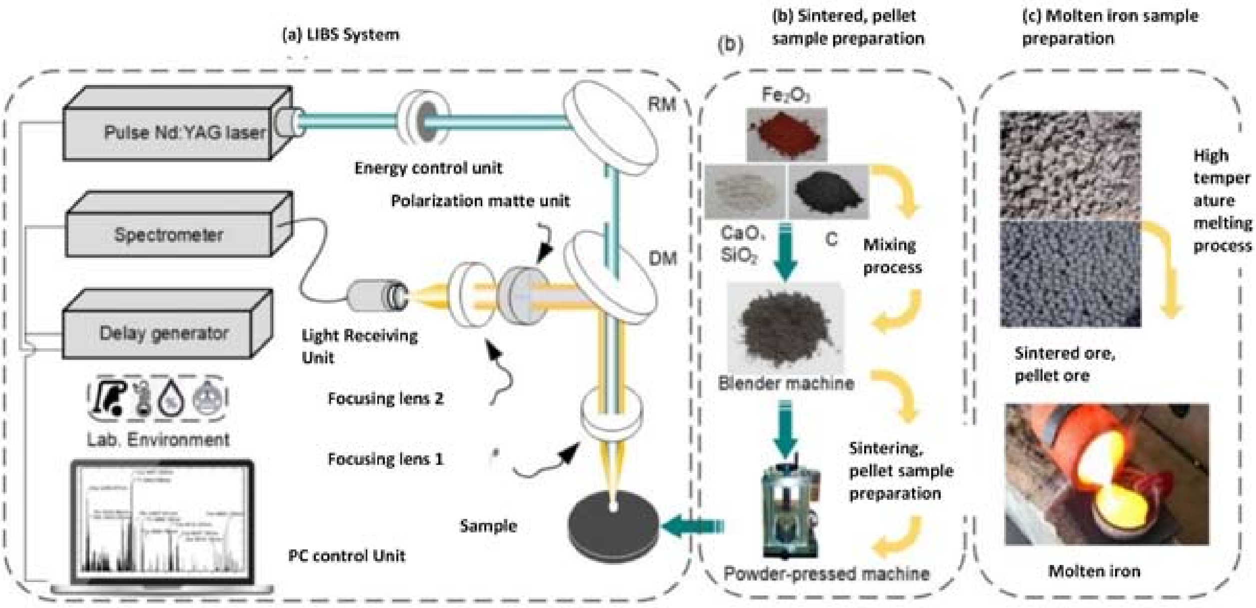

Figure 2-36 Schematic diagram of the online inspection system, (a) LIBS system; (b) sintered and pellet sample preparation; (c) iron sample preparation.

4. Research Outlook

By understanding the processing flow, chemical reactions, and current status of detection technologies involved in each process of iron and steel making, this work provides an in-depth analysis of key technical indicators and detection needs of the steel production process. The configuration of online detection for specific application scenarios is proposed, providing suggestion for managers or decision makers in the steel industry.

With the continuous improvement of industrial technology, intelligentization can comprehensively improve the level of enterprise research and development, production, management and service, and provide comprehensive solutions for cost reduction, efficiency increase, energy conservation and consumption reduction for each production unit of the iron and steel enterprise. In the future, online detection technology in the iron and steel industry will tend to combine multiple measurement technologies, artificial intelligence technology and big data, so as to improve the intelligent level of iron and steel enterprises and promote the iron and steel industry.

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Topic 7: Carbon Neutral Pathway of Critical Non-Ferrous Metals for Energy Storage

1. Research Background

With the development of renewable energy and distributed energy generation, energy storage technology has received increasing attention. The current energy storage technologies mainly include pumped storage, hydrogen storage, battery storage, compressed air storage, and etc. Among them, battery storage has been developing rapidly in recent years given its advantages in high energy density, fast response rate and strong environmental adaptability. At the same time, lithium-ion batteries such as lithium iron phosphate batteries commonly used in energy storage power plants are also widely used in new energy vehicles. Compared to traditional industrial products, the manufacturing of batteries requires the support of many non-ferrous materials such as lithium, cobalt and nickel. It is foreseeable that in the future, along with the large-scale adoption of renewable energy generation and new energy vehicles, the supply and consumption of battery-related non-ferrous metals will usher in a blowout growth. By 2040, the demand for lithium, cobalt and nickel in battery consumption will increase by 13 to 42 times, 6 to 21 times and 6 to 19 times compared to the demand in 2020, respectively. Compared with traditional bulk consumption metals (steel, copper, aluminum), the production and processing of battery-related non-ferrous raw materials has higher energy consumption and carbon emissions intensities. For example, the emissions from the production of a ton of lithium carbonate and nickel sulfate are three times and 10 times higher than the production of a ton of steel, respectively. Given the backdrop of the carbon neutrality target, how to reduce carbon emissions from the entire industry chain of related non-ferrous metals continuously determines both the cleanliness of the whole industry chain and the cost competitiveness and scale of future resource supply, which has comprehensive industrial, social and academic values.

2. Research Methods

This project looks at the critical non-ferrous metal industry of batteries, which is highly relevant to the development of low-carbon energy transition, and constructs an environmental externality impact assessment system from the perspective of the whole life cycle of raw material mining and processing, cathode material production, battery manufacturing, and installation and use. While exploring the path to achieve the carbon neutrality of the critical non-ferrous metal industry related to batteries, taking into account the performance of the final product and social benefits, and finally answers the following important questions. The key materials list for low-carbon energy technology development, the social metabolic mechanism of critical non-ferrous metals for batteries, the environmental externality impact under complex technology application conditions, and the formulation of policy and technology system to realize the synergistic development of "low-carbon energy transition and carbon neutral non-ferrous metals industry". The research methods and main contents are shown in Figure 2-37.

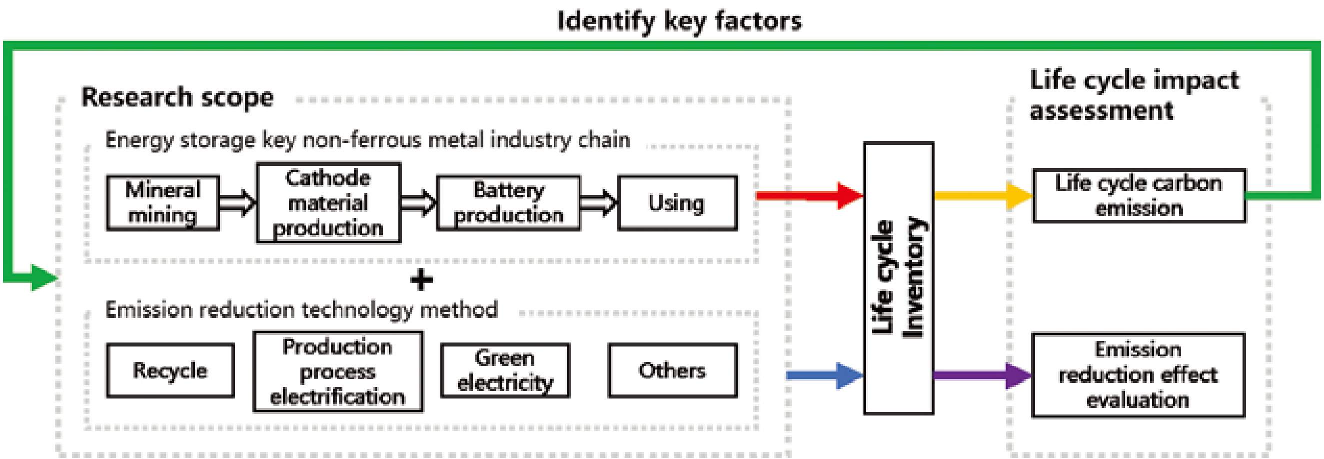


Figure 2-37 Research Method and Main Content

3. Key Findings and Policy Recommendations

(1) Clarify the energy environmental impact of key materials for energy storage at all stages of their life cycle

Based on the research of the battery production process and by tracing the upstream production chain of key materials, this topic illustrates the energy and environmental impacts of key materials for energy storage at each stage during their entire life cycle. Figure 2-38 shows the energy consumption of the industry chain of critical non-ferrous metals for energy storage, including the whole process of the industry chain (Fig. A) and the production process of battery cells (Fig. A), and the measures with emission reduction potential are labeled. Figure A depicts from left to right the mineral mining, processing and refining, advanced compound production, cell production, battery system production and final recycling, forming a closed-loop power battery industry chain, where the pie chart indicates the proportion of various energy consumption in the corresponding link. The cell production process can be expanded into the process flow in Figure B, and the shade of the bottom color of each process indicates the magnitude of energy consumption, and the pie chart on the right side shows the energy consumption distribution of battery production more clearly.

According to Figure 2-38, the overall energy and environmental impacts of key materials for energy storage at each stage of their full life cycle is as follows.

1) Along the supply chain, the type and proportion of fossil energy used is decreasing overall.

2) In the upstream part of the supply chain, about 1/3 of the energy is provided by fossil fuels, including natural gas, coal and diesel fuel, etc. In the subsequent processing and refining part, fossil fuels accounts for nearly 3/4 in proportion, most of which is natural gas, the rest is coal and a small amount of residual oil.

