Review of China's Industrial Low-Carbon Transition Policies

Jifeng Li[1,*], Xue Han[2], Chenglong Zhang[3], Yingkang Lyu[4], Jinyu Chen[5]

[1]Institute for Resources and Environmental Policies, Development Research Center of the State Council of China, Beijing, China

[2]Institute for Resources and Environmental Policies, Development Research Center of the State Council of China, Beijing, China

[3]State Grid Energy Research Institute, Beijing, China

[4]Infinite-Sum Modelling CO. LTD., Shenzhen, Guangdong, China

[5]Institute of Economy and Technology of State Grid Fujian Electric Power CO. LTD, Fuzhou, Fujian, China

*Corresponding author

Keywords: Industry, Carbon emissions, Energy, Low-carbon transition, Achievements, Goals

Abstract: Achieving China's carbon peaking and carbon neutrality goals requires a comprehensive and profound systemic transformation. The green and low-carbon transition of the industrial sector is an essential path to balance development and emission reduction, posing a significant challenge. Research indicates that since the 11th Five-Year Plan period, China has placed great emphasis on industrial energy conservation. Through optimizing industrial structures, setting technical standards, and implementing a series of policies and actions, significant achievements in energy conservation have been realized. The carbon intensity of major energy-intensive industries has shown a continuous downward trend. To meet the requirements of carbon peaking and carbon neutrality, it is necessary to systematically promote the low-carbon transition on the foundation of industrial energy conservation. Based on existing studies, it is evident that major energy-intensive industries in China must adopt a combination of structural optimization, advancements in energy-saving technologies, recycling, and energy decarbonization measures to effectively support the national carbon peaking goals. However, the low-carbon transition in the industrial sector currently faces challenges such as relatively weak material and process foundations, the misalignment of mainstream business models with low-carbon requirements, technological innovation bottlenecks, low consumer awareness of sustainable consumption, and significant pressure for a just transition. Accordingly, the preliminary policy framework for China's industrial low-carbon transition needs to be more targeted and synergized.

1. Introduction

On September 22, 2020, the Chinese leader announced at the General Debate of the 75th United Nations General Assembly: "China will scale up its nationally determined contributions by adopting more vigorous policies and measures, striving to peak carbon dioxide emissions before 2030 and achieve carbon neutrality before 2060." This declaration demonstrated China's role as a responsible major country. However, achieving the dual-carbon goals entails a comprehensive and profound transformation, which cannot be accomplished with ease. To this end, President Xi emphasized the need to "correctly understand and accurately address carbon peaking and carbon neutrality" and stated, "Green and low-carbon development is a complex project and a long-term task for the comprehensive transformation of economic and social development. The carbon peaking and carbon neutrality goals must be unwaveringly pursued, but cannot be achieved in one stroke; instead, they require steady progress." Achieving carbon neutrality will inevitably lead to profound changes in China's energy system, national economy, and production and consumption patterns.

The report of the 20th National Congress of the Communist Party of China outlined a grand blueprint for the future, aiming to comprehensively advance the great rejuvenation of the Chinese

  DOI: 10.25236/icssem.2025.070

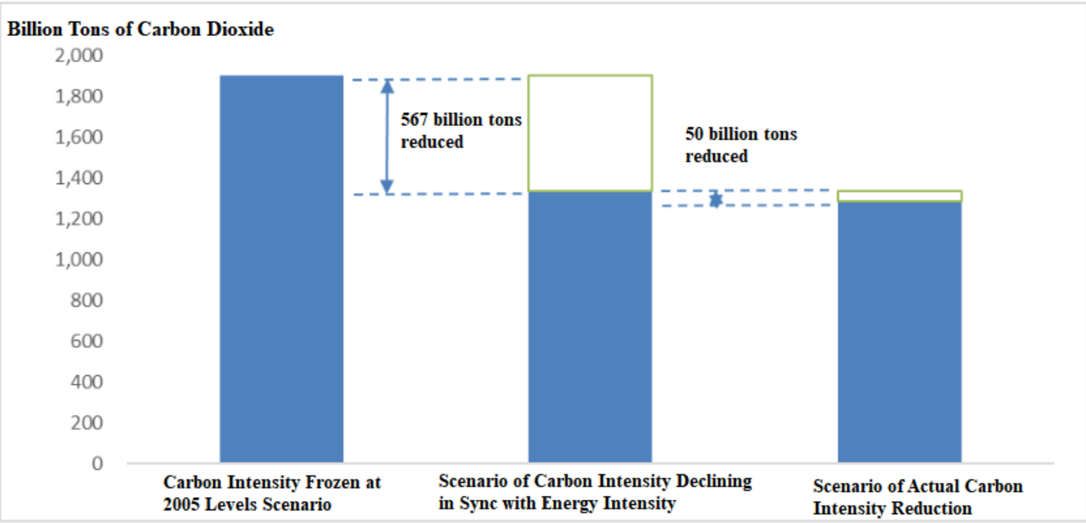
nation through Chinese modernization. It also proposed a "two-step" strategic arrangement for building a modern socialist country in all respects by the middle of the 21st century. Within the new development pattern that prioritizes the domestic circulation while promoting the mutual reinforcement of domestic and international circulations, industry will undoubtedly remain a pillar of economic development in the long term. The industrial sector's contribution to the economy is expected to remain above 30% for an extended period. Therefore, promoting the green and low-carbon transition of industry is an indispensable path for balancing development and emission reduction, representing a daunting yet crucial task. The Chinese government has long attached great importance to industrial energy conservation and carbon reduction, enacting a series of policies and achieving remarkable results. Moving forward, guided by the dual-carbon goals, China must unwaveringly advance the low-carbon transition of its industrial sector.

2. Analysis of China's Industrial Decarbonization Policies and Achievements (2005-2020)

2.1. Trends in Carbon Emissions and Carbon Intensity (2005-2020)

Since becoming a party to the United Nations Framework Convention on Climate Change in 1992, China has actively promoted energy conservation and emission reduction efforts[1-2] (Bo Fan et al., 2018; Wu et al., 2020). Notably, since the 11th Five-Year Plan first proposed achieving "results in controlling greenhouse gas emissions," China has made significant progress in carbon reduction. According to the 2021 Report on Chinas Policies and Actions for Addressing Climate Change, China's carbon intensity in 2020 decreased by 48.4% compared to 2005, exceeding the pledged target of 40%-45% reduction to the international community. This achievement fundamentally reversed the rapid growth trend of carbon dioxide emissions.

