

Jiangsu Carbon Neutrality Planning Research

Executive Summary

1. Current economic development and emissions profile

As one of China's leading provincial economies, Jiangsu ranks second nationwide in terms of gross domestic product, accounting for more than 10 percent of the national total. With the effects of the pandemic subsiding, the province achieved a GDP of RMB 12.90 trillion in 2023. General public budget revenue reached RMB 905.9 billion, a 2.9 percent increase from the previous year, of which tax revenue totaled RMB 741.39 billion, up 1 percent. Strategic emerging industries and high-tech industries accounted for 37.8 percent and 46.5 percent of the output value of large-scale industrial enterprises, respectively, and the digital economy exceeded RMB 4 trillion. Industrial restructuring accelerated during this period, with notable progress in cultivating advanced manufacturing clusters and key industrial chains. As a result, the manufacturing base has become more robust, and industrial competitiveness has continued to strengthen. At the same time, however, total carbon dioxide emissions rose rapidly, increasing from 232 million tons in 2000 to 928 million tons in 2023, representing a fourfold increase (Fig. 1).

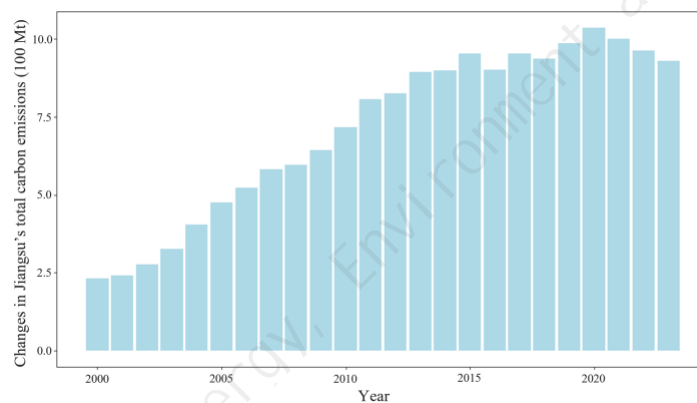


Fig. 1 The trend of total carbon emissions in Jiangsu Province from 2000 to 2023.

From a sectoral perspective, Jiangsu's central challenge lies in the continued dominance of heavy industry. Growth in industrial output remains the primary driver

of rising industrial CO₂ emissions. The largest contributors include coal mining and washing, petroleum processing, coking, and nuclear fuel processing, as well as the manufacturing of chemical raw materials and products, ferrous metal smelting and rolling, and the production and supply of electricity and heat. Together, these sectors account for 88.2 percent of industrial CO₂ emissions. Since the 13th Five-Year Plan period, Jiangsu's sustained efforts to promote low-carbon transformation have led to a gradual decline in industrial CO₂ emissions and a continuous reduction in emissions intensity. Carbon emissions from energy-intensive industries have largely stabilized. Although the secondary sector still accounts for a substantial share of total emissions, its proportion has begun to fall. However, the reductions achieved by the secondary sector have not been sufficient to offset the growing emissions from the tertiary sector, resulting in an overall upward trend in Jiangsu's total CO₂ emissions.

Carbon emissions from Jiangsu's transportation sector increased from 10.1864 million tons in 2000 to 56.1602 million tons in 2014, representing an average annual compound growth rate of 12.97 percent. Highway transportation contributed more than 80 percent of total emissions from the sector and showed a consistent upward trend.

Carbon emissions from the full life cycle of buildings in Jiangsu peaked in 2012 and have since shown an overall decline. Emissions from the building sector decreased from 240.16 million tons in 2002 to an estimated 223.51 million tons in 2026.

Carbon emissions from Jiangsu's crop production sector primarily originate from agricultural soil use, which accounts for 77.73 to 86.95 percent of total emissions. Emissions from agricultural inputs account for the remaining 13.05 to 22.27 percent. Between 2000 and 2020, the net carbon sink in agricultural areas along the Jiangsu Coastal Economic Belt increased from 7.16 million tons to 10.02 million tons. The spatial distribution of carbon storage exhibits pronounced heterogeneity.

