Xinjiang Carbon Neutrality Planning Research

Executive Summary

1. Current economic development and foundations for emissions reduction

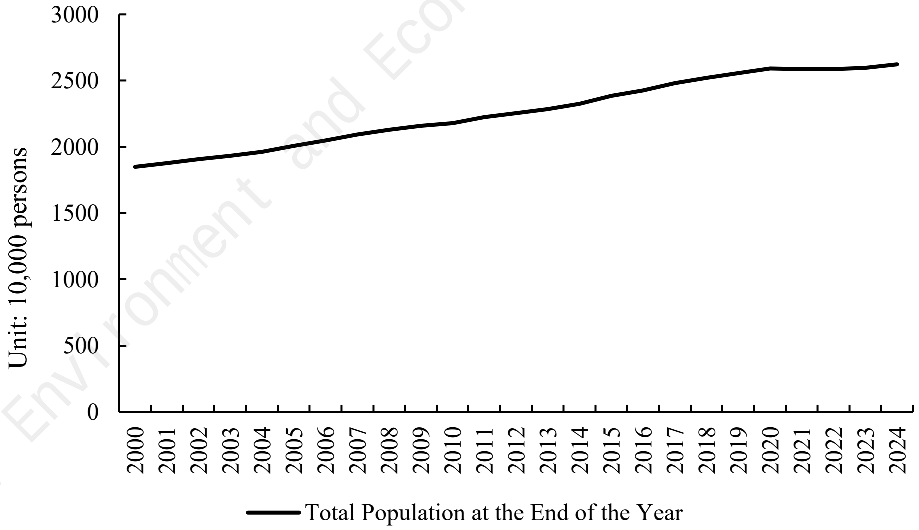
Xinjiang Uygur Autonomous Region is located in the hinterland of the Eurasian Continent. It is China's provincial-level administrative region with the largest land area, the most land-neighboring countries and the longest land boundary line, covering a total area of 1.6649 million square kilometers, accounting for approximately one sixth of China's total land area. Xinjiang occupies a particularly important strategic position in the overall national development and undertakes the Five Strategic Orientations entrusted by the Central Government of the People's Republic of China.

1.1 Population Development

Xinjiang's total population features steady growth and continuous structural optimization(Fig.1). By the end of 2024, the permanent resident population of the whole region reached 26.23 million, an increase of 248,000 compared with the end of the previous year. The annual birth population stood at 246,000 with a birth rate of 9.42‰; the death population was 158,000 with a mortality rate of 6.05‰; and the natural growth rate reached 3.37‰. In terms of age structure, Xinjiang has a relatively low degree of aging: the proportion of the population aged 60 and above was 8.9% by the end of 2024, 13.1 percentage points lower than the national average, and the working-age population aged 16 to 59 accounted for 65.6%, showing a distinct demographic dividend advantage. In terms of gender ratio, the male population accounted for 51.7% and the female population 48.3% by the end of 2024, with the male proportion slightly higher than the national level.

The urban-rural structure has been continuously upgraded and the urbanization process has been accelerated. The urbanization rate reached 60.4% by the end of 2024, an increase of 1.2 percentage points over the end of the previous year. The urban permanent resident population was 15.83 million, an increase of 5.2779 million compared with 2010, and the proportion of urban population rose by 13.73 percentage points in a decade, making the urban-rural population distribution more rational.

At the same time, the vitality of population mobility has been continuously enhanced. Xinjiang saw a net population outflow of about 30,000 on an annual average in 2021-2022; it achieved a net population inflow of 90,000 in 2023; and the net population inflow reached 160,000 in 2024, reflecting the continuous increase in Xinjiang's attractiveness to the population.

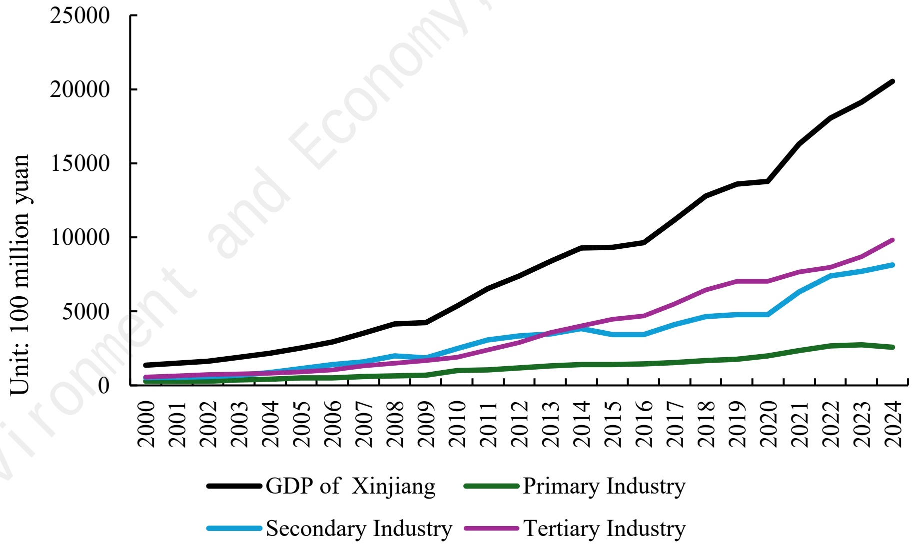


Data Source: Xinjiang Statistical Yearbook and Statistical Communiques

Fig. 1 Total Population of Xinjiang at the End of the Year

1.2 Economic Development

In recent years, Xinjiang's economic aggregate has been on a steady rise with outstanding performance in core indicators(Fig.2). The regional gross domestic product (GDP) of Xinjiang soared from 136.356 billion yuan in 2000 to 2,053.408 billion yuan in 2024, breaking the 2 trillion yuan mark for the first time, with an average annual growth of 11.96%. The per capita regional GDP rose from 7,372 yuan to 78,660 yuan, and residents' income increased in tandem with economic development. In 2024, Xinjiang's regional GDP grew by 6.1% year-on-year, the added value of industrial enterprises above designated size rose by 8%, fixed asset investment increased by 6.9%, and general public budget revenue grew by 10.5%, with the growth rates of major economic indicators ranking among the top in China. The safeguard of people's livelihood has been continuously strengthened. In 2024, the per capita disposable income of all residents in Xinjiang reached 30,899 yuan, with an average annual growth of 7%. Among them, the per capita disposable income of rural residents registered an 8.2% growth, 2.7 percentage points higher than that of urban residents, indicating a gradual narrowing of the urban-rural income gap.