Based on data from the Third National Communication on Climate Change and the Second Biennial Update Report on Climate Change, and using 56.65 billion tons of carbon dioxide emissions from energy activities in 2005 as the baseline, Chinas emissions reached 89.2 billion, 94.7 billion, and 94.5 billion tons of carbon dioxide in 2015, 2019, and 2020, respectively (See Figure 1). The total carbon emissions from 2005 to 2020 are estimated to be 128.2 billion tons of carbon dioxide (Ministry of Ecology and Environment, 2018)[3-4].



Source: Calculated by the authors based on publicly available data.

Figure 1. Analysis of Cumulative Carbon Dioxide Emissions (2005-2020)

Had carbon intensity remained at the 2005 level, with the actual GDP growth rate, Chinas cumulative carbon emissions from 2005 to 2020 would have reached approximately 190 billion tons of carbon dioxide. This indicates that by actively promoting industrial structure optimization, advancing energy conservation and emission reduction in key industries, and striving to develop clean energy, China cumulatively reduced carbon dioxide emissions by 61.7 billion tons over 15 years, equivalent to a 32.5% reduction[5] (Li Jifeng et al., 2021). Among these reductions, measures such as industrial structure adjustments and energy efficiency improvements contributed approximately 56.7 billion tons of carbon dioxide reductions, accounting for 91.9% of the total, while clean energy measures contributed 5 billion tons, with a contribution rate of 8.1%.

2.2. Development of China's Industrial Energy Conservation and Carbon Reduction Policies

The 11th Five-Year Plan proposed the goals of building a resource-conserving and environmentally friendly society and embarking on a new path of industrialization. With the inclusion of ecological civilization into the "five-sphere integrated plan," national development strategies and plans have gradually clarified and deepened requirements for green industrial development. From 2005 to 2020, China's industrial energy conservation and carbon reduction policies primarily focused on the following three aspects:

2.2.1. Policies for Promoting Industrial Structure Optimization and Upgrading

Since the Decision of the State Council on the Promulgation and Implementation of the Interim Provisions on Promoting Industrial Structure Adjustment in 2005, China has continuously introduced a series of policies aimed at optimizing and adjusting industrial structures. These measures targeted the elimination of outdated and energy-intensive capacities while consistently driving industrial structure optimization and upgrading. Starting in 2005, the government began issuing updated versions of the Guiding Catalogue for Industrial Structure Adjustment, categorizing industries into encouraged, restricted, and eliminated categories. The latest version, the fifth edition, was released in 2021.

Additionally, the Strategic Emerging Industries Classification was issued by the National Bureau of Statistics in 2018, and the Guiding Catalogue for Green Industries was introduced by the National Development and Reform Commission in 2019. Alongside these catalogs, supporting policies for investment, financing, and taxation were implemented, effectively guiding industrial investment toward strategic directions.

2.2.2. Enhancement of Energy Conservation and Green Development Standards in Industry

Since 2008, China has systematically developed energy consumption limit standards for unit products, covering seven major categories: steel, coal, electricity, petrochemicals, nonferrous metals, building materials, and general-purpose standards. For each category, three benchmark values were established: maximum allowable value, entry value, and advanced value.

According to the Notice on Further Strengthening the Update, Upgrade, and Application of Energy Conservation Standards, issued by the National Development and Reform Commission and the State Administration for Market Regulation in 2023, China has implemented 108 mandatory national standards for energy consumption limits, 66 mandatory national energy efficiency standards, and 190 recommended national energy conservation standards. These efforts have established a comprehensive energy conservation standard system, providing strong legal support for accelerating energy conservation initiatives across various industries.

2.2.3. Implementation of Energy Conservation Policies and Actions

In 2015, the State Council's Made in China 2025 identified "comprehensively promoting green manufacturing" as one of its nine strategic priorities. Key initiatives included the Green Manufacturing Project, green product promotion, and industrial resource recycling[6] (Ministry of Industry and Information Technology, 2021).

By 2020, China had established 2,121 green factories, 171 green industrial parks, and 189 green supply chain enterprises. Over 20,000 types of green products, as well as more than 4,000 energy-saving, water-saving, and resource recycling technologies and equipment, had been promoted. The total output value of the environmental protection equipment manufacturing industry achieved an average annual compound growth rate exceeding 10%. A series of industrial resource recycling bases with significant demonstration effects were constructed, with a comprehensive utilization rate of general industrial solid waste reaching 55.4%, and the volume of recycled resources utilized reaching approximately 380 million tons.

2.3. Analysis of China's Industrial Carbon Emission Reduction Achievements

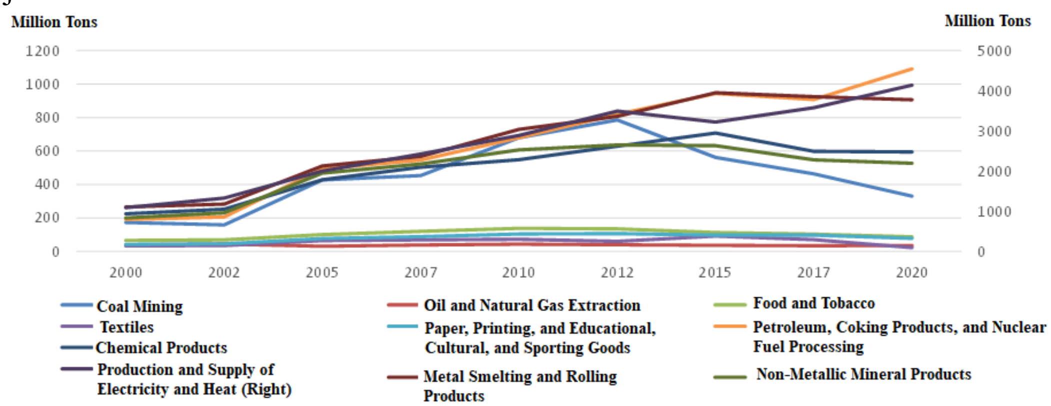
To objectively evaluate the implementation of the aforementioned industrial energy conservation and carbon reduction policies, this study assesses industrial emission reduction outcomes using two indicators: sectoral carbon emissions and carbon intensity trends. The analysis is based on data from Chinas energy statistics and input-output tables (National Energy Administration, Energy Statistics Division, 1990–2021; National Bureau of Statistics, National Economic Accounting Division, 1992–2020). Using annual energy statistics yearbooks, we collected data on energy consumption by type for 25 industrial sectors since 1995. Following established carbon emission accounting methods[7] (Liu Zhu et al., 2018), sectoral carbon emissions were calculated. The industrial sector includes the power sector, where coal and natural gas consumption for electricity generation are attributed to the power sector. To avoid double counting, emissions from other industries consider only direct consumption of coal, petroleum products, and natural gas, focusing on direct carbon emissions from production processes.