From the perspective of Jiangsu's share of national carbon emissions, the province accounts for roughly 10 percent of China's total emissions, a proportion slightly higher than its share of national GDP. The share first declined from 11.15 percent in 2000 to

8.21 percent in 2010, then rose with fluctuations over the following decade. By 2023, Jiangsu's total carbon emissions accounted for 12.33 percent of the national total. In 2024, this pattern remains largely unchanged, with Jiangsu's emissions share continuing to exceed its economic share.

In terms of carbon intensity, Jiangsu has seen a clear downward trend over the past two decades. At the provincial level, carbon intensity has steadily decreased from 2.058 tons per RMB 10,000 of GDP in 2000 to 0.723 tons in 2023, representing an average annual decline of 4.26 percent. Based on current economic trends, Jiangsu's carbon intensity is expected to decline further to approximately 0.670 tons per RMB 10,000 of GDP in 2024.

Across Jiangsu's regions, the low-carbon development pattern of southern, central, and northern Jiangsu generally follows a "higher in the south, lower in the north" distribution. Southern Jiangsu has contributed an increasingly large share of the province's total carbon emissions, while the contributions from central and northern Jiangsu have gradually declined. Per capita emissions, however, show a continued upward trend. Southern Jiangsu serves as the province's core economic zone, characterized by a strong manufacturing base and high industrial output. The region hosts a large concentration of energy-intensive and high-emission sectors such as steel, cement, and petrochemicals, whose production processes typically generate substantial carbon emissions. In contrast, northern Jiangsu has a lower level of economic development and a slower pace of industrialization, with a smaller share of energy-intensive industries and a relatively cleaner energy consumption structure. From 2001 to 2023, all 13 prefecture-level cities in Jiangsu achieved reductions in carbon intensity. The fastest-declining areas include northern cities such as Xuzhou, Yancheng, and Lianyungang, as well as Suzhou. Xuzhou's carbon intensity was 4.43 tons per RMB 10,000 of GDP in 2001, ranking second-highest in the province. Following the implementation of various emissions-reduction policies, its carbon intensity fell to 1.73 tons per RMB 10,000 of GDP by 2023.

2. Carbon neutrality index analysis

This study constructs a composite carbon neutrality index to provide an integrated assessment. The five sub-indicators, including energy consumption, carbon emission level, carbon emission efficiency, carbon rebalancing capacity, and ecological carrying capacity, represent different dimensions of the carbon emission system and help reveal its weaknesses more intuitively. The direction of influence of each sub-indicator on the overall index is shown in Table 1.

Table 1. Indicator system for the carbon neutrality index evaluation.

No.	Primary indicator	Secondary indicator	Calculation method	Indicator direction
1	Energy consumption	Energy intensity	Energy consumption / GDP	-
		Share of clean energy	Clean energy consumption / total energy consumption	+
		Energy dependence	Net energy imports / total energy consumption	-
2	Carbon emission level	Carbon emission intensity	CO ₂ emissions / GDP	-
		National carbon capacity	Total carbon sequestration of different ecosystem types / total area	+
		Localized emission factors	Adjusted based on IPCC emission factors	-
3	Carbon emission efficiency	Input share	Share of economic, labor, and energy inputs	-
			Science and technology investment share	+
		Output share	Share of economic and technology outputs	+
4	Carbon rebalancing capacity	Green technology investment	CO ₂ emissions per unit of output	-
		Pollution co-control capacity	Green technology investment / operating revenue	+
		Share of built-up area	Degree of coordinated reduction of pollutants	+
5	ecological carrying capacity	Urban green coverage	Proportion of built-up urban area Forest, cropland, and grassland coverage	-
		Water area ratio	Share of water surface area	+

Based on the indicator system developed in this study, China's carbon neutrality index experienced a sharp decline in 2012, as shown in Fig. 2, but increased gradually from 2012 to 2024. Since the announcement of the national carbon goals, China has placed strong emphasis on emissions reduction, and a series of policies has accelerated the country's low-carbon transition.