Data Source: Xinjiang Statistical Yearbook and Statistical Communiques

Fig. 2 Gross Regional Product and Value-added of the Three Industries in Xinjiang

After years of adjustment and optimization, Xinjiang's industrial structure has transformed from a traditional resource-dependent model to a diversified and coordinated one. In 2024, the proportion of the three industrial sectors stood at 12.5:39.6:47.9, with the tertiary industry accounting for nearly half of the total economy and emerging as the primary driver of economic growth. The industrial structure presents distinct characteristics of the tertiary industry leading the growth, the secondary industry upgrading quality and the primary industry consolidating the foundation.

The primary industry has solidified the foundation for people's livelihood and achieved large-scale and high-quality development centered on characteristic agriculture. Xinjiang now ranks first in China in grain yield per unit area, and its cotton output accounts for 92.2% of the national total. Advantageous industrial chains have taken shape for characteristic forest and fruit products as well as animal husbandry products, making Xinjiang an important national base for agricultural product supply. The secondary industry focuses on advancing new-type industrialization, based on its advantages in energy and mineral resources, it is promoting the upgrading of coal, oil and gas, new energy and other industries, and at the same time fostering deep-processing industries such as textile and garment manufacturing and intelligent equipment manufacturing to reduce reliance on the primary export of resources. The tertiary industry has continued to unleash vitality, with the rapid development of culture and tourism, logistics and industries related to free trade pilot zones. In particular, the construction of the core area of the Belt and Road Initiative has driven the expansion and quality improvement of cross-border trade, modern logistics and other fields, injecting strong impetus into the optimization of the industrial structure.

1.3 Resource Endowment

Xinjiang, as an important resource-rich region and strategic reserve base in China, boasts a vast territory and abundant resources. Its unique endowments of various resources have laid a solid foundation for the high-quality economic and social development and also forged core advantages for its service and integration into the new development paradigm. In terms of land and agricultural resources, the directly usable land area for farming, forestry and animal husbandry in Xinjiang reaches 1 billion mu, with unique solar-thermal, water and land resources. Despite the uneven spatial and temporal distribution of water resources, the total volume is guaranteed. Its glacial reserves account for 42.7% of the national total, making it a strategic reserve for national food security and the supply of important agricultural products. Xinjiang is accelerating the construction of a base for green animal husbandry products and high-quality fruit and vegetable production. In terms of energy and mineral resources, the technically exploitable reserves of solar energy and wind energy in Xinjiang rank first and second in China respectively. The predicted reserves of energy resources such as oil, natural gas and coal account for a significant proportion of China's onshore resources. Xinjiang has a rich variety of minerals, with 153 discovered mineral types accounting for 88% of the national total, and the proven in-situ reserves of many minerals ranking among the top in China. A number of world-class ore deposits have also been found here. As the core area for the construction of China's three bases and one corridor, Xinjiang provides important support for the national energy and critical mineral resource security. In terms of location resources, located in the hinterland of the Eurasian continent and bordering 8 countries, Xinjiang has 19 open ports for external trade and 56 national-level key opening-up and industrial development platforms. The China (Xinjiang) Pilot Free Trade Zone has been approved for establishment. Its unique advantage of five ports connecting eight countries and one route linking Europe and Asia has made Xinjiang the forefront of China's opening-up to the west. Relying on its geographical conditions of connecting with the east for outbound development and attracting the west for inbound cooperation, Xinjiang can effectively leverage both the domestic and international markets and resources, occupying an important position in the joint construction of the Belt and Road Initiative and the construction of the new development paradigm.

1.4 Carbon Emission Status

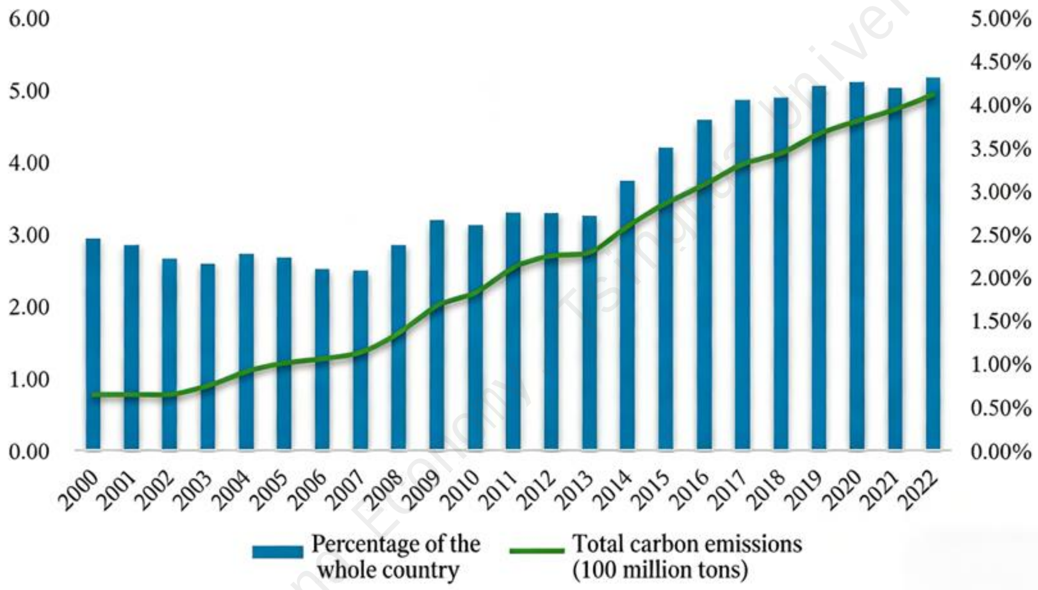
(1) Total Carbon Emissions

Accounting results show that Xinjiang's carbon emissions witnessed a sustained and rapid growth from 2000 to 2022. According to the accounting data of total carbon emissions in Fig. 3, its total carbon emissions rose year by year from 78 million tons in 2000 to 495 million tons in 2022. The cumulative net increase reached 417 million tons over the 22 years, with an overall growth of more than five times and a notable average annual growth rate. This growth process presents obvious phased characteristics. Carbon emissions exceeded 200 million tons in 2009, reaching 202 million tons, then surpassed 300 million tons in 2014, reaching 312 million tons, broke the 400 million ton mark in 2019, reaching 440 million tons, and neared the 500 million ton level by 2022. In terms of annual growth, carbon emissions increased by 17 million tons in 2021 compared with the previous year, and 21 million tons in 2022 compared with the previous year, showing a sustained strong growth momentum.

At the same time, Xinjiang's share of the national total carbon emissions has also risen significantly in tandem. Starting at 2.44% in 2000, this proportion remained in the range of 2.07% to 2.44% from 2001 to 2007. Since 2008, the proportion has entered a sustained upward trajectory, reaching 3.51% in 2015, exceeding 4% to 4.09% in 2018, and hitting 4.31% in 2022. It is particularly noteworthy that the proportion surged rapidly from 3.11% to 3.83% between 2014 and 2016, and has remained at a high level of over 4.2% since 2020.