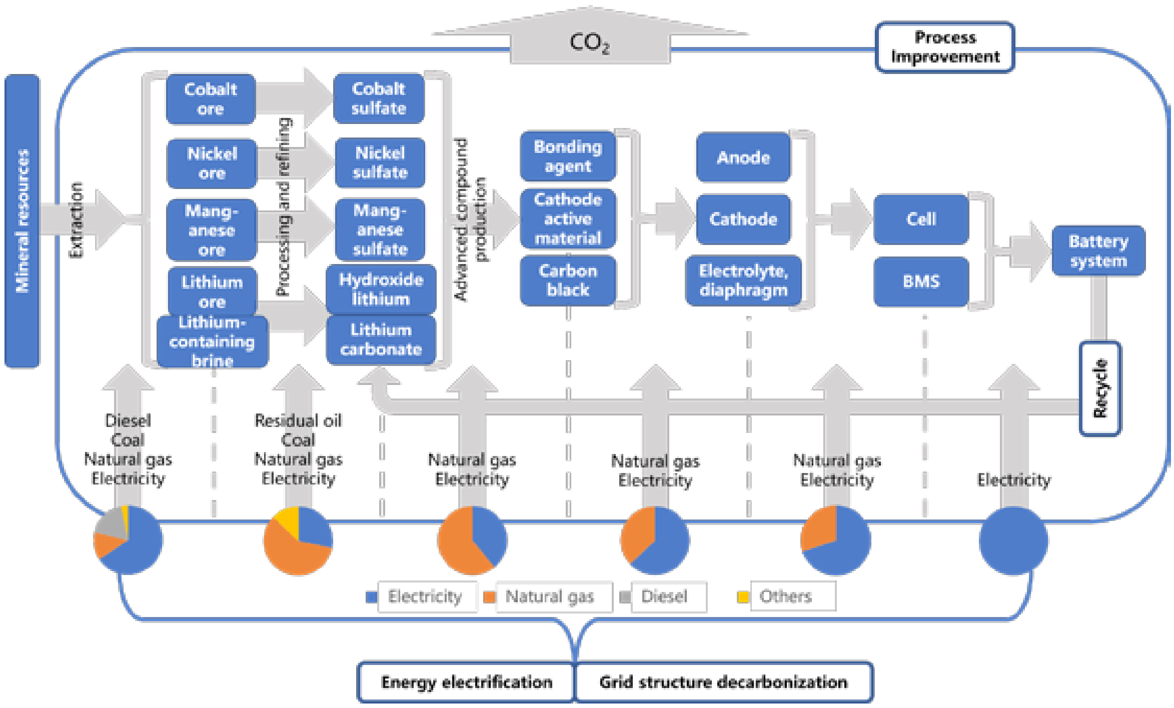
3) In the middle and lower parts of the supply chain, the only fossil energy required is natural gas, and there is a gradual decreasing trend of the proportion of energy demand in each segment, especially in the battery system production segment, which is the most downstream part of the supply chain, where all the energy required is provided by electricity.

4) In the cell production process, the energy consumption of drying and vacuum drying processes is high, accounting for about 3/4 of the total energy consumption of cell production, and its energy is mainly provided by electricity and natural gas.

5) Natural gas accounts for a high proportion of energy consumption in many parts of the chain, and its main role is to provide a heat source, which can be replaced by electricity under certain conditions. If the grid structure is clean, replacing natural gas with electricity can effectively reduce carbon emissions in the supply chain.

6) Retired batteries can be recycled to obtain products such as sulfate and carbonate of key metals, and this link can replace part of the upstream link of the industry chain, thus reducing fossil energy consumption.

(a)



(b)

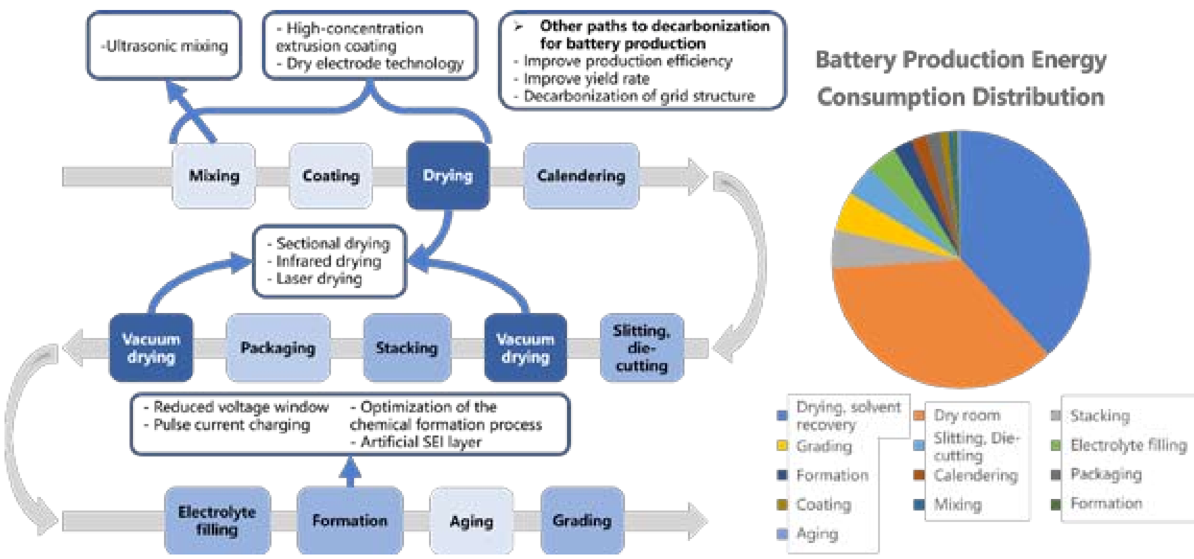


Figure 2-38 Energy consumption of the whole industry chain of critical non-ferrous metals for energy storage (a) and energy consumption of the production process of battery cells (b)

(2) Revealing the life cycle carbon emissions of key materials for energy storage

The research focuses on entire life cycle inventory analysis of the key materials supply chain for power batteries and energy storage. Compiling and quantifying the data inventory of the input and output of the studied product system, including process mapping, data collection and analysis. The results obtained from the inventory analysis were characterized using the CML-IA baseline V3.06 method, with a focus on the GWP (Global Warming Potential, in kg CO_2 eq/kWh). Figure 2-39 shows the carbon emissions of the whole life cycle of different types of power batteries, including the carbon emission values of cathode active material production, battery assembly and other parts. Among them, the carbon emission of cathode active material production is closely related to the key materials for energy storage, which includes two parts, the carbon emissions of cathode material production process and the carbon emissions of corresponding raw materials in the life cycle. The carbon emissions of battery assembly is the carbon emission of the process shown in Figure 2-38(b), and the carbon emission of other parts is the life-cycle carbon emission of raw materials other than cathode materials.

Studies on the whole life cycle carbon emissions of power batteries have shown that:

1) At the existing manufacturing level, the life-cycle carbon emissions of lithium nickel cobalt manganese oxide (NCM 811) battery production and manufacturing are about 87 kg/kWh, of which the carbon emissions of cathode material production and battery assembly account for 50% and 30% respectively.

2) Lithium nickel cobalt aluminum oxide (NCA) batteries, another type of ternary lithium battery, have slightly lower life-cycle carbon emissions than NCM 811 batteries, and the difference between the two mainly comes from the carbon emissions of cathode material production.

3) Compared with NCM 811 batteries, the life-cycle carbon emissions of lithium iron phosphate (LFP) batteries are reduced by about one-third, and the difference between them mainly comes from the production of cathode materials and battery assembly. Specifically, since the mass energy

density of LFP batteries is lower than that of NCM 811 batteries, and the assembly process and energy consumption of both batteries are basically the same, the carbon emissions per kWh of LFP battery assembly is slightly higher than that of NCM 811 batteries. life cycle carbon emissions of LFP batteries are significantly lower than those of NCM 811 batteries.

4) As a new type of energy storage battery, the whole life cycle carbon emission of sodium-ion battery is comparable to that of LFP battery, and the ratio of carbon emission of each part is close. At present, sodium ion battery is still in the laboratory stage, and it is foreseeable that with the improvement of production process, energy density and industrial chain, potentially further reducing the whole life cycle carbon emissions.

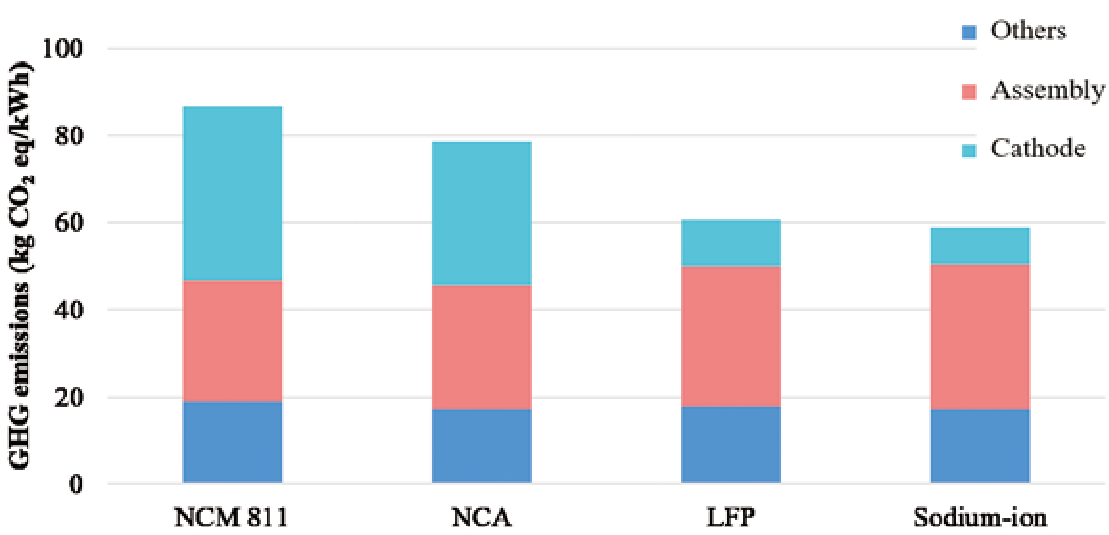


Figure 2-39 Life cycle carbon emissions of different types of power batteries

(3) Carbon neutral technology roadmap for energy storage materials

This topic has evaluated the carbon emission reduction technologies of the vehicle battery industry chain, and the emission reduction effects of different technologies acting individually are shown in Figure 2-40. The vehicle battery industry chain emission reduction is mainly outlined by recycling, process improvement and improvement of energy consumption structure.