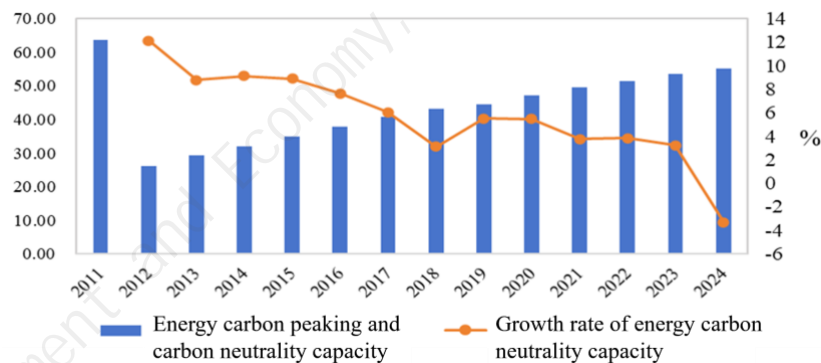


Fig. 2 China's carbon neutrality capacity and growth rate.

Jiangsu's carbon neutrality index has increased steadily since 2010, as shown in Fig. 3. The trend is largely consistent with the national pattern and reflects the effectiveness of the emissions-reduction measures introduced after 2010. After 2020, the index showed slight fluctuations due to the effects of the pandemic and other factors. Continuous monitoring of this indicator is necessary to support timely adjustments to policy strategies.

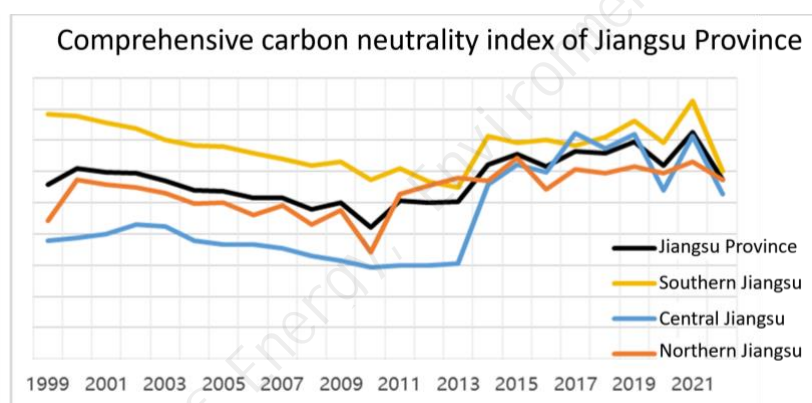


Fig. 3 Jiangsu Province Carbon Neutrality Index.

Across regions, southern Jiangsu shows the most mature progress toward carbon neutrality. Its early phase of rapid growth has gradually shifted toward a stable growth stage, and the convergence trend is clear. The region's strong high-tech industry base provides advantages in energy efficiency and emissions reduction technologies, which support the convergence of its carbon neutrality index. Central Jiangsu lags in carbon neutrality performance. The region can accelerate convergence by strengthening economic cooperation with southern Jiangsu and adopting advanced carbon neutrality technologies and practices. Northern Jiangsu remains relatively balanced. It has neither shown rapid convergence nor clear divergence. Although northern Jiangsu faces challenges in energy transition, it also has opportunities to promote convergence through the development of renewable energy and the expansion of environmental industries. Within Jiangsu Province, cities with higher composite carbon neutrality index scores and relatively balanced development include Nanjing, Suzhou, Wuxi, and Yangzhou. Taizhou and Xuzhou fall toward the lower end. While differences exist across cities, the overall gap is not substantial, as shown in Fig. 4.

