

China's Low-Carbon Transition: Current Status and International Insights

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Abstract

Amid escalating global climate change, low-carbon transition has become a central global concern. As the world's largest developing nation and leading carbon emitter, China faces significant pressure to cut emissions while sustaining economic growth. This paper analyzes the current state and challenges of China's low-carbon transition. Despite recent government initiatives—such as carbon trading schemes and clean energy investments—emission reduction progress remains slow. Challenges include reliance on carbon-intensive industries, limited energy diversity, slow technological innovation, an incomplete policy framework, and low public awareness. International comparisons reveal significant differences in carbon emissions and trends between China and regions like the U.S., EU, and India. The paper also examines low-carbon strategies in the UK, Germany, and Japan, offering recommendations for China to optimize industrial and energy structures, boost technological innovation, refine policies, raise public awareness, and enhance international cooperation to support the sustainable development of China's low-carbon transition.

Keywords

China's Low-Carbon Transition, Carbon Emissions, International Experiences

1. Introduction

Since the Industrial Revolution, fossil fuel-driven human activities have caused a continuous rise in atmospheric CO₂ levels, leading to ecological risks and cascading effects on Earth's ecosystems. To counteract the alarming trend of global warming, 197 countries signed the Paris Agreement in 2015, pledging to limit the global temperature increase to well below 2°C above pre-industrial levels, with an ambition to cap it at 1.5°C. As a responsible developing nation, China plays a pivotal

role in global climate action and environmental governance. On September 22, 2020, at the 75th United Nations General Assembly, President Jinping Xi announced China's goals to peak carbon emissions before 2030 and achieve carbon neutrality by 2060. Consequently, exploring optimized pathways for urban low-carbon transitions is critical for harmonizing low-carbon development with high-quality economic growth under China's "dual carbon" targets.

Promoting low-carbon economic transformation has become a crucial strategy for achieving high-quality economic development. The challenge of effectively reducing carbon emissions and advancing low-carbon transitions has drawn significant attention from scholars both domestically and internationally. Numerous studies have analyzed urban low-carbon transitions, focusing on key factors such as environmental legislation, the digital economy, digital finance, and industrial transformation policies.

Yu et al. (2022) found that urban environmental legislation promotes low-carbon transitions primarily through the effects of environmental information disclosure, supervision, and industrial upgrading, along with positive spatial spillover effects. Comprehensive environmental and air pollution legislation, in particular, was shown to be especially effective in fostering low-carbon economic transformation. Additionally, urban environmental legislation has a more pronounced impact on low-carbon transitions in innovative policy pilot cities, "two control zones" cities, non-old industrial base cities, and cities in the middle and lower reaches of the Yangtze River Economic Belt. These findings offer essential theoretical and practical insights for advancing low-carbon economic transformation.

Moreover, the digital economy has been shown to reduce urban carbon emissions and improve total factor carbon productivity by enhancing energy efficiency, advancing green technology, and upgrading industrial structures (Zhang et al., 2022). Zhu and Zhang (2022) demonstrated that digital finance directly boosts urban green total factor productivity. Additionally, through scale, technology, and structural effects, digital finance indirectly enhances green total factor productivity by correcting capital misallocation, fostering green innovation, and advancing industrial structure upgrading.

Fu et al. (2023) highlighted that industrial transformation policies significantly improve urban total factor carbon productivity. These policies have a notable impact on low-carbon governance in resource-based, compound, and cluster cities, though they are less effective in old industrial bases and mono-industrial cities. Industrial transformation policies, driven by government initiatives, primarily promote urban low-carbon transitions through structural upgrading and green innovation mechanisms, while the benefits of agglomeration economies have yet to materialize in the short term.

Liu et al. (2022) synthesized lessons from the UK, Germany, and Japan, concluding that accelerating technological innovation, improving construction efficiency, strengthening collaborative governance, and enhancing construction

quality can all facilitate urban low-carbon transitions. They also emphasized the importance of considering China's economic growth trends and the internal and external factors influencing urban development when devising low-carbon urban strategies, with a focus on fairness, efficiency, and quality. [Bunning et al. \(2013\)](#) investigated sustainable low-carbon urban planning in Australia. Additionally, [Caprotti \(2017\)](#) identified that focusing on district-level transformations by leveraging economic, engineering, technological, and political resources is a key strategy for achieving urban low-carbon goals in Hong Kong SAR and other regions. [Zhang and Zhang \(2020\)](#) showed that the combined effects of low-carbon technological advancement and environmental regulation policies facilitate the low-carbon transition of resource-based cities by channeling more capital into technological innovation and concentrating efforts in low-carbon industries, thereby driving low-carbon economic growth.

Building on existing research, this paper provides a thorough analysis of the current state and challenges of China's low-carbon transition. It compares China with other regions, including the United States, the European Union, and India, highlighting key differences in carbon emissions and growth trends. The paper also examines the low-carbon transition experiences of countries such as the United Kingdom, Germany, and Japan.