Due to the unavailability of publicly detailed annual value-added data by sector, this study mainly relies on sectoral value-added data from input-output tables. Since 2000, China has released input-output tables for nine years: 2000, 2002, 2005, 2007, 2010, 2012, 2015, 2017, and 2020. To address discrepancies in sector classifications and data granularity between energy consumption statistics and input-output tables across different years, this study adopts the 2020 classification as the baseline, aligning energy consumption and sectoral classifications for unified analysis. The unified analysis focuses on these nine years. The results for carbon emissions from industrial energy use by sector from 2000 to 2020 are summarized as follows:

2.3.1. The Industrial Sector as the Dominant Source of Carbon Emissions

The industrial sector has consistently been the largest contributor to China's carbon emissions, especially high-energy-consuming industries (See Figure 2). The analysis indicates that the industrial sector accounts for over 80% of China's energy-related carbon emissions, maintaining approximately 85% since 2005. This is primarily due to the increasing share of carbon emissions from power generation, heating, and the gas sector, which rose from 36% of total national energy carbon emissions in 2000 to 44% in 2020. In contrast, the direct carbon emissions share of the manufacturing sector has remained stable at around 35%-40%.

Among industrial energy carbon emissions, the top 10 emitting sectors include power generation and heating, petrochemical refining, metal smelting, chemical manufacturing, non-metallic mineral products, coal mining, wholesale and retail, agriculture, food processing, and textiles and apparel. In terms of trends, the coal mining sector reached its peak emissions between 2010 and 2015, thanks to improvements in the utilization of coal gangue. However, sectors like power generation and heating and petrochemical refining continue to show increasing emissions, while emissions in the remaining seven major sectors have stabilized.



Source: Calculated by the authors based on publicly available data.

Figure 2. Sectoral Carbon Emission Trends (2000–2020)

2.3.2. Sectoral Carbon Intensity Trends Show Significant Divergence

To compare carbon intensity both horizontally and longitudinally across sectors, sectoral value-added data from input-output tables were adjusted to constant 2020 prices using the producer price index for industrial products published in Chinas Statistical Yearbook. This index, available since 1989, provides continuous price indices for eight product categories: fuels and power, ferrous metal materials, non-ferrous metal materials and wires, chemical raw materials, wood pulp, building materials and non-metallic products, agricultural and sideline products, and textile raw materials.

The results indicate significant variations in carbon intensity across sectors. In 2020, the carbon intensities of the power generation and heating sector and the petrochemical refining sector were the highest, at 17.2 tCO_2/10,000 yuan and 9.6 tCO_2/10,000 yuan, respectively. Other high-intensity sectors included metal smelting (3.5), coal mining (3.9), non-metallic products (3.5), chemical manufacturing (2.0), and petroleum and natural gas extraction (1.6 tCO_2/10,000 yuan), all of which exceeded the national average of 0.9 tCO_2/10,000 yuan. Most other sectors were significantly below the national average.

From a longitudinal perspective, carbon intensity in most sectors has shown a declining trend since 2000, with the average carbon intensity in 2020 approximately 80% lower than in 2000. However, the reduction rates for the power generation and heating sector and the petroleum and natural gas extraction sector were relatively low, at just 60%. During the early years following China's accession to the WTO in 2002, some sectors even experienced temporary increases in carbon intensity.

2.3.3. The Power Sector Shows Noticeable Fluctuations in Carbon Intensity Trends

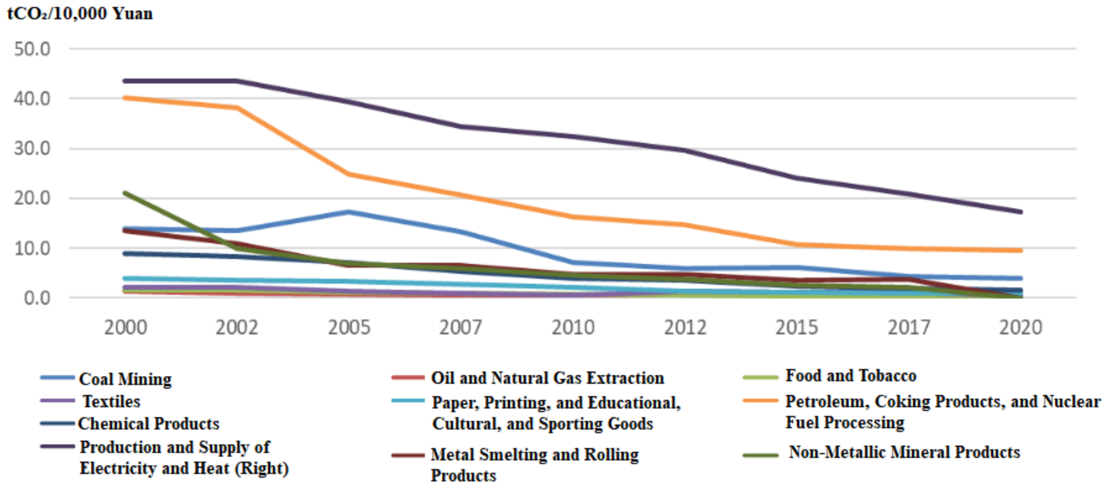
From 1995 to 2002, the carbon intensity of the power sector consistently declined, but it increased between 2002 and 2012 before entering a new phase of steady decline after 2012. During the 2002－2012 decade, China experienced rapid growth in coal-fired power capacity, and the average coal consumption for power generation decreased continuously, dropping from 392 grams of standard coal per kilowatt-hour in 2000 to 325 grams in 2012. However, market-driven coal price increases, coupled with the rising operating costs in the power sector due to subsidies for the rapid development of non-fossil energy, led to a decline in the profitability of the power industry. A detailed analysis indicates that the primary reasons for the increase in carbon intensity during this period were the transition between old and new technologies and the rise in fuel prices, which weakened the profitability of the power sector. After 2012, with strengthened environmental pollution control, the growing issue of coal overcapacity suppressing market prices, and the rapid decline in renewable energy generation costs, the carbon intensity of the power sector began to steadily decrease.