The secondary resources obtained from recycling can offset part of the primary resource production, and can produce a certain emission reduction effect when the carbon emissions from the recycling process are lower than those from the primary resource production. At present, vehicle battery recycling technology mainly includes hydro-metallurgical recycling, pyro-metallurgical recycling and direct recycling. Hydro-metallurgical recycling firstly dismantles and sorts the retired vehicle battery, then acid leaching or alkali leaching of the cathode material, and finally the metal elements are recovered by solvent extraction, ion exchange and chemical precipitation. Instead of sorting retired vehicle batteries, pyro-recovery is carried out directly through high-temperature melting. The plastic, diaphragm, graphite, electrolyte and other materials in the battery are burned, and metal elements such as nickel, cobalt and manganese are recovered in the form of alloy, while lithium elements exist in the slag. The main principle of direct method recovery is to separate the battery components by physical separation, magnetic separation and appropriate heat treatment while avoiding the decomposition of the active material, and then the cathode active material is repaired by re-lithiation or hydrothermal process. Hydro-metallurgical recovery and fire recovery technologies have been put into industrial practice on a large scale. Process improvement, on the other hand, takes the high energy consumption stages in the energy storage key material industry chain as the entry point to reduce process energy consumption by improving production technologies, and some potential low-carbon production technologies are shown in Figure 2-38(b). However, some of the improved technologies are still in the laboratory or even theoretical stage, and their feasibility and carbon reduction effect of application to actual production still need to be further verified. The idea of improving the energy consumption structure is relatively simple and can be roughly divided into two steps, i.e., using 100% green electricity in the grid and using electricity to replace all other energies that can be substituted in the chain.

According to Figure 2-40, the effects of different carbon reduction measures for key materials for energy storage are as follows.

1) Carbon emissions can be reduced to a certain extent through resource recovery and recycling, but the carbon reduction effect varies among different recycling processes.

2) Pyro-recovery can reduce carbon emissions by only 3.5%. This technology needs to consume a lot of coal and electricity in the processes of melting, casting and sintering, and the process itself has high carbon emissions, even close to the carbon emissions of primary resource production, so the carbon reduction effect is not ideal. This technology is not being commonly adopted in China at present.

3) The carbon reduction effect of direct recycling and hydro-metallurgical recycling is significant, which can reduce more than 50% and 30% respectively. Direct recycling can directly obtain the battery cathode material, which can offset more carbon emissions from primary resource production. The direct product of hydro-metallurgical recycling is usually the metal salt of key elements, which needs to be further processed to obtain the cathode material, but the recycling process has lower energy consumption and produces lower carbon emissions in the recycling process, so it can also realize a significant emission reduction effect. At present, China has grasped the industrial application of hydro-metallurgical recovery, while direct recovery is still in the laboratory stage as a whole, and only individual enterprises have put it into actual production.

4) According to the projection of China's power energy structure, with the increase of the proportion of green power, the life-cycle carbon emissions of vehicle battery production can be reduced by 12% and 75% in the power structure of 2030 and 2050, and the whole life-cycle near-zero emissions can be gradually achieved. For energy consumption that cannot be replaced by green power, carbon capture technology will be required to achieve near-zero emissions.

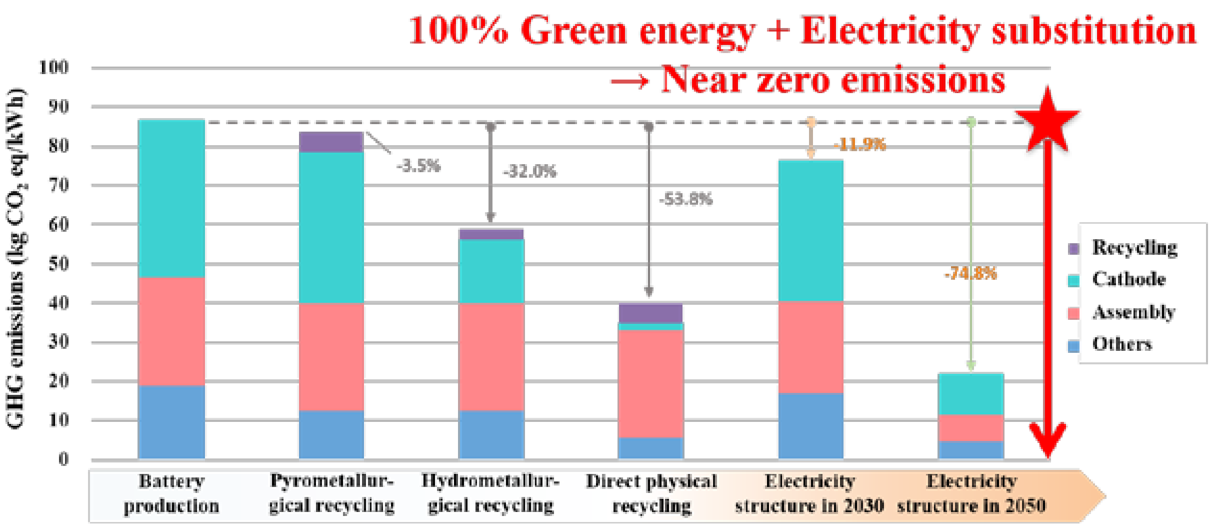


Figure 2-40 Carbon neutral technology route for energy storage materials and assessment of the effect of carbon reduction measures

In addition to CO_2 , battery manufacturing produces SOx, NOx, PM2.5, VOC and other pollutant emissions to a certain extent, but the emissions are lower than those of traditional cars considering the whole life cycle perspective of car use, and the emissions are generally far from densely populated areas, causing less human harm; the environmental impact caused by improper disposal of lithium-ion batteries is much lower than that of lead-acid batteries, and the ecological risk is comparable to that of rubber tires. The research results clarify the carbon emissions of relevant critical non-ferrous metals and their emission reduction paths, and play a guiding role in the low-carbon development of relevant non-ferrous metals and downstream industries, while laying a foundation for importing carbon emission costs in further techno-economic analysis and revealing the cost and scale of resource supply.

(4) Policy recommendations for reducing carbon emissions from key materials for energy storage

The rapid growth and potential of China's new energy vehicle market has stimulated the rapid development of the vehicle battery and its upstream key materials industry. From the perspective of the whole life cycle of the vehicle, under the current energy structure and industrial status in China, the carbon emission of electric vehicles is lower than that of traditional internal combustion engine vehicles, but there is still room for further reduction. Therefore, in order to reduce the life-cycle carbon emissions of electric vehicles and eventually achieve the goal of carbon neutrality, policy should focus more on reducing the carbon emissions of key materials for energy storage from both the supply side of vehicle batteries and resource recovery. This topic puts forward the following policy recommendations.

1) Integrating sustainable resource supply and low carbon development. For key metal materials for energy storage such as lithium, cobalt and nickel, each element can be mined from a variety of minerals. For example, lithium resources can come from both lithium ore and brine refining; nickel elements mainly exist in nickel sulfide ore and nickel laterite ore. The difficulty of mining and smelting process of different minerals are very different, and their carbon emission level will also be different, taking lithium as an example, the carbon emission of lithium brine extraction technology is lower than that of lithium ore extraction. Therefore, priority should be given to low-carbon mineral sources under the premise of securing resource supply.

2) Support and encourage the research, development and application of low-carbon technologies in the whole life cycle of vehicle batteries. On the one hand, encourage enterprises to adopt more low-carbon production technologies in all aspects of the vehicle battery industry chain, such as dry electrode technology and segmented drying, to accelerate the low-carbon upgrading and transformation of the industry; on the other hand, promote the R&D and innovation of battery chemistry systems, accelerate the R&D and application of new batteries, and reduce the demand for high-carbon emission resources for vehicle batteries.

3) Establish a well-functioning vehicle battery recycling system as soon as possible. The government should effectively strengthen the monitoring and management of used vehicle batteries, implement refined traceability management of vehicle battery recycling, clarify and

implement the distribution of vehicle battery recycling responsibilities, establish an access system for the vehicle battery recycling industry, and guide the standardized development of the industry.

4) Promote the development and application of advanced recycling technology for vehicle batteries. First, the recycling target metals need to comprehensively cover lithium, cobalt and nickel, with continuously improvement in the recycling process and increase the rate of metal recovery; second, encourage recycling enterprises to strengthen battery testing technology research and development, solve the issue of safety in gradient utilization as soon as possible, and reasonably extend the life cycle of vehicle batteries; third, accelerate the research and development and application of advanced recycling technologies such as direct recycling, and with the gradual decarbonization of the primary production link of resources need to further reduce carbon emissions in the recycling process in order to ensure its emission reduction effect.