The innovation of this paper lies in its comprehensive analysis and unique perspective on the urgency of China's low-carbon transition through cross-border comparisons. It emphasizes the specific practices of countries that have successfully achieved low-carbon transitions and offers actionable strategies that serve as practical references for designing China's transition pathway.

The paper's main contributions are threefold: First, it provides policymakers with detailed data and a robust analytical framework to better understand China's low-carbon transition status and bottlenecks, facilitating the development of more effective policies. Second, it presents a diverse range of solutions and strategies for China's transition, derived from a systematic review of international experiences. Third, it raises awareness of the low-carbon transition's critical importance and urgency by highlighting its role in addressing global climate change, promoting sustainable economic development, and enhancing national competitiveness, thereby fostering broader social engagement and support for advancing China's low-carbon transition.

2. China's Low-Carbon Transition: Current Status and Issues

2.1. Current Status of China's Low-Carbon Transition

In the early 1990s, China's economy was relatively underdeveloped, and its carbon emissions were comparatively low. According to World Bank data, China emitted 2.173 billion tons of CO₂ in 1990, less than half of the United States' emissions. However, as China's economy rapidly expanded and industrialization and urbanization accelerated, carbon emissions began to rise sharply. Between 1990 and 2000, China's carbon emissions increased by 53.98%.

As the 21st century began, China emerged as a major global hub for manufacturing and industrial production, leading to a continued surge in carbon emissions. From 2000 to 2010, China's carbon emissions grew by 153.25%, largely due to its heavy reliance on coal for energy, resulting in significant CO₂ emissions.

Starting in 2011, the Chinese government adopted proactive environmental policies and measures to address the challenges of carbon emissions and climate change. In 2013, China launched a national carbon emissions trading pilot program to promote carbon market development and emissions reduction. The country also increased investments in clean energy, particularly in renewable sources like solar and wind power. Between 2011 and 2019, the growth in carbon emissions began to slow, with a brief decline observed from 2014 to 2016. During this period, the government implemented a range of policies, including enhancing energy efficiency, promoting clean energy, and tightening industrial emission standards. Additionally, China made significant strides in developing new energy vehicles and energy-efficient buildings to further reduce emissions.

At the 2014 UN Climate Change Summit, China committed to peaking its carbon emissions by 2030 and increasing the share of non-fossil fuels in its energy consumption to 20%. To meet this target, China has consistently increased its investment in renewable energy and gradually reduced its dependence on coal. By 2019, although China remained among the highest emitters globally, the growth rate of emissions had slowed. Meanwhile, China achieved remarkable progress in the renewable energy sector, becoming the world's largest producer of solar and wind power, according to the National Energy Administration.

2.1.1. International Comparison of Carbon Emissions

Figure 1 illustrates significant disparities in carbon emission trends across different countries and regions from 1990 to 2019.

China is currently the world's largest carbon emitter. From 1990 to 2019, rapid industrialization, urbanization, and a heavy reliance on coal fueled a nearly four-fold increase in China's carbon emissions, from 2,173.36 million tons to 10,707.22 million tons. Notably, between 2002 and 2011, the annual growth rate of these emissions averaged 10.40%.

Similarly, the United States, the world's second-largest emitter, experienced a notable increase in carbon emissions during this time, despite some progress in energy efficiency and the adoption of clean energy technologies. However, unlike China, U.S. emissions have been on a gradual decline since 2010, primarily driven by the widespread adoption of natural gas and increased investments in renewable energy.

In contrast, the European Union has managed to maintain a relatively stable level of carbon emissions during this period. Through aggressive emission reduction policies, such as improving energy efficiency, promoting renewable energy, and establishing carbon markets, the EU has even achieved a slight decline in emissions.

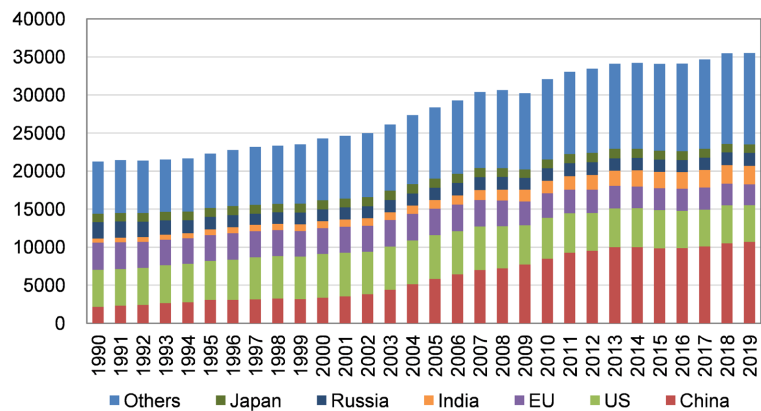


Figure 1. Carbon emissions by country/region (million tons), 1990-2019. Data source: World Bank database.