These data clearly reveal two core trends. First, Xinjiang's carbon emission growth rate has long been higher than the national average, with its share rising from 2.44% to 4.31%, a substantial increase that directly indicates its emission growth rate is far above the national mean. Second, the growth process is not linear and uniform, but features stepwise leaps at key nodes such as 2009, 2014 to 2016 and after 2020. This strongly reflects the profound impact of external driving factors such as the development of local heavy industry, energy structure and the commissioning of specific major projects.

By 2022, both Xinjiang's total carbon emissions and its share of the national total had hit a record high, marking it as one of the key regions driving the growth of national carbon emissions. The evolution of its emission trajectory will exert an increasingly important influence on China's macro goals of achieving carbon peak and carbon neutrality.



Data Source: Calculated based on the data from China Statistical Yearbook, China Energy Statistical Yearbook and Xinjiang Statistical Yearbook.

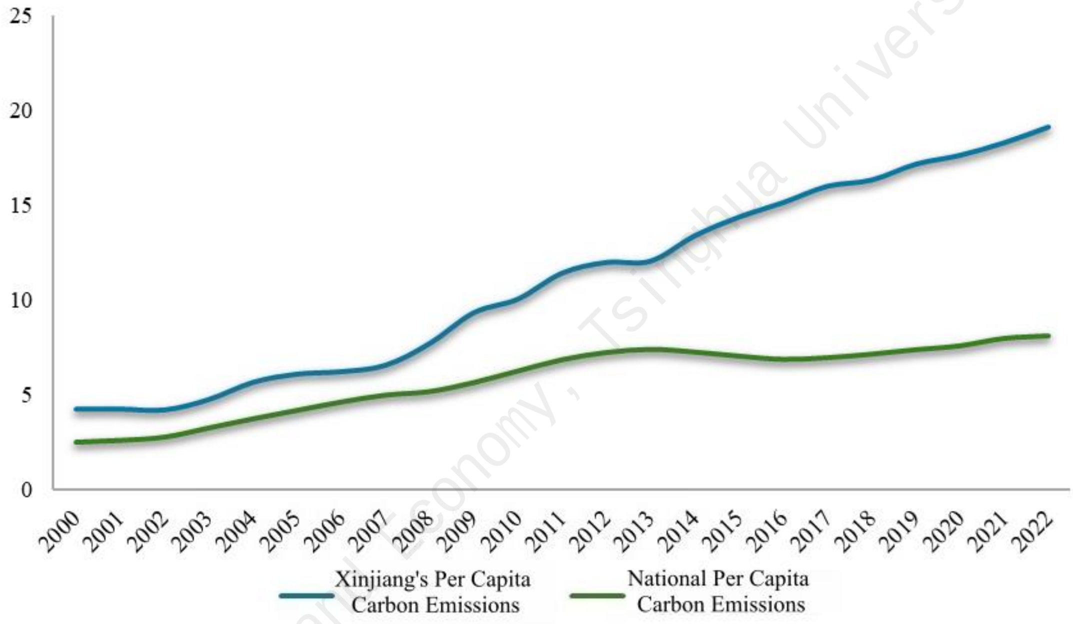
Fig. 3 Trends in Total Carbon Emissions and Share of Xinjiang

(2) Per Capita Carbon Emissions

Fig. 4 shows the calculation results of per capita carbon emissions. Xinjiang's per capita carbon emissions witnessed a sustained and robust upward trend from 2000 to 2022. In 2000, Xinjiang's per capita carbon emissions stood at 4.24 tons, while the national average was 2.54 tons, with Xinjiang's figure being about 1.70 tons higher than the national level. Since then, both figures have kept growing, but the growth rate and margin of Xinjiang have been far higher than the national average. By 2022, Xinjiang's per capita carbon emissions had reached 19.14 tons, compared with the national per capita level of 8.12 tons, with Xinjiang exceeding the national average by about 11.02 tons. Over the 22 years, Xinjiang's per capita carbon emissions have increased by about 3.5 times, while the national figure has only risen by about 2.2 times, and the absolute gap between the two has expanded significantly from 1.70 tons to 11.02 tons.

The growth process has exhibited distinct phased characteristics and disparities. In the initial stage from 2000 to 2003, Xinjiang's per capita carbon emissions fluctuated between 4.20 and 4.75 tons, slightly higher than the national average. Starting from 2004, Xinjiang entered a phase of rapid growth, breaking the 9-ton mark in 2009 to reach 9.34 tons. In the same year, the national figure was 5.67 tons, making Xinjiang's per capita carbon emissions about 1.65 times that of the national average. In 2014, Xinjiang's per capita carbon emissions exceeded 13 tons. In contrast, the national per capita carbon emissions, after reaching 7.42 tons in 2014, saw a slight drop to 6.89 tons from 2015 to 2016, showing a characteristic of fluctuation at a plateau. In sharp contrast, Xinjiang's per capita carbon emissions were not significantly affected during the same period and continued to rise steadily, breaking the 15-ton mark in 2016, and the growth trajectories of the two began to diverge markedly. In the mid-to-late stage of the 13th Five-Year Plan and the early stage of the 14th Five-Year Plan, the gap expanded at an accelerated pace. Xinjiang's per capita carbon emissions exceeded 17 tons in 2019, 18 tons in 2021, and hit a historical high of 19.14 tons in 2022. The national per capita carbon emissions, however, grew slowly in the range of 7 to 8 tons. In terms of the relative gap, the ratio of Xinjiang's per capita carbon emissions to the national average has been on a continuous rise: it was about 1.67 times in 2000, rose to about 1.65 times in 2009, exceeded 2.2 times in 2016, and by 2022, Xinjiang's per capita carbon emissions had reached about 2.36 times the national average.

The data indicates that Xinjiang's per capita carbon emissions not only have a high baseline level but also possess much stronger growth momentum than the national average. The continuous expansion of this gap profoundly reflects the disparities between Xinjiang and the national overall development path in terms of industrial structure, energy consumption intensity and development model. As an important energy and chemical industry base and a heavy industry cluster, the rapid rise in Xinjiang's per capita carbon emissions is a direct reflection of the synchronous high-speed growth of its economic aggregate and total carbon emissions at the per capita level, and it also indicates that Xinjiang will face more prominent pressure and challenges in per capita carbon emission reduction in the national carbon emission reduction process in the future.



Data Source: Calculated based on data from China Statistical Yearbook, China Energy Statistical Yearbook and Xinjiang Statistical Yearbook.