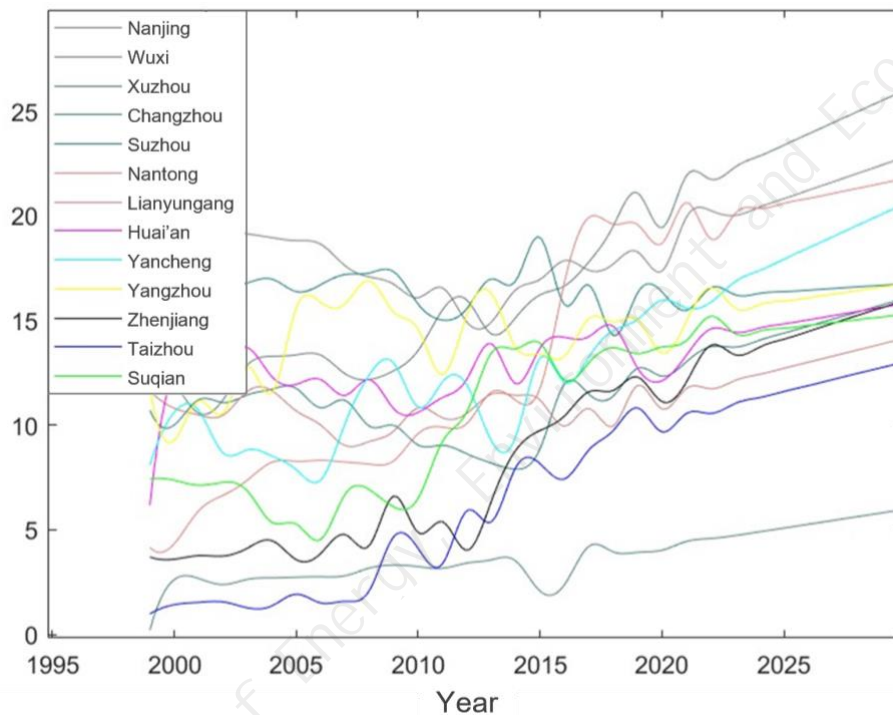


Fig. 4 Trend chart of the comprehensive carbon neutrality index for all cities in Jiangsu Province.

3. Target setting

Based on current carbon emission levels and recent trends, Jiangsu's carbon emissions are expected to continue increasing in the short term. The province is projected to reach its carbon emissions peak between 2030 and 2035. With the adoption of strict targets for reducing carbon intensity and consistent implementation, Jiangsu has the potential to achieve peak emissions before 2030. According to existing studies, Jiangsu's emissions at the time of peaking are estimated to be approximately 930 million tons. After consultation with experts in the energy sector, this estimate appears to be relatively low compared with expected real-world conditions. Taking into account Jiangsu's development trajectory, previous research, and expert input from the provincial Energy Bureau and Department of Ecology and Environment, this report concludes that Jiangsu is likely to peak its carbon emissions around 2035, with peak emissions of roughly 1.05 billion tons. After reaching the peak, emissions will decline steadily. Jiangsu is expected to achieve carbon neutrality by 2060, with emissions falling to about 231 million tons, as shown in Fig. 5, which would reduce the province's share of national emissions to around 8 percent. As low-carbon measures are further implemented, Jiangsu's carbon intensity will continue to decline and is expected to reach approximately 0.404 tons per RMB 10,000 of GDP by 2035 and about 0.041 tons by 2060, as shown in

Fig. 6.

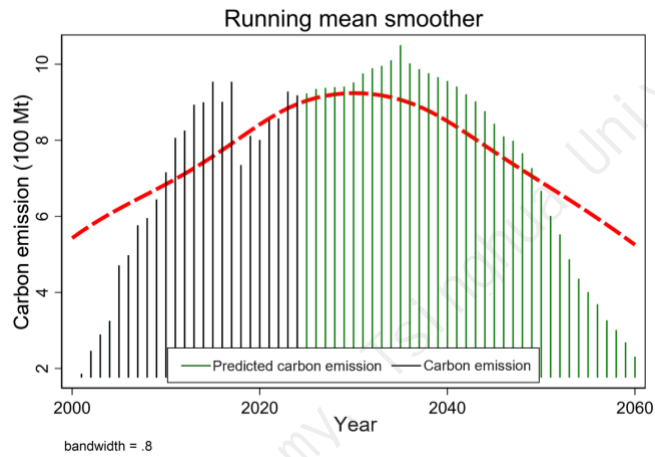


Fig. 5 Carbon emissions in Jiangsu Province.

Note: The projections in this report refer only to carbon dioxide emissions and do not include the effects of carbon sinks or emissions reductions from CCUS.