2.3.4. The Petrochemical and Coking Sector Exhibited a Pattern of Rising and Then Declining Carbon Intensity

Although petroleum refining and coal coking are categorized as two separate industries in energy statistics, they are combined as energy processing and conversion industries in the input-output tables. From the perspective of carbon intensity trends, the period from 2000 to 2005 saw a significant rise in carbon intensity, driven by strong domestic demand and exports. During this time, China entered a phase of rapid growth, with accelerated real estate development and continuous infrastructure construction increasing the demand for coke in the steel industry. The rapid expansion of coking enterprises resulted in a continuous rise in carbon intensity. Subsequently, technological advancements led to a steady decline in the carbon intensity of the petrochemical and coking industries, though as of 2020, it had not yet fallen below the low point recorded in 2000.

2.3.5. Carbon Intensity in High-Emission Industries, Including Chemicals, Metallurgy, Building Materials, and Paper Manufacturing, Has Generally Shown a Steady Decline

Overall, since 2005, industrial energy conservation and carbon reduction policies have effectively driven continuous declines in carbon intensity across various industries (See Figure 3). These policies have created a favorable regulatory environment and fostered strong awareness among industrial enterprises regarding energy conservation and carbon reduction, yielding significant emission reduction achievements. However, the recent slowing pace of carbon intensity reduction in many high-emission industries reflects a marginal decrease in their energy conservation and carbon reduction potential. This indicates that future industrial carbon reduction will require innovative strategies and new measures.



Source: Calculated by the authors based on publicly available data.
Figure 3. Trends in Sectoral Carbon Intensity (2000–2020)

3. Industrial Low-Carbon Transition Policies Toward Carbon Peaking by 2030

On September 22, 2020, China introduced several industrial low-carbon transition policy documents and formulated relevant laws and regulations. These policies emphasized "deep implementation of intelligent and green manufacturing projects, promoting high-end, intelligent, and green development in the manufacturing sector" and suggested aligning with future industrial transformation directions by "building strategic and globally significant industrial chains" and "fostering and strengthening new drivers for industrial development." China's policy and legal framework for industrial low-carbon transition is gradually being refined.

3.1. Strategic Plans, Policies, and Legal Frameworks for Industrial Low-Carbon Transition in China

Since 2021, guided by the strategic goals of carbon peaking and carbon neutrality, China has strengthened top-level design and professional guidance, resulting in the rapid improvement of the strategic, policy, and legal framework for industrial low-carbon transition (see Table 1).

Table 1 Major Policy Documents for China's Industrial Green Development Since 2021

Order Number	Release Time	Name	Reference Number
1	February 02,2021	Guidelines on accelerating the establishment and improvement of a green, low-carbon and circular economic development system	No.4,2021
2	September 03,2021	Guidelines on strengthening industry integration and promoting green development of industry	Ministry of Industry and Information Technology no. 159,2021
3	On November 15,2021	The 14th Five-Year Plan for green industrial development	The Ministry of Industry and Information Technology regulations no. 178,2021
4	On November 30,2021	Implement the implementation plan of achieving carbon neutrality and promote the green and high-quality development of new infrastructure such as data centers and 5G	No.1742,2021
5	On December 21,2021	The "14th Five-year Plan" raw material industry development plan	The Ministry of Industry and Information Technology no.

			212,2021
6	On December 31,2021	Action Plan for Innovation and Development of Smart Photovoltaic Industry (2021-2025)	Ministry of Industry and Information Technology No.226,2021
7	January 13,2022	Action Plan for high-quality Development of Environmental Protection Equipment Manufacturing Industry (2022-2025)	Ministry of Industry and Information Technology 2021
8	January 15,2022	Notice on the release of the Green Manufacturing List in 2021	Department of Industry and Information Technology Section Letter no. 2022 No.7
9	January 20,2022	Guidelines on promoting the high-quality development of the iron and steel industry	The Ministry of Industry and Information Technology, no. 6,2022
1 0	January 27,2022	The implementation plan for accelerating the comprehensive utilization of industrial resources	The Ministry of Industry and Information Technology no. 9,2022
11	June 23,2022	Action plan for improving industrial energy efficiency	The Ministry of Industry and Information Technology no. 76,2022
12	July 07,2022	Implementation plan of carbon peak in industry	The Ministry of Industry and Information Technology no. 88,2022
13	August 22,2022	Action Plan for Green and Low-carbon Development of the Information and Communication Industry (2022-2025)	Ministry of Industry and Information Technology No.103,2022
14	August 24,2022	We will accelerate the action plan for green, low-carbon and innovative development of power equipment	Ministry of Industry and Information Technology no. 105
15	January 17,2023	Guidelines on promoting the development of the energy and electronics industry	Ministry of Industry and Information Technology No.181,2022

In terms of industrial low-carbon transition strategies, the State Council issued the Guiding Opinions on Accelerating the Establishment and Improvement of a Green, Low-Carbon, and Circular Economy System in 2021. This document, for the first time, proposed a systematic approach to building a green, low-carbon, and circular economy system from the full chain of production to consumption. It focuses on six aspects: production, distribution, consumption, infrastructure, green technologies, and legal and regulatory policies. The document systematically outlines requirements such as "green planning, green design, green investment, green construction, green production, green distribution, green living, and green consumption." This approach aligns with the objective laws of industrial development and clarifies the internal logic of establishing a green, low-carbon, and circular economy system. The 14th Five-Year Plan for Green Industrial Development emphasizes achieving carbon peaking and carbon neutrality goals, further strengthening seven key tasks: "deeply implementing green manufacturing, accelerating industrial structure optimization and upgrading, promoting energy conservation and carbon reduction in industry, comprehensively improving resource utilization efficiency, actively advancing clean production retrofits, and enhancing the supply capacity of green low-carbon technologies, green products, and services." Building on these, the Implementation Plan for Carbon Peaking in the Industrial Sector highlights practical pathways. It proposes achieving carbon peaking breakthroughs in key industries, constructing a green manufacturing system, improving resource and energy utilization efficiency, promoting the integration of digital, intelligent, and green technologies, and expanding the supply of green low-carbon products.