Fig. 4 Per Capita Carbon Emissions (tonnes per capita)

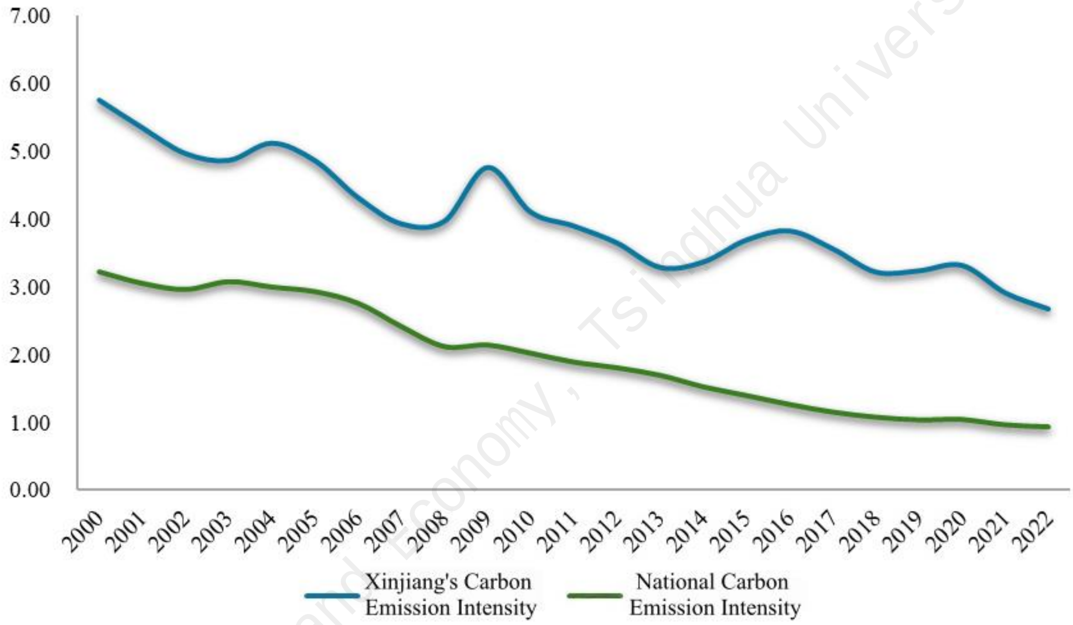
(3) Carbon Emission Intensity

Fig. 5 shows that Xinjiang's carbon emission intensity exhibited an overall downward trend from 2000 to 2022, yet it remained significantly higher than the national average with a relatively slow decline rate. In 2000, Xinjiang's carbon emission intensity stood at 5.75, compared with 3.21 for the whole country, a gap of 2.54 in Xinjiang's favor. By 2022, Xinjiang's intensity had dropped to 2.67 while the national figure fell to 0.94, narrowing the gap to 1.73. Notably, over the two decades and more, the national carbon emission intensity plummeted by more than 70%, whereas Xinjiang's decrease was approximately 53%, indicating a notable gap between Xinjiang's emission reduction efficiency and the national pace.

The changing process featured distinct phased characteristics. From 2000 to 2007, Xinjiang's carbon emission intensity declined steadily from 5.75 to 3.93, and the national intensity dropped from 3.21 to 2.41 over the same period, with both showing a steady downward momentum. However, Xinjiang saw a sharp rebound in 2009, with its intensity rising from 3.97 in 2008 to 4.76, while the national intensity edged up only slightly from 2.12 to 2.14, which widened the relative gap between the two. After that, both regions entered a channel of fluctuating decline in carbon emission intensity on the whole, but Xinjiang's downward trajectory was unstable. In particular, from 2014 to 2016, the national intensity continued to fall from 1.52 to 1.27, while Xinjiang's intensity rose against the trend from 3.36 to 3.82, showing a phased divergence from the national trend. Xinjiang's intensity rebounded slightly again in 2020, climbing from 3.23 in 2019 to 3.31, and the national figure inched up merely from 1.04 to 1.05 in the same year.

Further data indicates that although Xinjiang's carbon emission intensity decreased gradually on the whole, the gap with the national average remained substantial. In terms of the absolute difference, the gap between the two fluctuated from 2.54 in 2000 to 1.73 in 2022, and widened again in periods such as 2009 and 2015-2016. More crucially, from the perspective of the relative multiple, Xinjiang's carbon emission intensity was about 1.79 times that of the national level in 2000; this multiple once expanded to approximately 2.22 times in 2009, and though it narrowed on the whole afterward, Xinjiang's intensity was still about 2.84 times the national level by 2022. This reflects that Xinjiang has long borne a high carbon emission load per unit of economic output.

Despite making certain progress in reducing carbon emission intensity, Xinjiang lags behind the national overall progress in both the decline rate and stability. The persistently high and slowly declining emission intensity is closely linked to Xinjiang's economic structure dominated by heavy and chemical industries as well as energy and resource-based industries.



Data Source: Calculated based on data from China Statistical Yearbook, China Energy Statistical Yearbook and Xinjiang Statistical Yearbook.

Fig. 5　Carbon Emission Intensity (tonnes per 10,000 yuan)

1.5 Challenges Faced

To achieve the carbon neutrality goal, the prominent problems existing in Xinjiang are mainly as follows:

Energy transition is confronted with structural path dependence. Xinjiang's energy structure is dominated by coal, with a relatively low proportion of renewable energy. Severe technological bottlenecks are prominent in the development of renewable energy, and the intermittency and instability of wind power and photovoltaic projects have not been effectively resolved. In addition, energy transition requires a large amount of capital investment, while Xinjiang's level of economic development is relatively low, making fund raising a difficult task. The imperfection of the market mechanism is also a major obstacle.

Industrial emission reduction faces relatively high economic costs. The industrial sector in Xinjiang has a high volume of carbon emissions, especially key industries such as iron and steel, building materials, petrochemical and chemical engineering, which occupy an important position in Xinjiang's economic development and are characterized by high energy consumption and high emissions. On the one hand, the cost of technological transformation is relatively high, placing great economic pressure on enterprises that can hardly afford the expenses of large-scale technological upgrading. On the other hand, Xinjiang's capacity for industrial technological innovation is relatively weak, lacking the application of advanced low-carbon technologies. In addition, industrial restructuring is fraught with great difficulties. Xinjiang's industrial structure is dominated by heavy industry, and restructuring requires a large amount of capital investment and policy support, while also facing issues such as employment pressure and social stability.

Ecosystem vulnerability leads to weak carbon sink capacity. Xinjiang is located in arid and semi-arid areas, with a fragile ecosystem and limited carbon sink capacity. On the one hand, Xinjiang has a low forest coverage rate, with severe degradation of grassland and wetland ecosystems, leaving limited space for the improvement of carbon sink capacity. On the other hand, ecosystem restoration requires a large amount of financial and technological support, for which Xinjiang's investment is relatively insufficient. Meanwhile, ecosystem restoration is extremely difficult. Problems such as low forest coverage and the degradation of grasslands and wetlands make the restoration work arduous, which is also constrained by natural factors such as climate change and water scarcity. In addition, the measurement and monitoring system for ecosystem carbon sinks is imperfect, making it difficult to accurately assess the ecosystem's carbon sink capacity, which affects the progress of ecosystem restoration work and the evaluation of the contribution of carbon sinks to the carbon neutrality goal.