5) The planning of new production capacity of the whole vehicle battery industry chain gives priority to areas rich in renewable energy, and promotes the improvement of electrification in each production link of the industry chain.

4. Research Outlook

Application has been submitted for the topic "Carbon emission and cost study of primary and secondary resources of critical non-ferrous metals" in the latter half of the year's topic guide around "Decarbonization Cost and Pathway Study (Topic 5)". Based on the results of this project, further exploration in deepen carbon emission accounting and costing, assess the impact of volatility of primary price resources, assess the impact of battery recycling regulations, and reveal the evolution of the supply of primary and secondary resources of critical non-ferrous metals.

5. Members of the Research Team

	NAME	TITLE	AFFILIATION
1	Han Hao	Associate Professor	School of Vehicle and Mobility/ The Joint Centre of Tsinghua-Rio Tinto
2	Shilong Du	PhD student	School of Vehicle and Mobility
3	Hao Dou	Master student	School of Vehicle and Mobility
4	Yunfeng Deng	PhD student	School of Vehicle and Mobility
5	Xin Sun	PhD student	School of Vehicle and Mobility
6	Dengye Xun	PhD student	School of Vehicle and Mobility

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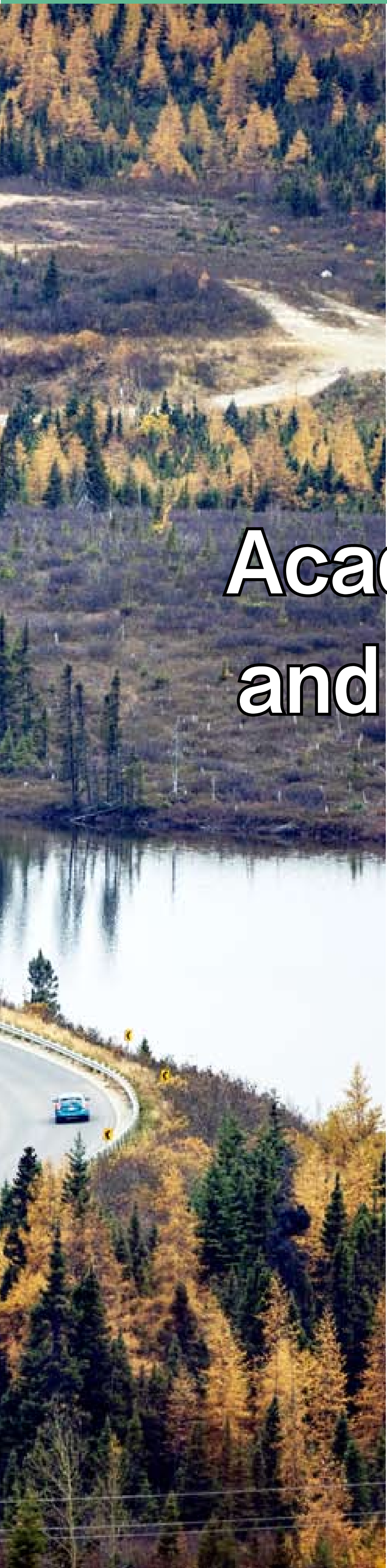
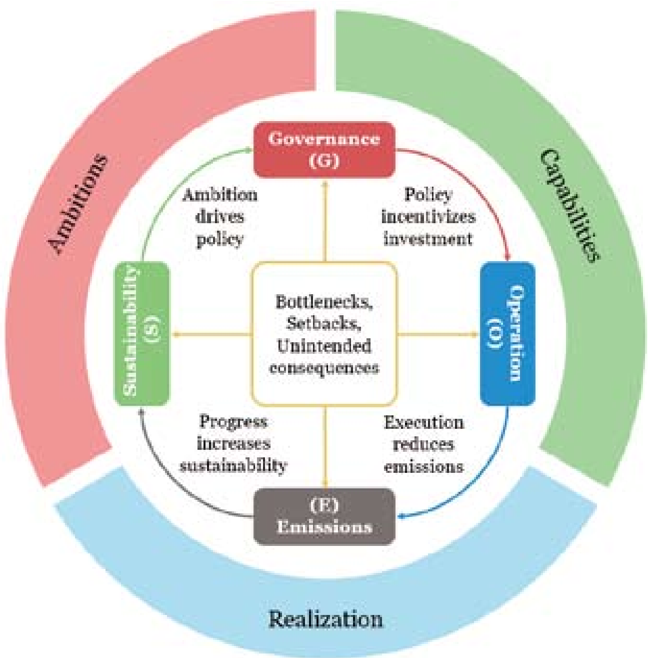


Chapter 3: Academic Achievements and Policy Contributions

This chapter introduces selected academic papers from the Centre and academic views on policy issues and finally discusses subjects of debate from industry perspectives.

1. Key Academic Papers Introduction

This section contains abstracts of academic papers published by the faculty members and their teams under the Centre's flagship project Carbon Neutralization in the Metal Industry.



Paper Information

Title: Realizing ambitions: A framework for iteratively assessing and communicating national decarbonization progress.

Authors: Chuan Zhang, Honghua Yang, Yunlong Zhao, Linwei Ma, Eric D. Larson, Chris Greig

Publication: iScience

Publication Date: January, 2022

DOI: 10.1016/j.isci.2021.103695

Abstract

A growing number of governments are pledging to achieve net-zero greenhouse gas emissions by mid-century. Despite such ambitions, realized emissions reductions continue to fall alarmingly short of modeled energy transition pathways for achieving net-zero. This gap is largely a result of the difficulty of realistically modeling all the techno-economic and sociopolitical capabilities that are required to deliver actual emissions reductions. This limitation of models suggests the need for an energy-systems analytical framework that goes well beyond energy-system modeling in order to close the gap between ambition and reality. Toward that end, we propose the Emissions-Sustainability-Governance-Operation (ESGO) framework for structured assessment and transparent communication of national capabilities and realization. We illustrate the critical role of energy modeling in ESGO using recent net-zero modeling studies for the world's two largest emitters, China and the United States. This illustration leads to recommendations for improvements to energy-system modeling to enable more productive ESGO implementation.

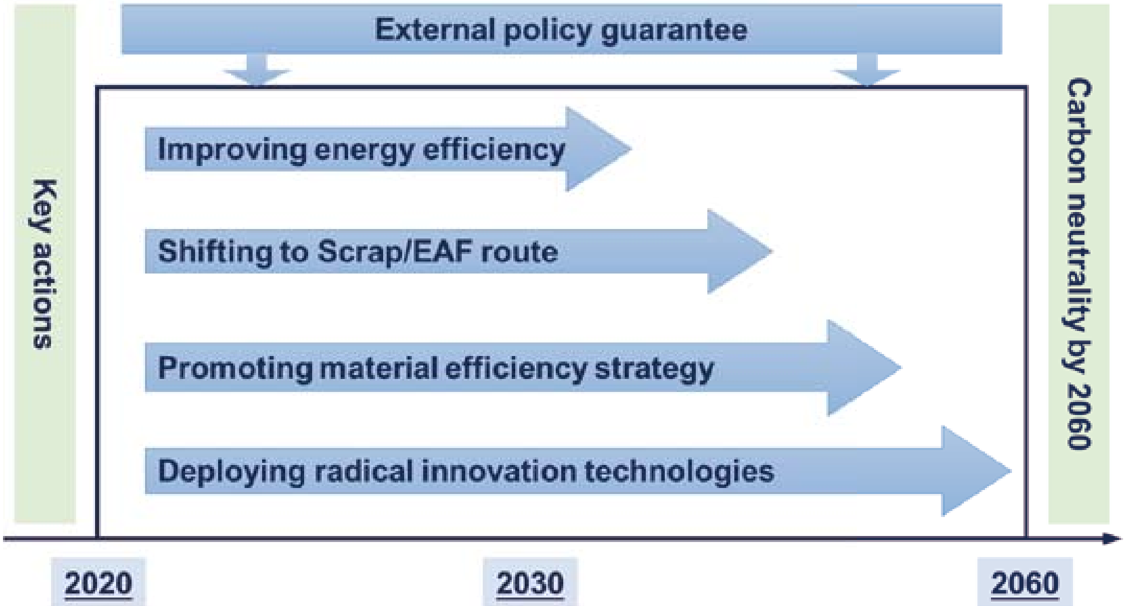
Paper Highlight

· Achieving national decarbonization ambitions depends on capacity.

· Proposes an emissions-sustainability-governance-operations (ESGO) analytical framework to improve the feasibility of modeling the transition to net zero emissions.

· Draws on the results of decarbonization modeling studies in China and the United States to illustrate the application of the ESGO framework.