In terms of policy support, China has developed and improved specific carbon reduction policies for energy-intensive industries, such as steel, building materials, petrochemicals, and non-ferrous metals, with carbon peaking implementation plans for these key sectors. For broader green industrial transformation and low-carbon development, China has introduced a series of action plans, including the Action Plan for Innovative Development of the Smart Photovoltaic Industry, the Action Plan for

High-Quality Development of the Environmental Protection Equipment Manufacturing Industry, the Action Plan for Improving Industrial Water Efficiency, the Action Plan for Improving Industrial Energy Efficiency, the Green Low-Carbon Development Action Plan for the Information and Communication Industry, and the Action Plan for Accelerating Green Low-Carbon Innovation and Development of Power Equipment. Additionally, the Guiding Opinions on Strengthening Industry-Finance Cooperation to Promote Green Industrial Development specifies key tasks for supporting green industrial development in the financial sector. The Guiding Opinions on Promoting the Development of the Energy Electronics Industry outlines the goal of cultivating an energy electronics industry ecosystem and fostering its development.

In terms of legal and regulatory support, since 2020, China has revised several environmental protection laws and regulations, such as the Law on the Prevention and Control of Environmental Pollution by Solid Waste. These laws include provisions related to low-carbon development, such as Article 3 of the Solid Waste Pollution Prevention and Control Law, which mandates the promotion of green development, clean production, and a circular economy. These legal provisions establish a foundation for implementing policies, standards, and action plans.

From the above plans, policies, and legal frameworks for green industrial development and low-carbon transition, it is evident that China emphasizes the organic integration of industrial development and carbon reduction. This emphasis is reflected in six key aspects: adjusting industrial layouts to curb blind development of high-energy-consuming projects, optimizing the scale of key industries, and promoting low-carbon industrial synergy; adjusting industrial energy use structures, accelerating the construction of industrial microgrids, implementing carbon reduction and energy-saving retrofits, and strengthening supervision; establishing green factories, constructing green low-carbon supply chains, creating green low-carbon industrial parks, and developing productive services such as green low-carbon evaluation and clean production audits and assessments; promoting the substitution of low-carbon raw materials, enhancing recycling of renewable resources, advancing remanufacturing of electromechanical products, and improving comprehensive utilization of industrial solid waste; deploying frontier technology research, promoting low-carbon technologies, and conducting pilot demonstrations to accelerate green low-carbon technological transformation in industries; and promoting the deep integration of new-generation information technology and manufacturing, establishing a digital carbon management system, and advancing models like "Industrial Internet + Green Low-Carbon" to proactively drive digital transformation in the industrial sector.

3.2. Analysis of Existing Policy Goals and Corresponding Measures

3.2.1. Five Quantitative Goals Set by Current Policies

(1) Carbon Emission Reduction Control Goals

This includes reducing carbon dioxide emissions per unit of industrial added value by 18% and achieving phased results in controlling the total carbon emissions of key industries such as steel, non-ferrous metals, and building materials.

(2) Pollution Emission Control Goals

These goals aim to continuously strengthen the capacity for controlling harmful substances at their source, significantly improve the level of clean production, and reduce the intensity of major pollutant emissions in key industries by 10%. Specific targets include completing ultra-low emission retrofits for 530 million tons of steel capacity, clean production retrofits for 460 million tons of coking capacity, and clean production retrofits for approximately 4,000 non-ferrous metal kilns.

(3) Energy Efficiency Improvement Goals

These goals include continuously improving resource productivity in key industries, reducing energy consumption per unit of industrial added value by 13.5% for large-scale industries, and ensuring that energy consumption per unit of key industrial products, such as crude steel, cement, and ethylene, reaches world-class levels. Additional targets include reducing comprehensive energy consumption per unit of information flow by 20% compared to the end of the 13th Five-Year Plan and ensuring that more than 70% and 80% of newly installed high-efficiency motors and transformers, respectively, are in use by 2025.

(4) Recycling and Comprehensive Utilization Rate Goals

These goals aim to achieve a comprehensive utilization rate of 57% for major industrial solid waste by 2025, increasing further to 62% by 2030. The utilization rates for smelting slag (excluding red mud) and industrial by-product gypsum are targeted at 73% each. The total recovery and utilization of major recyclable resources is expected to reach 480 million tons, with specific targets for scrap steel (320 million tons), waste paper (60 million tons), and waste non-ferrous metals (20 million tons). Among these, the production of recycled copper, aluminum, and lead is targeted at 4 million tons, 11.5 million tons, and 2.9 million tons, respectively. Additional goals include establishing a relatively complete recycling system for power batteries and cultivating 50 remanufacturing solution providers.

(5) Green Manufacturing System Development Goals

These goals include establishing basic green manufacturing systems in key industries and regions, creating a batch of ecological (green) design demonstration enterprises, and promoting tens of thousands of green products. The total output value of the green environmental protection industry is targeted to reach 11 trillion yuan, with the environmental protection equipment manufacturing sector aiming for an output value of 1.3 trillion yuan.

3.2.2. Major Policy Measures Defined in Current Policy Documents

(1) Administrative Supervision and Management Measures

In the field of energy conservation, measures include energy assessment reviews for new projects, periodic energy conservation supervision and inspections, energy conservation law enforcement, and energy audits. These measures will be further strengthened and standardized, with expanded supervision coverage and innovative regulatory methods, such as exploring cross-regional energy conservation supervision.