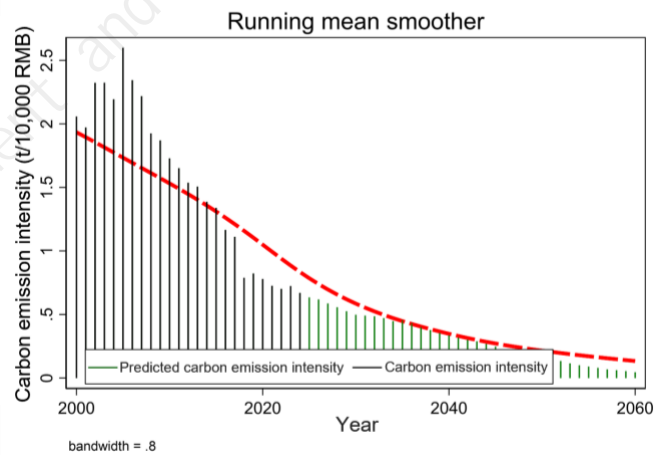


Fig. 6 Trend of Carbon Emission Intensity in Jiangsu Province (tons per RMB 10,000 of GDP).

Terminal energy intensity, the structure of power generation, and the composition of terminal energy consumption are the primary factors influencing carbon reduction. The contributions of lowering energy intensity, optimizing the industrial structure, increasing the level of end-use electrification, and adjusting the energy mix are estimated at 30.3 percent, 26.2 percent, 20.9 percent, and 17 percent, respectively. To achieve these goals, Jiangsu should adjust its industrial and energy structure between 2025 and 2035 by increasing the share of non-fossil energy to 30 percent and reducing emissions per unit of energy consumption by 28.6 percent, thereby achieving peak carbon emissions. Around 2050, the share of non-fossil energy should rise to 50 percent, with emissions per unit of energy consumption reduced by 46.1 percent. By

approximately 2060, the share of non-fossil energy is expected to exceed 80 percent, emissions per unit of energy consumption should fall by 54.6 percent, and total carbon emissions will decline by 77.9 percent, enabling the province to reach carbon neutrality.

Scenario analysis shows that under the baseline scenario, total carbon emissions from key industries in Jiangsu are projected to reach 599 million tons by 2060, with an average annual growth rate of 4.47 percent. With the implementation of targeted measures, emissions would decline significantly, with emissions peaking in either 2025 or 2030 and then gradually decreasing thereafter.

4. Emissions reduction pathways for key sectors

(1) Fossil energy (non-power generation)

Coal: As one of China's major economic provinces, Jiangsu continues to rely heavily on coal in non-power generation sectors. In 2024, coal consumption in the province reached approximately 208.88 million tons. Most coal use is concentrated in industrial activities, particularly in steelmaking, cement production, and other heavy industries. Coal consumption in non-power generation accounts for 47 percent of total coal use in Jiangsu. The main challenges for the low-carbon transition in this sector include an underdeveloped system for green coal utilization technologies, shortages of technical expertise in the coal-chemical industry, and insufficient incentives from the current carbon market mechanisms. Key pathways for reducing emissions include improving technologies for the clean and efficient use of coal, promoting the transition from coal to natural gas where applicable, strengthening the innovation system for low-carbon technologies, enhancing carbon market development and emissions management, and accelerating adjustments to the industrial and energy structure.

Oil: As a major hub of China's chemical industry, Jiangsu has experienced rapid growth in its petrochemical sector, forming an industrial cluster centered around the Lianyungang petrochemical base. In 2023, CO₂ emissions from oil use in non-power

generation sectors reached 165.33 million tons, primarily from transportation and petrochemical production. The main challenges for the low-carbon transition in this sector include the slow uptake of new energy in transportation, limited opportunities for feedstock substitution in the petrochemical industry, insufficient incentives under the carbon market mechanism, difficulties in industrial restructuring, regional disparities in development, and a generally low level of public awareness regarding low-carbon practices. Key pathways include accelerating the development of transportation infrastructure, supporting innovation in petrochemical feedstocks, and strengthening the regulation and management of dispersed fuel use, along with targeted policy support.