· The EGSO framework is applicable to any country pursuing a net-zero emissions pathway design



Paper Information

Title: Low-Carbon Development for the Iron and Steel Industry in China and the World: Status Quo, Future Vision, and Key Actions
Authors: Yuancheng Lin, Honghua Yang, Linwei Ma, Zheng Li, Weidou Ni
Publication: Sustainability
Publication Date: November 2021
DOI: 10.1016/j.isci.2021.103695

Abstract

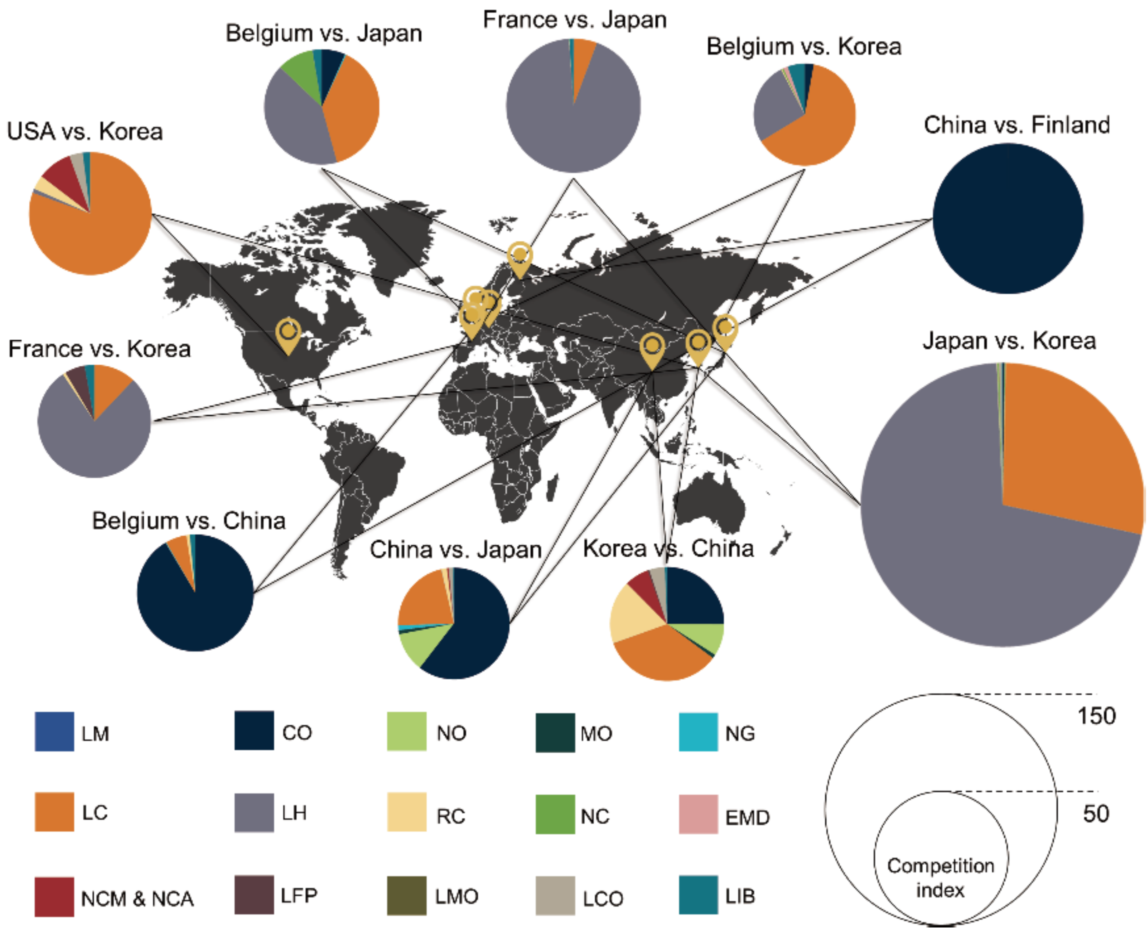
The low-carbon development of China's iron and steel industry (ISI) is important but challenging work for the attainment of China's carbon neutrality by 2060. However, most previous studies related to the low-carbon development of China's ISI are fagmented from different views such as production-side mitigation, demand-side mitigation, or mitigation technologies. Additionally, there is still a lack of a comprehensive overview of the long-term pathway to the low-carbon development of China’s ISI. To respond to this gap and to contribute to better guide policymaking in China, this paper conducted a timely and comprehensive review following the technology roadmap framework covering the status quo, future vision, and key actions of the low-carbon development of the world and China’s ISI. First, this paper provides an overview of the technology roadmap of low-carbon development around the main steel production countries in the world. Second, the potential for key decarbonization actions available for China’s ISI are evaluated in detail. Third, policy and research recommendations are put forward for the future low-carbon development of China’s ISI. Through this comprehensive review, four key actions can be applied to the low-carbon development of China’s ISI: improving energy efficiency, shifting to Scrap/EAF route, promoting material efficiency strategy, and deploying radical innovation technologies.

Paper Highlight

· This paper provides a timely and comprehensive overview of the low-carbon technology roadmap around the main steel production countries in the world, covering status quo, future vision, and key actions.

· Referring to the low-carbon technology roadmaps published by other steel-producing countries and to the actual situation in China, key actions available for the decarbonization of China’s ISI are evaluated one by one, including improving energy efficiency, shifting to Scrap/EAF route, promoting material efficiency strategy, and deploying radical innovation technologies.

· Suggestions on policy recommendations and next-step research priorities are given for the low-carbon development of China’s ISI.



Paper Information

Title: Global Competition in the Lithium-Ion Battery Supply Chain: A Novel Perspective for Criticality Analysis

Authors: Xin Sun, Zongwei Liu, Fuquan Zhao, Han Hao

Publication: Environmental Science & Technology

Publication Date: September 2021

DOI: 10.1021/acs.est.1c03376

Abstract

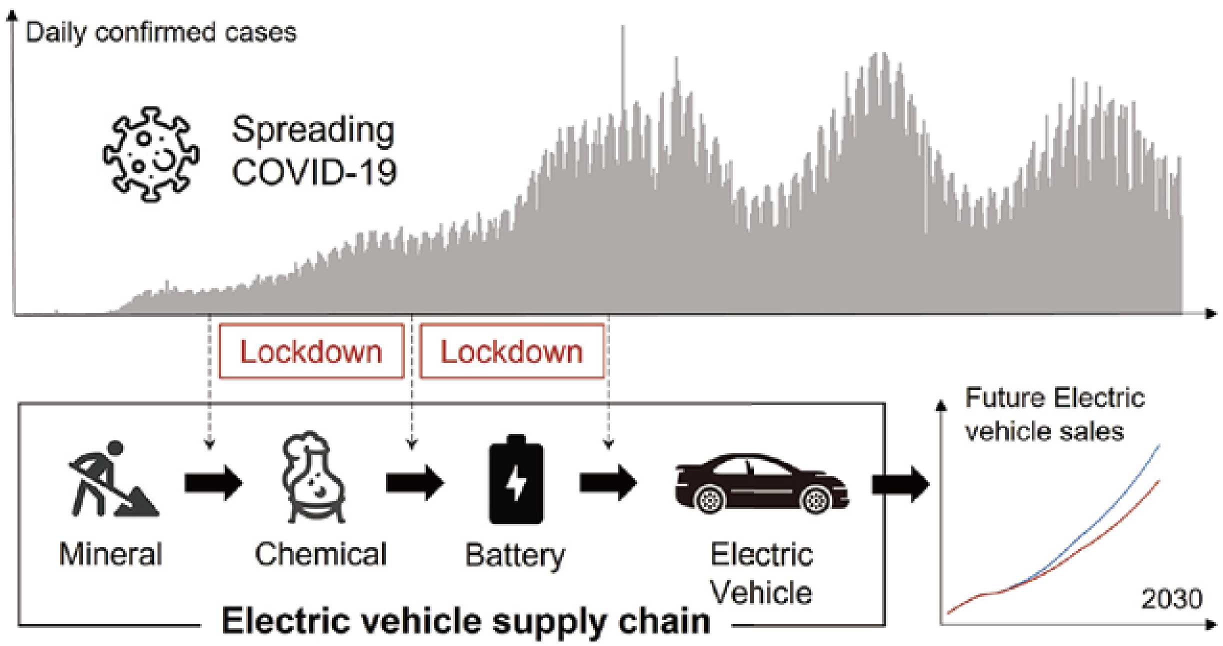
With the accelerated pace of energy transition, competition in the lithium-ion battery (LIB) supply chain is intensifying across a wide scope of countries. In order to understand the potential risk derived from the competitors, this study quantifies the global competition intensities of 15 categories of LIB-related commodities, which has not been well characterized by previous criticality analysis studies. On the basis of the collected data and designed treatment techniques, the "competition index" is developed for this purpose. Here, we show that lithium hydroxides, LIBs, and lithium carbonates were the focal points of global competition in the LIB supply chain in 2019, and there will be more competition for lithium hydroxide in the future. The competition for commodities related to LIBs among Korea, Japan, and the USA are the most notable. Such insights into the global conflict potential of LIB-related commodities provide a reference for underlying competitors and corresponding transition strategies of regional industrial structures. The index developed by us complements the criticality analysis framework, which could be expanded to assess the criticality of materials relevant with other industries.

Paper Highlight

· Developed new methods to quantify the intensity of global competition for specific commodities.

· Quantitative analysis of the global competitive potential of various core commodities covered in the entire global supply chain of LIBs.

· The methodology is fully data-oriented and can be extended to assess the competitive situation for other key commodities



Paper Information

Title: Modeling potential impact of COVID−19 pandemic on global electric vehicle supply chain
Authors: Xin Sun, Gang Liu, Han Hao, Zongwei Liu, Fuquan Zhao
Publication: iScience
Publication Date: March 2022
DOI: 10.1016/j.isci.2022.103903

Abstract

The on-going COVID-19 pandemic and consequent lockdowns cast significant impacts on global economy in the short run. Their impact on stability of global electric vehicles (EVs) supply chain and thus our climate ambition in the long run, however, remains hitherto largely unexplored. We aim to address this gap based on an integrated model framework, including assessing supply risks of 17 selected core commodities throughout the EV supply chain and further applying the supply constraints to project future EV sales until 2030. Our model results under three pandemic development scenarios indicate that if the pandemic is effectively contained before 2024, the global EV industry will recover without fundamentally scathed and thus can maintain the same growth trend as in the no-pandemic scenario by 2030. We suggest that fiscal stimulus in the postpandemic era should be directed more toward upgrading the quality of battery products, rather than expanding the production capacity.