Technological and financial bottlenecks result in a lack of support for the carbon emission trading market. Xinjiang's R&D capacity for low-carbon technologies is relatively weak, lacking the application of advanced low-carbon technologies, which places Xinjiang under significant technological bottlenecks in the process of achieving the carbon neutrality goal. At the same time, the achievement of the carbon neutrality goal requires a large amount of capital investment, while Xinjiang's level of economic development is relatively low with limited fiscal revenue, making it difficult to meet the capital demand for the carbon neutrality goal. The financial market is not well developed, failing to attract a large amount of social capital into carbon neutrality projects. In addition, the imperfection of the market mechanism is also a major obstacle.

2. Goal Formulation

In accordance with relevant documents, formulate Xinjiang's long-term goal for 2060 and goal for 2035.

Long-term Goal for 2060:

By 2060, Xinjiang will fully establish a modern development system of harmonious coexistence between humans and nature, realize the comprehensive green and low-carbon transformation of economic and social development, and become a national strategic base for clean energy, an ecological security barrier in border areas and a model for green and low-carbon development in China. A fundamental transformation will be achieved in the energy structure, with non-fossil energy consumption taking a dominant position and the efficiency of energy and resource utilization reaching the international advanced level. The modern industrial system will fully realize green, circular and low-carbon development, and near-zero emissions will be achieved in key industrial sectors. The urban and rural living environment will meet the standards of a livable model, green transportation and ultra-low energy consumption buildings will be comprehensively popularized, and a green lifestyle will become a new social trend. The carbon sink capacity of ecosystems will be continuously enhanced, a climate-resilient society will be basically established, the supply of high-quality ecological products will be more abundant, and the ecological security barrier will be more solid. Xinjiang will make an important contribution to the national achievement of the carbon neutrality goal and create a green, low-carbon and high-quality development model with distinctive Xinjiang characteristics.

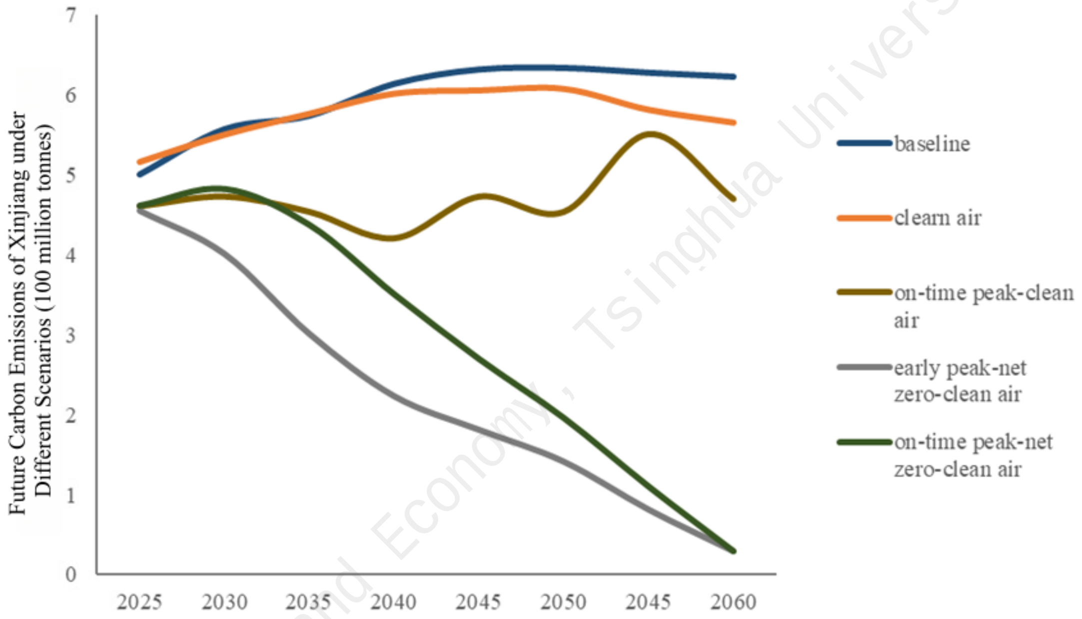
Key Goals for Economic and Social Development and Low-Carbon Transformation in 2030 and 2035:

The overall goal of Xinjiang's carbon neutrality development is anchored in the core direction of the coordinated advancement of economic development and carbon emission reduction, taking into account the dual requirements of growth and carbon reduction, with a clear and practically feasible goal system. Based on the 2024 benchmarks of a GDP of 2.05 trillion yuan, a total carbon emission of 520 million tCO_2e, a per capita carbon emission of 20.1 tCO_2/capita and a carbon emission intensity per unit of GDP of 2.5 tCO_2/10,000 yuan, Xinjiang plans to achieve the dual peaks of economy and carbon emissions by 2030: the GDP will rise to 2.92 trillion yuan, the total carbon emission and per capita carbon emission will peak at 610 million tCO_2e and 24 tCO_2/capita respectively, and the carbon emission intensity per unit of GDP will drop to 2.09 tCO_2/10,000 yuan simultaneously, demonstrating a development trend of decoupling between economic growth and carbon intensity. By 2035, Xinjiang will further realize sustained economic growth and a steady decline in carbon emissions: the GDP will increase to 3.71 trillion yuan, the total carbon emission and per capita carbon emission will fall back to 580 million tCO_2e and 22.3 tCO_2/capita respectively, and the carbon emission intensity per unit of GDP will continue to drop to 1.6 tCO_2/10,000 yuan, realizing the in-depth integration of high-quality economic development and ecological low-carbon transformation. The target data for each stage is scientifically calculated based on the scenario analysis in this report, which sets a clear quantitative benchmark for the advancement of Xinjiang's carbon neutrality work(Table 1.).

Table 1. Overall Goal Setting

Indicator	Unit	2024 Baseline Value	2030 Target Value	2035 Target Value	Data Source and Calculation Basis
GDP	Trillion yuan	2.05	2.92	3.71	Calculated based on scenario analysis in this report
Total carbon emissions	100 million tCO_2e	5.2	6.1 (Peak)	5.8	
Per capita carbon emissions	tCO_2/capita	20.1	24 (Peak)	22.3	
Carbon emission intensity per unit of GDP	tCO_2/10000 yuan	2.5	2.09	1.6	

3.Scenario Analysis



Data Source: China Future Emission Dynamic Assessment Model, Tsinghua University（Tongetal.,2020;Chengetal.,2023）

Fig. 6 Future Emission Projections of Xinjiang under Different Scenarios (100 million tons)

Fig. 6 shows the projections of Xinjiang's future carbon emissions under different scenarios, which are based on the Dynamic Projection Model for Emissions in China developed by Tsinghua University (Tong et al., 2020; Cheng et al., 2023). The model incorporates a variety of scenarios, including the baseline scenario, clean air scenario, on-time peak-clean air scenario, early peak-net zero-clean air scenario and on-time peak-net zero-clean air scenario. These scenarios respectively reflect the implementation of climate and pollution control policies to varying degrees.