In the field of green manufacturing, measures include green design evaluations, comprehensive utilization evaluations for industrial solid waste resources, green certification and star ratings for green products, and mandatory standards for controlling harmful substances. Efforts are also being made to establish interdepartmental collaborative regulatory mechanisms.

Additionally, policies will promote third-party certification and consulting services for green low-carbon development evaluations and clean production audits tailored to the needs of small and medium-sized enterprises (SMEs). Social evaluation agencies conducting third-party evaluations will be subject to lawful supervision and management.

(2) Promotion of Benchmarking and Pilot Demonstrations

Benchmarking and pilot demonstration projects are being established in various fields. These include "super-efficiency" and "zero-carbon" factories in energy conservation and low-carbon fields, pilot demonstrations for industrial wastewater recycling, and lists of enterprises for renewable resource recycling and utilization, industrial resource comprehensive utilization bases, and leading enterprises in industrial resource utilization.

In the field of green manufacturing, pilot projects include specialized and innovative "little giant" enterprises, single champion enterprises in manufacturing, and industrialization demonstrations of breakthrough low-carbon, zero-carbon, and negative-carbon key technologies.

At the regional level, pilot demonstration measures include high-standard construction of the Yangtze River Delta Ecological and Green Integrated Development Demonstration Zone and the Guangdong-Hong Kong-Macao Greater Bay Area's "Clean Production Partnership Program."

(3) Measures to Strengthen Foundational Capabilities

These measures include enhancing technical standards, evaluation methodologies, statistical detection and assessment methods, audit training, and the development of information systems and databases across various fields. Examples include promoting green design evaluation standards, formulating and revising standards for key areas such as low-carbon, energy conservation, water conservation, and resource utilization, and advancing the internationalization of standards for green design, product carbon footprints, green manufacturing, new energy, and new energy vehicles.

Infrastructure developments involve constructing foundational carbon emission databases for key industrial products, hazardous substance databases covering upstream and downstream industries, platforms for green low-carbon data across the full product lifecycle, and public service platforms for green manufacturing.

Efforts also focus on fostering professional carbon accounting institutions and developing production-oriented service industries, alongside establishing a series of innovation centers for manufacturing, industry, engineering research, and technology to support industrial development.

3.3. Analysis of Industrial Low-Carbon Transition Pathways in Existing Policies

3.3.1. Comprehensive Adjustment and Optimization of Industrial Structure and Layout

An analysis of existing industrial low-carbon transition policies reveals that adjusting or optimizing the industrial structure is a critical pathway for the transition. China primarily focuses on two aspects: developing green new industries and upgrading traditional industries (see Table 2).

Table 2 Categories of Industries Encouraged and Restricted in Industrial Green Development Policies*

Overall Direction	Industry category
ENCOURAGE	New energy, new materials, new energy vehicles, green and intelligent ships, green environmental protection, high-end equipment, energy electronics, etc
PLACE RESTRICTIONS ON	We will control the production capacity of steel, cement, plate glass, electrolytic aluminum, petrochemical and chemical industries (urea, ammonium phosphate, calcium carbide, caustic soda, and yellow phosphorus), and accelerate the green upgrading of iron and steel, non-ferrous metals, petrochemicals, building materials, textiles, light industry, and machinery.

Source: Compiled by the author based on publicly available information

Promoting the Development of Green New Industries. This includes three specific approaches:

1) Increasing the supply of green low-carbon products and environmental protection equipment. Examples include new energy vehicles, photovoltaic and solar thermal products, green building materials, energy-saving, water-saving, efficient, and safe smart home appliances, and other green consumer electronics; industrial energy-saving equipment such as high-efficiency heating systems and residual energy utilization equipment; industrial environmental protection equipment for wastewater, flue gas, and solid waste treatment; equipment for source classification, process control, and end-of-line treatment; and rural energy-saving and environmental protection equipment such as biomass energy systems and agricultural film pollution control.

2) Creating green consumption scenarios. Measures include promoting e-commerce platforms to establish special zones for selling green low-carbon products, encouraging enterprises to organize public open days on green low-carbon topics, and incentivizing green consumption through subsidies and reward points. These efforts aim to foster a green production and consumption model.

3) Developing green low-carbon service industries. This involves cultivating service industries in areas such as green manufacturing, low-carbon development, digital twins, and third-party certification and evaluation. Services provided include consulting, metering, monitoring, process management, analysis, evaluation, inspection, certification, auditing, and training.

Promoting the Green and High-End Upgrading of Traditional Industries. This includes two specific approaches:

1) Eliminating outdated production capacity. For energy-intensive, high-emission industries with excess capacity, measures include strengthening energy efficiency design requirements, strictly controlling production capacity, and implementing "dual controls" on energy consumption to curb blind development.

2) Encouraging relocation of energy-intensive industries. Industries such as electrolytic aluminum and industrial silicon are encouraged to relocate from coastal areas to regions rich in renewable energy and with strong resource and environmental carrying capacities. These measures aim to enhance green energy supply capabilities in resource-rich areas while guiding ecologically fragile regions to develop specialized and ecological industries suited to local resource conditions.

3.3.2. Promoting Energy Efficiency Through Conservation and Recycling

Advancing energy conservation through technological innovation and strengthening recycling are extensions and refinements of traditional low-carbon transition pathways. Specific measures include:

1) Improving processes and upgrading energy conservation retrofits.

This involves accelerating innovation and application of energy-saving technologies and equipment in key energy-consuming industries, enhancing energy efficiency for industrial kilns, boilers, motors, pumps, fans, compressors, and other critical equipment, and reducing power consumption in data centers and mobile base stations. Additional measures include using big data and artificial intelligence to optimize typical processes, improving recovery of residual energy at high and medium-low temperatures, and exploring large-scale utilization of industrial solid waste such as tailings, fly ash, coal gangue, smelting slag, industrial by-product gypsum, red mud, and chemical waste. Resource cycling among enterprises, industrial parks, and clusters is also strengthened to enhance overall resource utilization.

2) Enhancing the recycling and comprehensive utilization of resources.