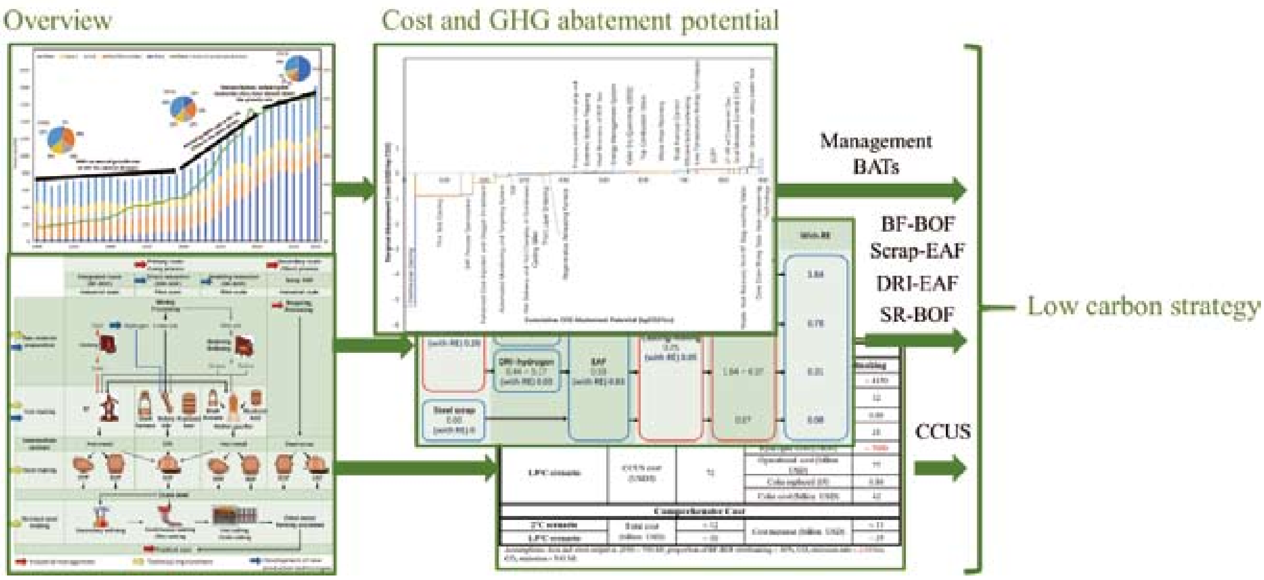
Paper Highlight

· Lithium is the most critical commodity for the electric vehicle industry

· Short-term COVID-19 pandemic will not cause constraints on the production side

· Long-term pandemic can seriously jeopardize electric vehicle market development

· Post-pandemic policies should focus more on improving battery quality



Paper Information

Title: A review of CO_2 emissions reduction technologies and low-carbon development in the iron and steel industry focusing on China

Authors: Lei Ren, Sheng Zhou, Tianduo Peng, Xunmin Ou

Publication: Renewable and Sustainable Energy Reviews

Publication Date: March 2021

DOI: 10.1016/j.rser.2021.110846

Abstract

The iron and steel industry (ISI) is energy-intensive and is responsible for approximately 25% of the global direct greenhouse gas (GHG) emissions from industrial sectors. As the largest steel producer and consumer, China bears the primary responsibility for saving energy and reducing GHG emissions; accordingly, they have developed many strategies for GHG abatement. However, owing to the high investment costs and long equipment service lives, the ISI must carefully weigh the cost and emission reduction potential of these approaches. This review discusses research findings aimed at technological improvements and ultra-low carbon technologies relevant to the ISI, emphasizing their cost-effectiveness and development prospects. Based on the life cycle analysis method, this review establishes a comprehensive analytical framework to integrate the results from different studies to consider more factors in the design of GHG emission reduction strategies. The results indicate that the full application of mainstream technological improvements can reduce CO_2 emissions by approximately 43%. Furthermore, combining these strategies with ultra-low carbon technologies can achieve a reduction of 80%–95%. The marginal cost reduction associated with implementing such technological improvements is in the range of −5 to 0.5 USD/kgCO_2. Applying carbon capture, utilization, and storage strategies or hydrogen-based technologies in China's ISI for deep decarbonization scenarios is expected to lead to cost reductions between 12 and 35 billion USD by 2050. We propose that China's ISI requires technological improvements in the short term and should prioritize ultra-low carbon technology development for the long term.

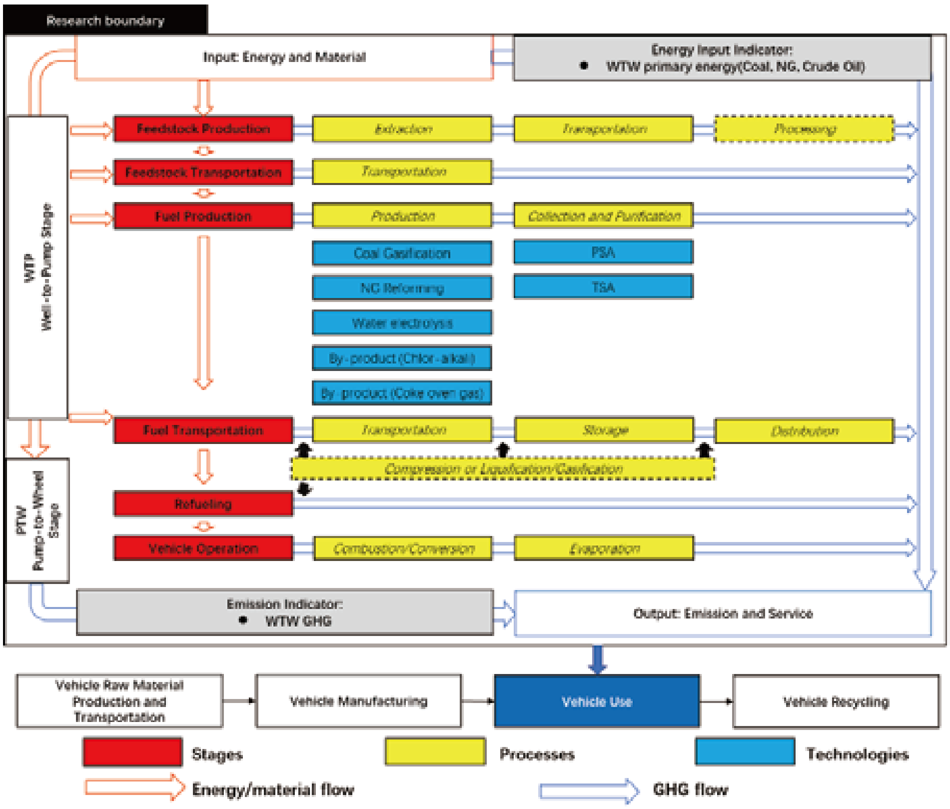
Paper Highlight

· Discussion of researches and pilot projects aimed at technological improvements of the iron and steel industry.

· Review and potential of the ultra-low carbon emission technologies in the iron and steel industry.

· Overview of energy consumption and GHG emissions of the iron and steel industry.

· Development strategies designed based on analysis of cost and GHG mitigation potential.



Paper Information

Title: Life-cycle energy consumption and greenhouse-gas emissions of hydrogen supply chains for fuel-cell vehicles in China

Authors: Lei Ren, Sheng Zhou, Tianduo Peng, Xunmin Ou

Publication: Energy

Publication Date: Septemeber 2020

DOI: 10.1016/j.energy.2020.118482

Abstract

A model is established to conduct life cycle analysis of primary-energy consumption and greenhouse gas emissions of hydrogen supply chains for fuel-cell vehicles in China. Battery electric vehicles and internal combustion engine vehicles are set as reference pathways.

Results show that the life-cycle primary-energy consumption is lowest for hydropower-based and nuclear-power-based electricity on hydrogen pathways, approximately ranging from 0.48 to 0.94 MJ/MJ H2. By-product hydrogen production also conserves energy while natural gas-based, coal-based, and grid power-based hydrogen pathways have no advantages in terms of life-cycle energy consumption. Similar results for life-cycle greenhouse gas emissions are found. Private-passenger fuel-cell vehicles fueled by hydropower-based and nuclear power-based hydrogen have outstanding potential to reduce greenhouse gas emissions, while those fueled by natural-gas-based hydrogen (with life-cycle greenhouse gas emissions ranging 187–235 g CO_2,eq/km) are comparable to conventional vehicles. Fuel-cell vehicles fueled by current grid power-based hydrogen have two to three times the life-cycle greenhouse gas emissions of internal combustion engine vehicles. Hydrogen-fuel-cell vehicles transit buses, owing to their high energy demands, do not have obvious advantages in terms of their life-cycle primary-energy consumption and greenhouse gas emissions compared with internal combustion engine vehicles/battery electric vehicles.