Natural gas: Jiangsu is the largest consumer of natural gas in China, with demand concentrated in thermal power generation, industrial end-use consumption, and transportation. In 2023, the province's natural gas consumption reached 37 billion cubic meters, with non-power generation sectors accounting for about 40 percent of total use. The main challenges for low-carbon transition in this sector include the high cost of high-efficiency equipment, supply chain pressures in natural gas storage and transportation, and lagging carbon emissions management for distributed energy systems. Key pathways include increasing subsidies for high-efficiency equipment, strengthening natural gas storage and transportation capacity, and improving regulatory frameworks for distributed energy management.

(2) Power generation and smart grids

Coal and gas power generation: Jiangsu ranks among the leading provinces in electricity generation. In 2023, the province generated 582.768 billion kilowatt-hours of electricity, with coal- and gas-fired power accounting for 75.80 percent of total output. In 2024, installed thermal power capacity reached 104.93 million kilowatts, representing 7.36 percent of the national total. The main challenges for the low-carbon transition in this sector include the high cost of emissions reduction retrofits for coal-fired power plants, supply and price volatility in natural gas, and insufficient capacity

to integrate renewable energy. Key pathways include increasing financial support for low-carbon retrofits, optimizing the layout of natural gas supply chains, and enhancing power grid dispatch and flexibility.

New energy power generation: Jiangsu is one of China's leading provinces in new energy power generation, encompassing wind, solar, biomass, and other renewable sources. In 2023, installed capacity from new energy reached approximately 70 million kilowatts, accounting for 38 percent of the province's total installed capacity. The main challenges for the low-carbon transition in this sector include the impact of renewable energy intermittency on grid stability, relatively high carbon emissions in the manufacturing of renewable energy equipment, and insufficient management of biomass fuel supply chains. Key pathways include accelerating upgrades in energy storage and grid dispatch systems, optimizing manufacturing processes for renewable energy equipment, and improving biomass fuel management frameworks.

Smart grids: Jiangsu is one of China's leading demonstration regions for smart grid development, with rapid progress in grid digitalization, decarbonization, and intelligent operation. In 2023, more than 30 percent of the electricity fed into the provincial grid came from clean energy sources, and multiple smart grid pilot projects were completed. In 2024, Jiangsu built the nation's first province-level digital smart grid. The main challenges for low-carbon transition in this sector include the relatively high carbon footprint associated with the manufacturing and operation of smart grid equipment, difficulties in coordinating cross-regional energy dispatch and transmission, and limited adoption of digital technologies. Key pathways include promoting low-carbon development across the smart grid industry chain, strengthening regional coordination and transmission optimization, and accelerating the deployment and application of smart grid technologies.

(3) Key industries

Steel: The steel industry is one of Jiangsu's traditional pillar sectors and plays a critical role in sustaining industrial growth and ensuring stable economic performance.

As one of China's major steel-producing provinces, Jiangsu has consistently ranked second nationwide in steel output in recent years, with overall production continuing to rise. The main challenges for the low-carbon transition in this sector include the high level of total carbon emissions, the need for further optimization of industrial layout, the relatively low proportion of electric arc furnace steelmaking, and the urgent need for breakthroughs in low-carbon technologies. Key pathways include phasing out outdated capacity, optimizing the spatial distribution of steel production, and increasing investment in low-carbon technological innovation.

Nonferrous metals: The nonferrous metals industry is an important component of Jiangsu's industrial value chain. It encompasses a wide variety of products with broad application areas and strong linkages to other sectors, playing a significant role in economic and social development. The provincial market is dominated by four major categories, including copper, aluminum, zinc, and lead, with the aluminum industry serving as the core segment of Jiangsu's nonferrous metals sector. The main challenges for the low-carbon transition in this sector include rising production costs, low efficiency in the reuse and recycling of nonferrous metals, and uneven levels of technological capability and equipment. Key pathways include promoting industrial restructuring and optimization, increasing the proportion of recycled nonferrous metals, and accelerating the development of intelligent manufacturing.