Comprehensive recycling of resources, such as scrap steel, non-ferrous metals, plastics, waste tires, waste paper, discarded electronic products, spent power batteries, waste oil, and textiles, is prioritized. High-value waste imports are gradually being reopened. Efforts focus on advancing processing technologies for recycling and transitioning from small-scale operations to a large-scale, technology-driven resource recycling industry to address existing gaps.

3) Leveraging digital tools for resource management.

Digital technologies, such as IoT and big data, are used to enable intelligent data collection, management, and application across the lifecycle of recycled resources. These systems support data analysis, flow monitoring, financial management, and the promotion of the "Industrial Internet + Recycling" model. High-end intelligent remanufacturing is also a focus, particularly for remanufacturing equipment in engineering machinery, heavy machine tools, and internal combustion engines.

3.3.3. Strengthening and Perfecting the Green Manufacturing System

Transforming traditional manufacturing practices comprehensively can establish a sustainable pathway for industrial low-carbon transition. Specific measures include:

1) Building green factories. These focus on green manufacturing technology innovation and integrated application.

2) Developing green industrial parks. By fostering "horizontal coupling and vertical extension," industrial parks aim to construct green low-carbon industrial chains and encourage enterprises within the park to adopt production models based on comprehensive utilization of energy and resources.

3) Establishing green supply chains. Leading enterprises are supported to play a guiding role in supply chain integration and innovation in low-carbon management. Efforts are made to embed green low-carbon concepts throughout the entire lifecycle of products, from design and raw material procurement to production, transportation, storage, usage, and recycling. This comprehensive supply chain management system aims to ensure a sufficient supply of green products.

4. Policy Reflections on Deepening China's Industrial Low-Carbon Transition (2020–2030)

4.1. Challenges in Deepening Industrial Low-Carbon Transition

Despite Chinas solid foundation in energy conservation and emission reduction and the broad scope of existing industrial low-carbon transition policies, several challenges remain. These include relatively weak materials and process foundations, misaligned mainstream business models, persistent technological innovation gaps, and significant pressures for a just transition. These challenges must be addressed to ensure the success of Chinas industrial low-carbon transition in the future.

4.1.1. Weak Foundation in Engineering Materials and Process Optimization

Improving processes and conducting green design face challenges due to the weak foundation in engineering materials. While the application of green, low-carbon materials is growing rapidly in consumer goods and packaging, progress in engineering applications remains slow. Developed countries, with over two centuries of industrialization, have accumulated extensive foundational knowledge and expertise in raw material properties, process optimization, and critical parameter selection—referred to as "Know How."

For example, in electric vehicle (EV) development, aluminum car bodies are often used to replace steel structures, significantly reducing weight and improving range. However, the requirements for impact resistance and fatigue performance vary for different parts, necessitating the use of aluminum materials with precisely matched properties. Additionally, the performance changes of aluminum during deformation in processing must be considered. Currently, much of the aluminum used by Chinese automakers is imported, as domestic suppliers cannot fully meet these needs (Wang Zutang, 2022). This highlights the insufficient accumulation of foundational material knowledge among Chinese industrial enterprises, which will have significant implications for the future industrial low-carbon transition.

4.1.2. Dominance of Cost-Reduction-Oriented Business Models

Chinese enterprises continue to prioritize cost reduction, which poses challenges for innovation and the creation of green products. Low costs have long been the main source of international competitiveness for Chinese products. Over time, most market entities have prioritized cost reduction as a key strategy to enhance competitiveness. However, excessive focus on cost efficiency and low profit margins limits the potential for low-carbon transition. Without administrative interventions, even minimal cost increases associated with low-carbon transition solutions are unlikely to be adopted by market-driven enterprises.

Similarly, midstream enterprises supplying raw materials and components to downstream companies often prefer inventory-based mass production to lower costs rather than order-based, precise production. Without strong government guidance, market mechanisms alone are insufficient to drive comprehensive and effective industrial low-carbon transition.

4.1.3. Dependence on Foreign Technology and Equipment

Technological innovation for low-carbon transition faces multiple challenges, with significant dependence on foreign technology and equipment. While China has prioritized research in areas such as advanced renewable energy, new power systems, safe and efficient nuclear energy, green and efficient fossil energy utilization, and energy digitalization, gaps persist in transitioning traditional energy-intensive industries, accelerating strategic emerging industries, and establishing clean, low-carbon energy systems.

According to the 14th Five-Year Plan for Energy Technology Innovation, two major gaps in energy technology innovation remain: (1) dependence on foreign core components, specialized software, and critical materials, and (2) a lack of original, leading, and disruptive technologies in the energy sector. Sustained investment in technology development and fostering experimental innovation are essential to advancing industrial low-carbon transition.

4.1.4. Lack of Comprehensive Regulations and Standards

Insufficient regulations and standards hinder the institutionalization and formalization of the transition. In carbon peaking and carbon neutrality legislation, China has issued only a few rules and departmental normative documents, such as the Interim Measures for the Administration of Carbon Emissions Trading, the Guide for Enterprise Greenhouse Gas Emission Reporting and Verification (Trial), and the Measures for Enterprise Environmental Information Disclosure by Law. These documents focus on carbon trading but lack specific regulations for industrial low-carbon transition.

The carbon peaking and neutrality standards system is divided into basic general standards, carbon reduction standards, carbon removal standards, and market mechanism standards, with further subdivision into 15 secondary and 63 tertiary subsystems. However, the carbon removal and market mechanism standards subsystems are still underdeveloped, with key industry carbon accounting and verification standards yet to achieve full coverage. To address this, the Implementation Plan for Establishing and Improving Carbon Peaking and Neutrality Standards and Measurement Systems was jointly issued by nine departments in 2022, and the Guidelines for the Construction of Carbon Peaking and Neutrality Standards System were issued in 2023. However, further efforts are needed to complete and refine the standards system.

4.1.5. Social Complexity of Transition in Coal-Dependent Industries

The massive scale of coal-related industries poses challenges for low-carbon transition due to its complex social impacts. Chinas industrial system is heavily reliant on coal as the primary energy source, supported by infrastructure such as coal mining capacity of nearly 5 billion tons, railway networks with over 2.4 billion tons/year transport capacity, and approximately 1.2 billion kilowatts of coal power generation capacity.