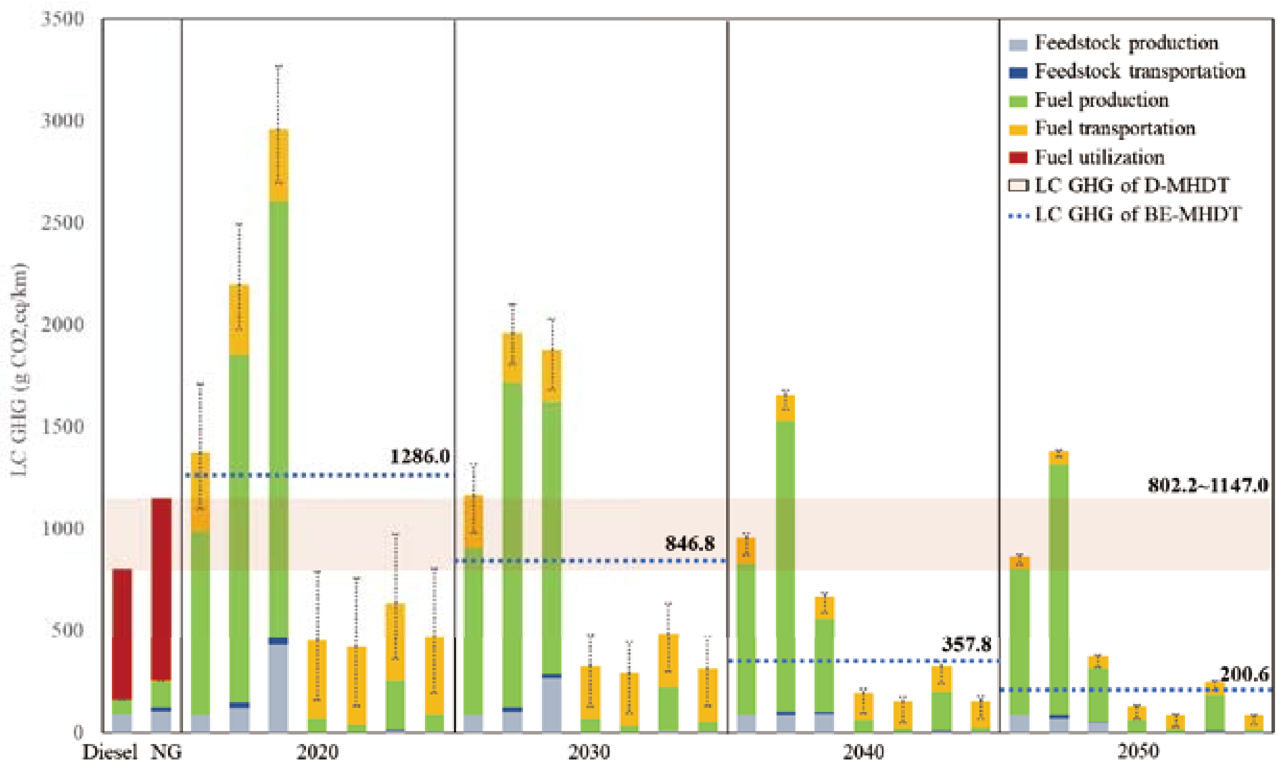
Paper Highlight

· A life-cycle analysis of the energy consumption and greenhouse gas emissions of hydrogen fuel cell vehicles in China.

· A description of the future low-carbon development of hydrogen technology and electricity.

· Energy savings achieved from hydrogen by-product production.

· Greenhouse gas emissions during hydrogen transportation and storage cannot be ignored.



Paper Information

Title: Greenhouse gas life cycle analysis of China's fuel cell medium- and heavy-duty trucks under segmented usage scenarios and vehicle types

Authors: Lei Ren, Sheng Zhou, Tianduo Peng, Xunmin Ou

Publication: Energy

Publication Date: June 2022

DOI: 10.1016/j.energy.2022.123628

Abstract

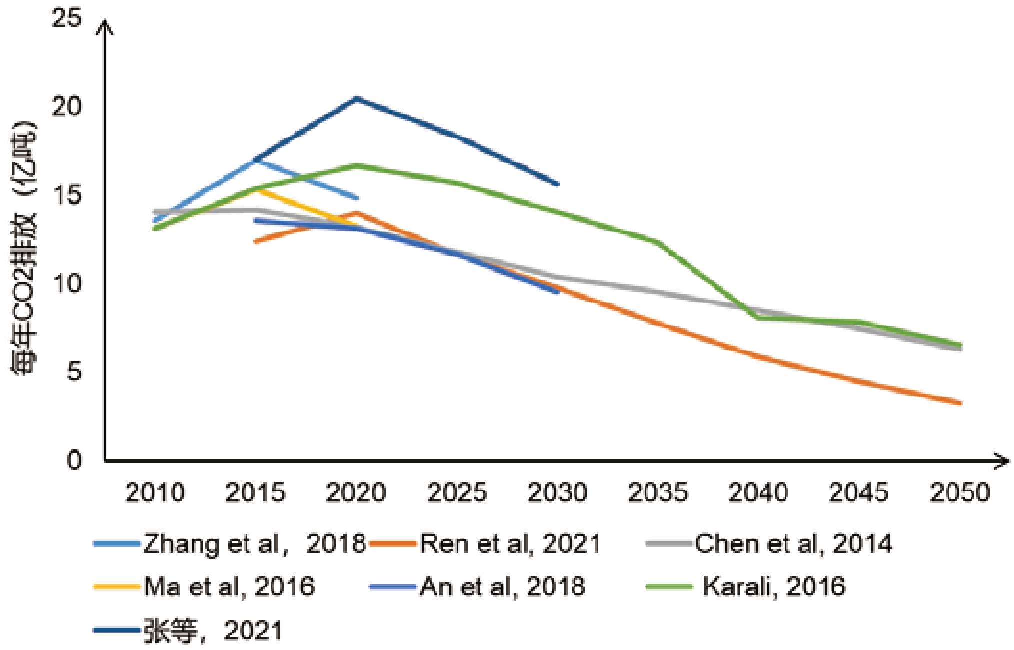
A unified and complete China life cycle model is established considering differences in various test conditions to provide a data check and harmonizing method for fuel economy for medium-and heavy-duty truck(MHDT), taking into account the differences in MHDTs weight classes, usage scenarios and power systems. Different penetration scenarios for alternative fuels are established to predict changes in MHDT fleets. The results show that hydrogen sources substantially impact the emission reduction potential of MHDTs. Renewable electrolysis and by-product hydrogen can reduce GHG emissions by 29.0–52.4%. Other hydrogen pathways, which rely on hydrogen transportation and storage technologies, will present the opportunity for emission reduction only after the grid becomes low-carbon. In terms of vehicle models, the battery mass of battery-electric MHDT accounts for over 15% of their curb weight, weakening their emission reduction benefit. By contrast, fuel cell Class 8 trucks may maximize emission reductions because of its lower mass of equipment. Under different scenarios, the MHDT fleet is expected to cut emissions by 12.1–69.9% by 2050. However, overly aggressive adoption of hydrogen could lead to an increase in emissions from 2020 to 2040. Thus, comprehensive consideration of the large-scale promotion of FC-MHDTs combined with China's energy transition and technological development is suggested.

Paper Highlight

· Integral GHG emission life cycle analysis of hydrogen and fuel cell trucks in China.

· Analyzed the influence of component sizing of 10 medium and heavy truck models.

· Established a harmonizing method to integrate prospective studies of fuel cell trucks worldwide.



Paper Information

Title: Low Carbon Development Pathway of China's Iron and Steel Industry under the Vision of Carbon Neutrality—Consensus and Uncertainty