Petrochemicals: The petrochemical industry is one of Jiangsu's traditional and pillar industries, with its economic scale ranking among the highest in the country. After years of development, Jiangsu has established a comprehensive industrial system that spans oil refining, ethylene production, basic chemical raw materials, synthetic materials, and specialty chemicals. The scale of the petrochemical sector places Jiangsu among the leading provinces nationwide, and the industry occupies a central position in the provincial industrial system. The main challenges for the low-carbon transition in this sector include the need to optimize the industrial structure, the persistent disadvantages associated with early-stage development patterns, insufficient levels of

industrial concentration, and a lack of coordinated planning for petrochemical industrial parks. Key pathways include improving the energy efficiency of processes and equipment within the petrochemical industry, implementing environmental and energy-saving retrofits, advancing the low-carbon transition of energy use in an orderly manner, and actively exploring low-carbon and zero-carbon development models for industrial parks.

Construction and building materials: The construction industry is a pillar sector in Jiangsu, serving as both an economic driver and a key source of employment. In recent years, the sector has maintained steady growth, with its overall scale consistently ranking among the highest in the country. The building materials industry is dominated by products such as cement and flat glass. From January to November 2024, cement production in Jiangsu declined by 10.6 percent compared with the same period of the previous year, while flat glass production increased by 8.6 percent. The main challenges for the low-carbon transition in this sector include the high resource and energy consumption and relatively high emissions associated with building materials production, the limited resilience of the industrial supply chain, shortages of skilled professionals in the building materials industry, and gaps in supportive policies and standards for green building materials. Key pathways include strictly controlling new production capacity, accelerating the adoption of green building materials, optimizing energy use in building materials manufacturing, promoting energy-saving and carbon-reduction technologies, encouraging industrial integration, and advancing low-carbon building development.

Transportation: Jiangsu's transportation sector ranks among the most advanced in China. In 2023, total freight volume reached 3.247 billion tons, an increase of 11.1 percent from the previous year. The number of registered motor vehicles rose to 26.318 million, marking a year-on-year growth rate of 7.39 percent. The main challenges for the low-carbon transition in this sector include low energy efficiency, high costs associated with energy conservation and emissions reduction, limited capacity for low-

carbon operations among transportation enterprises, and insufficient levels of digitalization and intelligent transport systems. Key pathways include adjusting the transportation structure, ensuring the effective promotion of new energy vehicles, improving the overall efficiency and integration of the transportation system, maintaining a policy framework guided by the government and driven by the market, and encouraging green travel behavior.

(4) Emerging industries

ICT Industry (Information and Communication Technology): Jiangsu is one of China's leading provinces in the development of the ICT sector. In 2023, the operating revenue of Jiangsu's ICT industry reached RMB 2.96 trillion, accounting for 10.7 percent of the national total and ranking second nationwide. Revenue increased by RMB 200 billion from the previous year, representing a year-on-year growth rate of 6.6 percent, which exceeded the national average of 4.8 percent and continued the industry's strong upward trend. The main challenges for the low-carbon transition in this sector include the relatively small scale of ICT services compared with manufacturing and the relatively high carbon intensity of ICT service activities. Key pathways include accelerating research and development of green and low-carbon technologies for data centers, increasing the share of renewable electricity use, and establishing systems for the recycling and recovery of end-of-life ICT products.

New energy vehicle industry: Jiangsu's new energy vehicle (NEV) industry has achieved strong development outcomes, with its overall scale ranking among the highest in the country. The hydrogen fuel cell vehicle sector has begun to accelerate, and the adoption of NEVs continues to expand. In 2023, Jiangsu produced 1.047 million NEVs, an increase of 52.4 percent from the previous year, accounting for 10.9 percent of national output. The main challenges for the low-carbon transition in this sector include the still relatively low penetration rate of NEVs, which is affected by insufficient charging infrastructure, as well as concerns about vehicle safety and driving range. In addition, the rising carbon emissions associated with the rapid expansion of

the NEV industry cannot be overlooked. Key pathways include accelerating the adoption of NEVs, improving supporting infrastructure for new energy transportation, and advancing research and development of upstream and downstream technologies such as hydrogen production.