The carbon emission projection results under different scenarios indicate that the implementation of more stringent climate and pollution control policies can significantly reduce carbon emissions, and the downward trend of carbon emissions is more pronounced especially under the scenarios of early peaking and on-time peaking.

Under the baseline scenario, Xinjiang's carbon emissions show a sustained growth trend, increasing from 500 million tons in 2025 to 623 million tons in 2060. This scenario assumes no additional climate and pollution control policies under the driving of the SSP1 socio-economic scenario, reflecting the changes in carbon emissions under the trend of natural growth.

Under the clean air scenario, the growth rate of carbon emissions slows down, with carbon emissions standing at 516 million tons in 2025 and dropping to 565 million tons in 2060. On the basis of the baseline scenario, this scenario gradually implements the Best Harmonic Emission (BHE) measures, demonstrating the inhibitory effect of pollution control policies on the growth of carbon emissions.

The on-time peak-clean air scenario further introduces medium and short-term (2020-2030) carbon peaking and emission reduction policies. Under this scenario, carbon emissions reach 461 million tons in 2025, peak at 473 million tons in 2030 and then start to decline, falling to 29 million tons in 2060. This shows that the implementation of carbon peaking policies can effectively control the peak of carbon emissions and drive a significant drop in carbon emissions.

The early peak-net zero-clean air scenario strengthens the carbon emission reduction policies before 2030 to achieve an early carbon peak. Under this scenario, carbon emissions stand at 455 million tons in 2025, drop to 401 million tons in 2030 and further to 181 million tons in 2045, and fall to 29 million tons in 2060. This scenario integrates carbon peaking policies, carbon neutrality goals and the best pollution control policies, demonstrating the significant inhibitory effect of early peaking policies on carbon emissions.

The main difference between the on-time peak-net zero-clean air scenario and the early peak-net zero-clean air scenario lies in the intensity of carbon emission reduction before 2030. Under this scenario, carbon emissions reach 462 million tons in 2025, drop to 483 million tons in 2030 and further to 270 million tons in 2045, and fall to 29 million tons in 2060. This scenario also integrates carbon peaking policies, carbon neutrality goals and the best pollution control policies, but with a relatively lower intensity of emission reduction before 2030.

Fig. 7 and Fig. 8 show a comparison of GDP changes under the scenarios of undifferentiated and differentiated emission reduction across all regions. For Xinjiang, the provincial undifferentiated emission reduction scenario implies more severe economic challenges. Compared with the differentiated emission reduction scenario that fully takes into account its role as an energy base and its development stage, under the one-size-fits-all path requiring all provinces to uniformly reduce emissions to 10% of the 2021 level by 2060, Xinjiang's cumulative GDP loss expands significantly from 5.15% to 8.17%. The equal distribution of emission reduction responsibilities that ignores regional heterogeneity will impose excessive transformation pressure on its economic structure supported by traditional energy and heavy chemical industries. This underscores the philosophy of the whole country as a single integrated system, namely the shared responsibility and interest balance based on a scientific understanding of regional differences. The successful transformation of Xinjiang not only relies on its own firm adherence to the path of industrial replacement featuring establishing the new before dismantling the old, but also urgently needs a differentiated national action framework that acknowledges its special circumstances and provides sufficient policy space and external support, so as to realize the unity of environmental and economic benefits, and the integration of national goals and regional equity.