Authors: LI Jin, XIE Canyang , CAI Wenjia, WANG Can

Publication: Chinese Journal of Evnironmental Management

Publication Date: February 2022

DOI: 10.16868/j.cnki.1674-6252.2022.01.048

Abstract

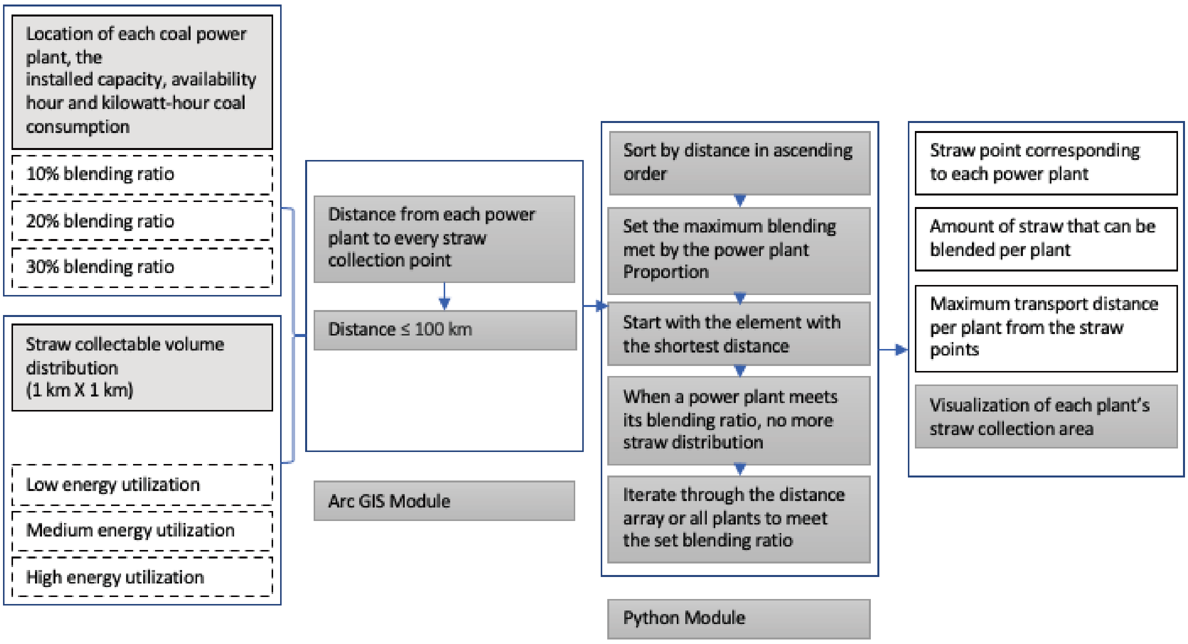
Low-carbon transformation of iron and steel industry plays a vital role in realizing the target of carbon peak and carbon neutrality in China. It is necessary to study its development path and technical roadmap under the "dual carbon" goal in advance. This study introduces the evolving trend of historical carbon emissions in China's iron and steel industry, and summarizes the main technology choices for the iron and steel industry to achieve low-carbon development. Based on the literature review, this study combines the relevant studies on the low-carbon development pathway of China's iron and steel industry in recent years, and comprehensively analyzes their quantitative predictions on the key elements of low-carbon development of iron and steel industry, including crude steel output, scrap steel resources, energy consumption intensity, low-carbon technology application, share of electric furnace steel, carbon dioxide emissions. We also briefly analyzes the similarities and differences of iron and steel industry transformation in China and abroad. Based on the above analysis, this paper puts forward the research needs of the development path of China's iron and steel industry under the "dual carbon" goal.Low-carbon transformation of iron and steel industry plays a vital role in realizing the target of carbon peak and carbon neutrality in China. It is necessary to study its development path and technical roadmap under the "dual carbon" goal in advance. This study introduces the evolving trend of historical carbon emissions in China's iron and steel industry, and summarizes the main technology choices for the iron and steel industry to achieve low-carbon development. Based on the literature review, this study combines the relevant studies on the low-carbon development pathway of China's iron and steel industry in recent years, and comprehensively analyzes their quantitative predictions on the key elements of low-carbon development of iron and steel industry, including crude steel output, scrap steel resources, energy consumption intensity, low-carbon technology application, share of electric furnace steel, carbon dioxide emissions. We also briefly analyzes the similarities and differences of iron and steel industry transformation in China and abroad. Based on the above analysis, this paper puts forward the research needs of the development path of China's iron and steel industry under the "dual carbon" goal.

Paper Highlight

· An overview summarizing the status of low carbon actions and research in the Chinese steel industry.

· summarizes and analyzes the research on key elements of the future low-carbon transition in the steel industry.

· Policy recommendations are made for the study of low carbon development pathways in the Chinese steel industry



Paper Information

Title: Potential analysis of coal-biomass co-firing power generation in China
Authors: ZHENG Dingqian; TIAN Shanjun; MA Sining; CHANG Shiyan
Publication: Clean Coal Technology
Publication Date: June 2022
DOI: 10.13226/j.issn.1006-6772.CC22022801

Abstract

Coal-biomass co-firing power generation(CBCP) can reduce CO_2 emissions and alleviate air pollution. Considering the low energy density of straw resources, the application potential of coal-fired coupled biomass power generation technology largely

depends on the spatial matching between coal-fired power plants and straw resources. Therefore, from the perspective of spatial analysis, it is of great significance to study the potential of coal-fired coupled biomass power generation. The possible potential of coal-fired coupled power generation was evaluated by spatial matching method based on high—resolution coal-fired power plants and straw resource data. The research results show that coal-fired power plants are highly spatial matched with straw resources in China, with about 89% of the collectible straw located within a 100 km radius of coal-fired power plants. The amount of co-fired straw in coal-fired power plants is affected by the energy utilization ratio of straw and the co-firing level of straw in power plants. The higher the energy utilization of straw is and the higher the co-firing level in power plants is, the more straw is that can Ix: co-firing in coal-fired power plants. Under the scenario of the high energy utilization rate of straw and 30% co-firing level, 1 066 power plants can find straw resources within a radius of 100 kin, of which 52.6% of power plants can meet the 30% co-firing level. In this scenario, the power plant can absorb 384 million ton of straw and reduce CO_2 by about 511 million ton. The results can provide technical support for the formulation of technical support policies for coal—biomass co-firing power generation and straw resource utilization policies in China.

Paper Highlight

· Designed spatial matching algorithms between power plants and straw resources.

· Analyzed the potential of coal-fired coupled biomass power generation in different regions.

2. Academic views on policy issues

This section is an excerpt of the insights and suggestions on industry development and policy measures published by the lead faculty members and the research team through interviews and policy proposals under the support of the Centre's flagship project Carbon Neutral Metals. Detailed reports can be accessed by scanning the QR code provided.

How to achieve industrial green development?

Linwei MA: Energy saving and carbon reduction, development of green economy is the key

This article is an interview with Linwei MA on the 14th Five-Year Industrial Green Development Plan, published on December 8, 2021.

To achieve the double-carbon goal, we should adhere to the principle of "no delay, and no rush”

This was part of the keynote speech delivered by Zheng LI , the Executive Vice President of Tsinghua University's Institute of Climate Change and Sustainable Development, at the Development Forum on "Building World-Class Low-Carbon Enterprises". Li said that the transformation of the energy system is the focus and key of the green low-carbon transformation, and that it is crucial and sensible to build coordinated and timely efforts between new energy development and traditional fossil energy transformation in the process of transformation. The article was published on Oct. 27, 2021.

To achieve carbon neutrality, the first thing is to introduce profoundly revolution to the energy system

This article is a speech delivered by Zheng LI, the Executive Vice President of Tsinghua University's Institute of Climate Change and Sustainable Development and the director of Tsinghua University's Low Carbon Energy Laboratory, at the Tsinghua Wudaokou Forum on "Carbon Neutral Economy". In his speech, Li Zheng said that energy use is the main source of carbon emissions, and the first and foremost task to achieve carbon neutrality is to introduce profound revolutions in the energy system. The article was published on September 17, 2021.

Accelerate the construction of infrastructure capacity to create a low-carbon steel and iron park.

The steel industry needs to accelerate breakthroughs in key technological challenges such as hydrogen steelmaking, CCUS and biomass applications; and to explore how to conserve steel demand and build smart energy industrial parks. The promotion of interdisciplinary exchanges and cooperation is essential to achieve these fundamental infrastructural capacities. This article is an interview with Linwei MA on these topics.

Technology options and industry competition promoting carbon neutrality in steel

The low-carbon transition in the steel industry is not only limited to the steel industry itself. It is also necessary to deal with the relationship between economic development, technology choice, and industry competition respectively while ensuring the carbon peak, in which the key is the need to overcome the uncertainty of technology development and investment costs. This article is a transcript of an interview with Xunmin OU on these issues.

Strengthen the research and development of online detection technology to help Wisdom to achieve carbon peak carbon neutrality intelligently

Online monitoring technology is an important direction for China's future development, with energy-saving and efficiency, optimization in processes, help supervision and other functions. Laser Induced Breakdown Spectroscopy (LIBS) technology is a promising technology for online chemical composition testing, which can contribute to the sound operation of the national carbon market and has wide application in the steel industry. It is expected to provide smart support for carbon neutralization. This paper is a This article is an interview with Zongyu HOU on these topics.

How to boost high quality renewable energy development in the new era

this program answers the question

In this article, Linwei MA is interviewed by People's Daily on the Implementation Plan for Promoting the High-Quality Development of Renewable Energy in the New Era. interpreting the key mission of the high-quality development of new energy in the new era. The article was published on June 9, 2022.

3. Industry perspectives on subjects of debate

Carbon neutrality in the metal industry is a complex issue. Although the state has issued many related policies, the implementation of these policies still depends on the actual situation in the industry. This report collected the industry views by the interview, and shares them with readers.

1. Low-carbon development of the steel industry should balance the relationship between economic development and emission reduction, and pay more attention to the sustainable development of the industry. The low-carbon development of the steel industry is not a simple issue of energy conservation and environmental protection, but involves the development pattern of the whole industry. It is a dynamic, continuous process. Emissions must be reduced in the development process, and vice versa. For example, while reducing emissions, China also faces the pressure of rising steel production. The steel industry strives to reach the carbon peak in the 14th Five-Year Plan period means that it requires a lot of hard work.

2. The low-carbon development of the steel industry must be measured from a lifecycle perspective, and make technical arrangements for the whole industry chain and long-term development. The steel industry has a long industry

chain, which includes ore mining, coke production, smelting and processing, and product use. It is necessary to consider carbon reduction from the life-cycle perspective. In view of the characteristics of China's steel industry, it is necessary to accelerate the development of carbon reduction technology for the "BF/BOF" route at the present stage, and strengthen the carbon emission reduction on the raw material side and the material saving on the demand side. Considering the quality of electric furnace steelmaking products and the availability of scrap steel, it is important to accelerate the research and development of major emission reduction technologies such as hydrogen steelmaking, but it will take time for these technologies to mature.

3. Low carbon development in the steel industry is a multidisciplinary matter that requires pragmatic cooperation across multiple disciplines, including resources, energy, and the environment. Low carbon development in the steel industry involves not only metallurgical expertise, but also cross-disciplinary expertise such as in the field of energy, chemicals, environment, and carbon capture, utilization and storage. To this end, it is hoped that universities can enhance communication with the industry, work together toward practical cooperation, and make positive contributions to the realization of the decarbonization of the whole steel chain. It is expected to focus on the two key elements of resource and energy, by combining national policies, industry development, and enterprise needs, to conduct research on relevant topics.

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