On the demand side, in addition to power generation and heating, Chinas crude steel production consumes approximately 600 million tons of coal annually. Phasing out coal will render existing infrastructure stranded assets, potentially increasing energy costs for society. Coal-dependent cities may struggle to cultivate new economic growth points, risking economic recession. Thus, ensuring a "just" transition for related industries and employees while promoting social stability presents significant challenges.

4.2. Policy Recommendations for Deepening Chinas Industrial Low-Carbon Transition

4.2.1. Accelerating the Green Transition of Engineering Materials

Industrial green transition requires promoting the substitution of traditional materials with more green and low-carbon materials. To address the current lack of accumulated research on material performance in China, technologies such as big data and artificial intelligence can be leveraged to simulate the performance of various engineering materials using limited measured data combined with computer simulation techniques. It is recommended to enhance policy support for big data analysis and computer simulation of material performance, thereby laying a solid foundation for the green transition of engineering materials.

4.2.2. Using the Carbon Trading Market to Drive Business Model Transformation

Apart from power generation enterprises already included in the national carbon emissions trading market, traditional high-carbon industries such as petrochemicals, chemicals, building materials, steel, non-ferrous metals, and paper also need to be integrated. Carbon pricing or carbon taxes can effectively push these industries toward low-carbon transition and establish long-term emission reduction expectations. China can accelerate the inclusion of these industries in the carbon trading market or establish a carbon tax mechanism linked to the carbon trading system. For industrial enterprises unable to enter the national carbon market, they can be encouraged to develop additional carbon reductions to participate in carbon credit trading. In this regard, it is necessary to expedite the establishment of a voluntary carbon trading mechanism, creating a favorable institutional environment for a broader range of industrial enterprises to voluntarily undertake green low-carbon transitions.

4.2.3. Optimizing the Model of Low-Carbon Technology Innovation by Leveraging National System Advantages

Low-carbon innovation demands new materials and processes, as well as the integration of digital technologies, necessitating interdisciplinary collaboration. To this end, it is suggested to strengthen the establishment of national laboratories and key laboratories in the "dual-carbon" domain and promote cross-sectoral major science and technology initiatives in this area. By integrating resources from enterprises, universities, research institutions, and financial sectors, and adhering to a demand-driven approach, breakthroughs in key technologies for multi-energy integration can be accelerated.

Efforts should also focus on forward-looking layouts for frontier and disruptive technologies while strengthening fundamental research.

4.2.4. Improving Legal Frameworks and Related Standards

In the legislation for carbon peaking and carbon neutrality, it is proposed to enact a Carbon Peaking and Carbon Neutrality Promotion (Guarantee) Law or a Climate Change Response Law as foundational legislation for industrial low-carbon transition. Based on this, administrative regulations such as the Industrial Green Low-Carbon Transition Regulation, Carbon Emissions Trading Management Regulation, Carbon Tax Collection and Management Regulation, and Carbon Sink Construction and Carbon Removal Regulation can be introduced. Additionally, considering trends in wind and photovoltaic power generation and the development of hydrogen energy and related industries, it is necessary to revise laws and regulations such as the Renewable Energy Law to standardize the industrial low-carbon transition.

In terms of standards, it is recommended to follow the guidelines of the Carbon Peaking and Carbon Neutrality Standards System Construction Guide to complete the subsystems for carbon reduction standards, carbon removal standards, and market mechanism standards within the specified timeline. This will establish foundational standards for accounting methods, accounting rules, and trading rules necessary for nationwide carbon reduction, carbon trading, and carbon tax collection in the industrial sector.

4.2.5. Setting Just Transition Capacity as the Upper Limit for Transition Pace

Considering the critical role of coal in supporting Chinas industrial system, industrial low-carbon transition goals should not be overly aggressive and should be implemented prudently. Policies should aim to steadily define the goals for industrial low-carbon development. At the same time, efforts should focus on expanding the positive externalities of technologies emerging from the transition, maximizing the economic growth potential of industrial transformation, and exploring pathways to offset transition costs through positive externalities.

Acknowledgements

This work was supported by a grant from Manage science and technology projects of State Grid Corporation of China “Research and application of key technologies for multi-regional collaborative emission reduction simulation considering inter-provincial carbon emission transfer” (1400-202357320A-1-1-ZN).

References

[1] Bo Fan, Zhuang Guiyang. Evolution and Stages of China's Climate Change Policies [J]. Yuejiang Academic Journal, 2018, 10(06):14-24+133-134. DOI: 10.13878/j.cnki.yjxk.2018.58.002.

[2] Wu F, Huang N, Liu G, et al. Pathway Optimization of China's Carbon Emission Reduction and Its Provincial Allocation Under Temperature Control Threshold [J]. Journal of Environmental Management, 2020, 271:111034.

[3] Ministry of Ecology and Environment of China. The Third National Communication on Climate Change [R]. Beijing: Ministry of Ecology and Environment (2018-12). https://tnc.ccchina.org.cn/archiver/NCCCcn/UpFile/Files/Htmleditor/202007/20200723152332694.pdf

[4] Ministry of Ecology and Environment of China. The Second Biennial Update Report on Climate Change [R]. Beijing: Ministry of Ecology and Environment (2018-12). https://tnc.ccchina.org.cn/archiver/NCCCcn/UpFile/Files/Htmleditor/202007/20200723155226725.pdf

[5] Li Jifeng, Guo Jiaofeng, Gao Shiji, et al. Pathway Analysis of Achieving Carbon Neutrality in

China Before 2060 [J]. Development Research, 2021, 38(04):37-47.

[6] Ministry of Industry and Information Technology of China. The 14th Five-Year Plan for Green Industrial Development [R]. Beijing: Ministry of Industry and Information Technology (2021-12). http://www.gov.cn/zhengce/zhengceku/2021-12/03/5655701/files/4c8e11241e1046ee9159ab7dcad9ed44.pdf

[7] Liu Zhu, Guan Dabo, Wei Wei. Accounting for Carbon Dioxide Emissions in China [J]. Science China: Earth Sciences, 2018, 48(07):878-887.