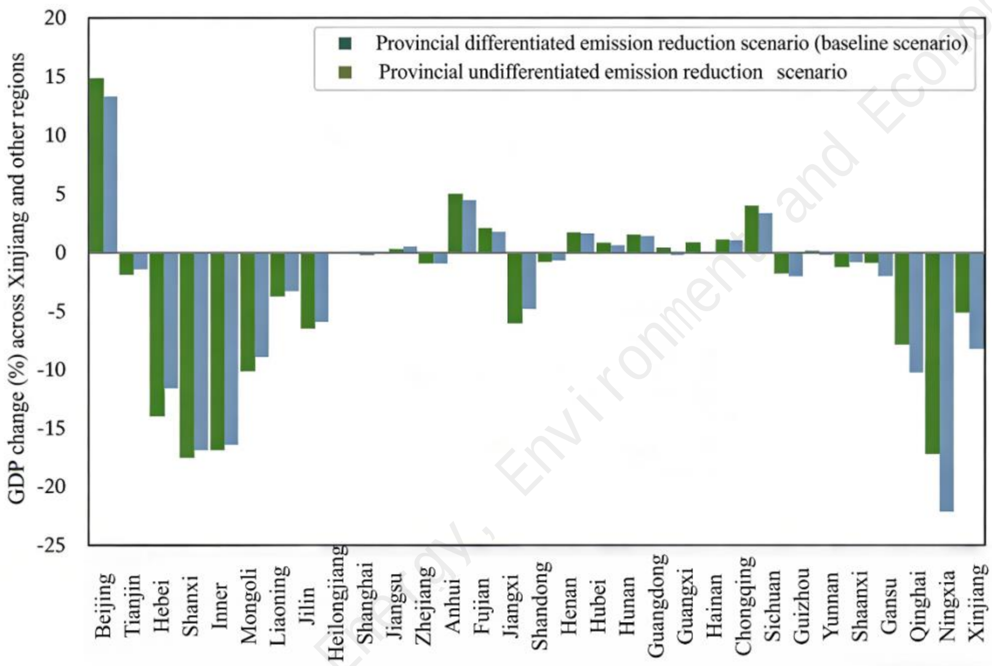


Fig. 7 Comparison of Regional GDP Changes under Two Scenarios in 2060

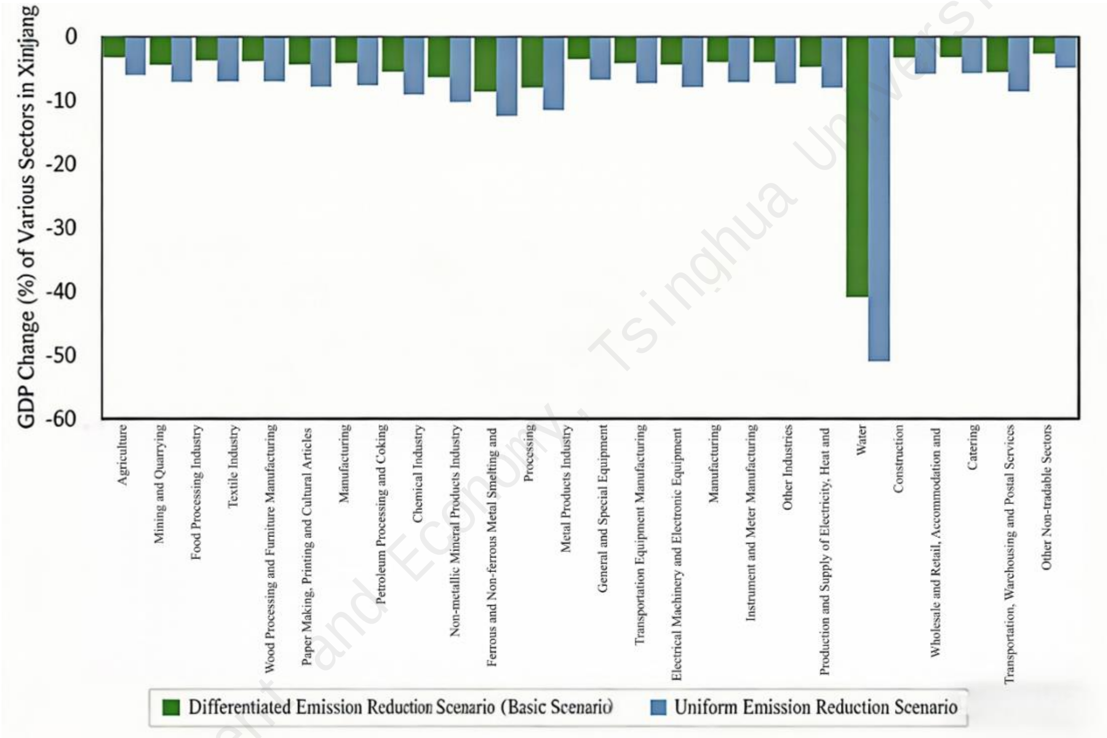


Fig. 8 Comparison of GDP Changes of Various Sectors in Xinjiang under Two Scenarios in 2060

4. Key Fields and Major Tasks

4.1 Key Areas

The industrial sector is the core carrier of carbon emissions, characterized by a high proportion of traditional high-energy-consuming industries and great transformation difficulties. Its low-carbon transition is the key to achieving carbon peaking, and carbon reduction shall be promoted through the dual paths of stock emission reduction and incremental emission control. The energy sector is the primary source of carbon emissions and a core supporting field. Leveraging its inherent advantages in the clean transformation of fossil energy and the large-scale development of new energy, it shall tap the maximum carbon reduction potential while safeguarding national energy security, balancing ecological and economic benefits. The transportation sector sees a rapid growth in carbon emissions with huge emission reduction potential, which is highly associated with Xinjiang's characteristics of vast territory and great demand for the transportation of bulk commodities. Synergistic carbon reduction can be achieved through facility optimization, equipment upgrading and the development of the new energy industry, connecting all links of production and living. The urban and rural construction sector features rigid and extensive carbon emissions, with prominent problems such as high heating energy consumption and low building energy efficiency. Relying on new urbanization and rural vitalization, energy-saving transformation and clean heating substitution shall be promoted to realize the dual values of carbon reduction and people's livelihood improvement. The ecological carbon sink sector is a unique advantage and important supplement for Xinjiang's carbon neutrality. Boasting a vast ecological space and diverse ecosystems, it shall enhance carbon sequestration capacity through ecological governance, achieve end-of-pipe carbon sequestration to offset emissions, alleviate the emission reduction pressure on high-energy-consuming industries, and at the same time consolidate the ecological security barrier. The circular economy sector addresses the carbon emission problem from the source of resource utilization, which is in line with the characteristics of Xinjiang's resource-based industries. Relying on the circular transformation of industrial parks and the comprehensive utilization of solid waste, it shall realize resource reduction, reuse and recycling, ease the contradiction between resource development and ecological protection, provide the whole-chain support for carbon reduction in the industrial, energy and other sectors, and balance ecological and industrial development benefits.

4.2 Key Technologies

The key technologies for achieving carbon neutrality mainly include the following categories.

(1) Key Technologies for Industrial Carbon Reduction

① Carbon Capture, Utilization and Storage (CCUS) Technologies. As the core technologies for industrial emission reduction, they include post-combustion carbon capture technologies for refining, coal chemical and other industries, carbon dioxide dense-phase pipeline transportation technologies, carbon dioxide enhanced oil recovery and storage technologies, and carbon dioxide hydrogenation conversion technologies for chemical production. Xinjiang Oilfield has developed the Junggar Model featuring "carbon source supply guarantee - high-efficiency displacement - safe storage", and the Shihezi Dunhua Gas Project has realized the full-chain coverage of carbon dioxide capture, transportation and utilization with a capacity of 2.8 million tons. ② Low-carbon Transformation Technologies for High-energy-consuming Industries. In the oil and gas chemical industry: high-efficiency heat exchange, heat pump process and high-end polyolefin synthesis technologies; in the coal chemical industry: green hydrogen-coupled coal chemical technology and low-temperature pyrolysis technology for low-rank coal (with an energy conversion efficiency of up to 93%); in the non-ferrous metal industry: digital intelligent electrolyzers and leaching residue resource utilization technologies; in the iron and steel industry: short-process steelmaking and waste heat recovery technologies; in the building materials industry: low-resistance cyclone preheaters and non-carbonate raw material substitution technologies (Source: Department of Industry and Information Technology of Xinjiang Uygur Autonomous Region). ③ Industrial Digitalization and Intelligent Regulation Technologies. Industrial internet platforms, full-process production energy efficiency optimization systems, and real-time carbon emission monitoring and regulation technologies to support the precise carbon reduction of high-energy-consuming enterprises.

(2) Key Technologies for Energy Substitution

① High-efficiency New Energy Development Technologies. Linear Fresnel concentrated solar power technology (with a mirror field area of 1.63 million square meters and an annual power generation capacity of 3.2 billion kWh), high-efficiency photovoltaic modules and tracking systems, "photovoltaic + desert control" coordinated development technology, and integrated construction technology for 10-million-kilowatt-level new energy bases. ② New Energy Storage and Power Grid Adaptation Technologies. Compressed carbon dioxide molten salt energy storage technology (with an electricity-to-electricity conversion efficiency of 64%), all-vanadium redox flow battery hybrid energy storage technology (with a response time of less than 5 milliseconds), hydrogen energy storage peak shaving technology, as well as UHV power transmission, smart power grid dispatching, and distributed power grid connection technologies. ③ Clean Fossil Energy Technologies. "Three-in-one transformation" technologies for coal-fired power units (flexibility transformation, energy-saving transformation, and heating transformation), coal quality grading and utilization technology, and high-efficiency coal gasifier and synthesis reactor technologies. ④ Full Hydrogen Industry Chain Technologies. Green power electrolysis water hydrogen production technology, high-efficiency hydrogen storage and transportation technology, hydrogen heavy-duty truck application technology, and integrated wind-solar-hydrogen-storage-vehicle technology.