Hydrogen production industry: Most of Jiangsu's hydrogen resources come from by-product hydrogen generated in chemical, steelmaking, and other industrial processes. Considering purification costs, purity requirements, quality, stability, and environmental performance, hydrogen used in fuel cell applications primarily originates from by-product hydrogen produced in chlor-alkali plants. With its large installed capacity of renewable energy, Jiangsu has significant potential for renewable hydrogen production, and the province already possesses a relatively complete hydrogen production industry chain. The main challenges for the low-carbon transition in this sector include the high cost of hydrogen production and the limited diversity of production methods. Key pathways include accelerating breakthroughs in core technologies and expanding hydrogen production approaches, optimizing the power generation mix, and improving the energy structure that supports hydrogen production.

(5) Agriculture and ecosystems

Crop production: Jiangsu has long been one of China's major grain-producing provinces. The primary grain crops, ranked by output, are rice, wheat, and corn. In 2023, total grain production reached 37.977 million tons, placing the province eighth nationwide. However, due to factors such as the northward shift of grain production zones and rising labor costs, Jiangsu's share of national grain output has gradually declined. The main challenges for low-carbon transition in this sector include the energy consumption associated with mechanization, which has become the greatest source of uncertainty for achieving peak agricultural emissions; limited economic returns from low-carbon agricultural technologies; the need to balance low-carbon agricultural pathways with the governor's responsibility system for grain security; and insufficient low-carbon awareness among crop producers. Key pathways include

reducing and optimizing the use of chemical inputs such as fertilizers and pesticides, developing green agriculture, guiding residents toward healthier and lower-carbon dietary patterns while reducing food loss and waste, strengthening research and technological innovation in crop production, and cultivating new generations of skilled farmers.

Livestock production: The livestock sector accounts for a smaller share of national output compared with crop production in Jiangsu, and livestock activities are mainly concentrated in household-based farming of sheep and pigs. The main challenges for the low-carbon transition in this sector include rising consumption of meat, eggs, and dairy products, which increases the difficulty of emission reduction; the relatively small scale of potential emission reductions and the limited diversity of mitigation measures in Jiangsu's livestock sector; and the prevalence of small-scale, dispersed farmers, which creates challenges for data monitoring and management. Key pathways include optimizing the structure of livestock production by reducing the number of ruminant animals, developing greener livestock management technologies, and promoting low-carbon practices in feed and manure management.

Terrestrial ecosystems: The total carbon storage of Jiangsu's terrestrial ecosystems is 975.72 Tg C, of which soil carbon storage accounts for 922.03 Tg C, representing 94.5 percent of total organic carbon. Forest ecosystems store 174.81 Tg C, while grassland vegetation holds approximately 0.138 Tg C. The carbon sequestration rate of lakes in Jiangsu is about 0.35 Tg C per year. The main challenges for the low-carbon transition in this sector include severe agricultural non-point source pollution, limited forest area with constrained potential for expansion, and imbalanced forest age structure and species composition. Key pathways include expanding forest area to strengthen forest carbon sinks, developing low-carbon ecological agriculture to enhance agricultural carbon sequestration, leveraging the province's extensive wetland resources to expand wetland carbon sinks, and improving carbon budget assessment across terrestrial ecosystems to establish a stronger scientific foundation for policy and

management.

Marine ecosystems: Jiangsu has a coastline of 954 kilometers and a marine area of approximately 37,500 square kilometers, accounting for 37 percent of the province's land area and offering substantial carbon storage potential. In 2021, carbon sequestration from marine aquaculture in Jiangsu was about 55,000 tons. Blue carbon storage in coastal zone sediments is estimated at 2.02×10^6 tons within the top one meter, indicating considerable room for enhancement. Annual carbon sequestration from shellfish and algae aquaculture generally remains between 60,000 and 70,000 tons. The main challenges for low-carbon transition in this sector include the rapid expansion of coastal industrial zones that has significantly reduced coastal wetlands, hydrodynamic and substrate alterations caused by port development, degradation of marine water quality resulting from land-based wastewater discharge and the relocation of chemical industries, disruption of migratory pathways due to the construction of offshore wind farms, and ecological imbalance driven by the expansion and transformation of aquaculture systems. Key pathways include reducing nutrient inputs into coastal waters and coordinating land-sea strategies to increase carbon sinks, developing technical measures to facilitate carbonate precipitation, and promoting marine ecological restoration and integrated aquaculture, including approaches such as artificial upwelling.