(3) Key Technologies for Ecological Carbon Sink Enhancement

① Arid Area Ecological Restoration and Carbon Sink Enhancement Technologies. Saline water irrigation afforestation technology for mobile dunes, non-irrigation afforestation technology for active dunes, construction technology of oasis "narrow forest belt, small grid" protection system, grazing prohibition and enclosure restoration technology for degraded grasslands, and in-situ planting technology of halophytes in saline-alkali land. ② Carbon Sink Measurement and Monitoring Technologies. Multi-source remote sensing and forest inventory data fusion technology, forest age-carbon density model (with a coefficient of determination of 0.785-0.957), desert ecosystem carbon sink accounting method, and dynamic monitoring technology for forest and grass carbon sinks. ③ Carbon Sink Value Conversion Technologies. Forest and grass carbon sink project development technology, third-party verification technology, carbon sink product trading connection technology, and "carbon sink + cultural tourism" integrated development technology.

(4) Key Technologies for System Coordination

① Circular Economy Technologies. Industrial solid waste resource utilization technology (recovery and utilization of coal chemical waste residue and non-ferrous smelting slag), construction waste recycled aggregate preparation technology, sewage resource utilization technology, and circular sharing technology for logistics loading equipment. ② Low-Carbon Transportation Technologies. Hydrogen heavy-duty truck and new energy vehicle application technology, intermodal transportation optimization technology, smart logistics dispatching system, and charging pile and hydrogen refueling station layout and construction technology. ③ Low-Carbon Urban and Rural Construction Technologies. Zero-energy building integration technology (solar photovoltaic, ground-source heat pump, fresh air heat recovery integration), prefabricated building and assembly decoration technology, low-carbon heating and heating pipe network insulation technology, and building-integrated photovoltaic technology. ④ Digital Collaborative Management and Control Technologies. Carbon emission big data platform construction technology, virtual power plant operation technology, demand response technology, and green building materials blockchain traceability technology.

4.3 Key Tasks

Xinjiang's main tasks for carbon neutrality focus on six key fields, centering on low-carbon transformation and green development, and clarifying the core measures and goals of each field: In the industrial field, promote the low-carbon transformation of traditional high-energy-consuming industries, drive the "oil reduction and chemical increase" of the oil and gas chemical industry, transform the coal chemical industry to high-end chemicals and supporting CCUS projects, optimize the production capacity and technology of the non-ferrous, iron and steel, and building materials industries, cultivate emerging low-carbon industries such as hydrogen energy and silicon photovoltaic, and strictly control the addition of "two high" projects and inefficient production capacity; In the energy field, accelerate the construction of 10-million-kilowatt-level new energy bases, build a diversified energy storage system, strengthen the power grid, improve the new energy consumption capacity, promote the "three-in-one transformation" of coal-fired power units and the clean and efficient utilization of coal, and promote the transformation of fossil energy into peak shaving power sources; In the transportation field, promote the low-carbon substitution of transportation equipment, popularize new energy buses and hydrogen heavy-duty trucks, eliminate old high-energy-consuming vehicles, optimize the transportation structure, improve intermodal transportation and green transportation infrastructure, and increase the proportion of green travel; In the urban and rural construction field, fully popularize green buildings, promote the energy-saving transformation of existing buildings and the development of prefabricated buildings, optimize urban and rural planning, popularize clean heating models, and increase the proportion of renewable energy in building energy consumption; In the ecological carbon sink field, coordinate the integrated governance of mountains, rivers, forests, farmland, lakes, grasslands and deserts, implement ecological restoration projects to enhance carbon sequestration capacity, promote the development and market trading of forest and grass carbon sink projects, and explore new models of carbon sink value conversion; In the circular economy field, take industrial parks as carriers, promote the resource utilization of industrial solid waste, improve the urban and rural waste collection, transportation, disposal and logistics recycling system, improve the efficiency of resource recycling, reduce resource consumption and carbon emissions, and comprehensively help achieve the carbon neutrality goal.

5. Policy Recommendations

Low-carbon transformation is a long-term project to promote systematic economic and social changes. It is necessary to provide comprehensive support for Xinjiang to achieve the goals of carbon peaking and carbon neutrality by improving the policy system, strengthening resource guarantees, and optimizing the governance mechanism. Based on Xinjiang's energy endowment, industrial structure and ecological function positioning, the following guarantee and implementation mechanisms are constructed.

5.1 Policy Guarantee

Improve the local legal framework, revise and improve supporting regulations, and formulate special regulations for key regions. Strengthen policy coordination and implementation, establish a "1+N" policy system, improve the target assessment system, and refine the industry supervision mechanism. Optimize industrial and energy policies:

in terms of industrial policies, implement a "low-carbon priority" industrial access system, control restricted industries, and phase out eliminated industries within a time limit; in terms of energy policies, improve the renewable energy consumption guarantee mechanism and deepen the reform of the power system.

5.2 Financial Support Guarantee

Increase financial capital investment, establish a regional special fund for low-carbon transformation, coordinate and integrate various funds, focus on supporting fields such as energy structure adjustment, emission reduction in key industries, and urban low-carbon transformation, and issue local government low-carbon special bonds. Innovate green financial instruments, promote carbon financial products, support enterprises in issuing green bonds, and establish low-carbon industry investment funds. Expand channels for social capital and international funds, guide the participation of social capital, actively utilize international funds, deepen green financial cooperation under the "Belt and Road" Initiative, and build a green investment platform with Central Asian countries.

5.3 Technological Guarantee

Lead low-carbon transformation through technological breakthroughs, build a full-chain system of "R&D-demonstration-promotion", enhance independent innovation capacity, and promote the transformation and application of technological achievements. Strengthen key technological research, and implement major science and technology projects focusing on key fields such as new energy, energy storage, hydrogen energy, CCUS, industrial energy conservation, and ecological carbon sinks. Intensify basic research and build industrial common technology platforms. Promote the transformation and demonstration of technological achievements, improve the technology transformation mechanism, build technology demonstration bases, and compile technology promotion catalogs. Improve the innovation service system, establish a technology evaluation service platform, strengthen the protection of intellectual property rights, and promote the integration of industry, university and research.

5.4 Talent Guarantee

Improve the organizational coordination mechanism, establish a leading group for carbon peaking and carbon neutrality work in the autonomous region, set up a joint meeting system, and strengthen coordination between the military and local governments. Strengthen the construction of talent teams, formulate talent development plans, cultivate local talents, introduce high-level talents, and improve the talent evaluation mechanism.