India, on the other hand, represents one of the fastest-growing sources of carbon emissions globally. As the country's economy and population rapidly expanded, so did its carbon emissions. Recognizing the urgency, the Indian government has initiated several measures to promote renewable energy and enhance energy efficiency, aiming to curb the rising emissions.

Russia's carbon emissions have shown variability over these years, largely due to shifts in its energy and industrial sectors. Economic transformations and policy adjustments have contributed to these fluctuations, reflecting the country's ongoing challenges in stabilizing its emissions.

Finally, Japan's carbon emissions have remained relatively stable over the past 30 years. The Japanese government has focused on improving energy efficiency, advancing nuclear energy, and promoting clean energy, which has collectively helped maintain stability in emissions.

In summary, while global carbon emissions have continued to rise, particularly due to the contributions of emerging economies like China and India, there remains a notable imbalance in emissions across different nations, highlighting the diverse challenges and responses among major emitters.

From 1990 to 2019, the six major global carbon emitters—China, the United States, the European Union, India, Russia, and Japan—consistently accounted for nearly 70% of global carbon emissions, as illustrated in **Figure 2**. However, the distribution of emissions among these entities has undergone significant shifts.

In 1990, the United States was the largest carbon emitter globally, responsible for 22.77% of total emissions, followed by the European Union at 16.75%. During this period, China, Russia, Japan, and India had relatively lower shares of global emissions. However, China's rapid economic growth and accelerated industrialization led to a dramatic increase in its carbon emissions. By 2005, China had overtaken the United States to become the world's largest carbon emitter. China's share of global emissions continued to rise, reaching 30.15% in 2019.

In contrast, the shares of the United States and the European Union gradually

declined. Although the United States remained the second-largest emitter, its emissions stabilized or slightly decreased. The European Union, through efforts to promote clean energy and improve energy efficiency, successfully reduced its share of global emissions. India's share also increased over these 30 years, though at a slower pace compared to China. Meanwhile, Russia and Japan saw a decline in their respective shares of global carbon emissions.

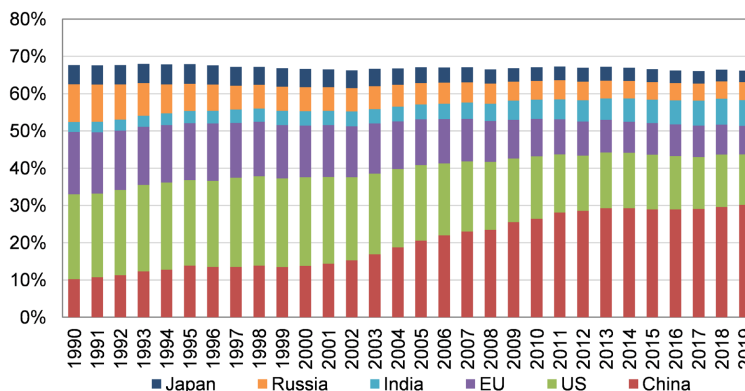


Figure 2. Proportion of carbon emissions from the six major global emitters, 1990-2019. Data source: World Bank database.

2.1.2. China's Carbon Emissions by Industry

From 1997 to 2019, China experienced substantial economic growth and industrialization, which significantly increased the country's carbon emissions, establishing it as one of the world's largest carbon emitters. Among the major industrial sectors, the energy sector stands out as a primary source of these emissions. The rapid pace of economic expansion and the rising demand for energy have driven extensive extraction, production, and consumption of coal, oil, and natural gas, all of which are major contributors to carbon emissions.

Manufacturing, a cornerstone of China's economy, also represents a significant source of carbon emissions. Key industries such as steel, cement, and chemicals generate large quantities of CO₂ and other greenhouse gases during their production processes. Additionally, China's urbanization and population growth have led to a dramatic rise in transportation needs, resulting in a surge in vehicle use and public transport. Consequently, the transportation sector has become a significant emitter due to its reliance on fossil fuels.

The construction industry plays a critical role in China's carbon footprint as well. Large-scale urban development and real estate expansion have driven extensive use of building materials, and both the construction process and the operational life of buildings contribute to carbon emissions.

Looking at specific subsectors, as shown in **Figure 3**, the electricity, steam, and hot water production and supply industry records the highest carbon emissions among 43 subsectors. This is followed by the ferrous metal smelting and pressing industry, as well as the non-metallic mineral products industry. Additionally, the transportation, storage, postal and telecommunications services, and the chemical

raw materials and chemical products industries are also significant contributors to carbon emissions. Overall, with the rapid economic development and industrialization in China, carbon emissions across these 43 industries have generally been on the rise. While government policies and measures have had some effect in curbing emissions, sustained efforts are essential to address the challenges posed by climate change and to achieve sustainable development.

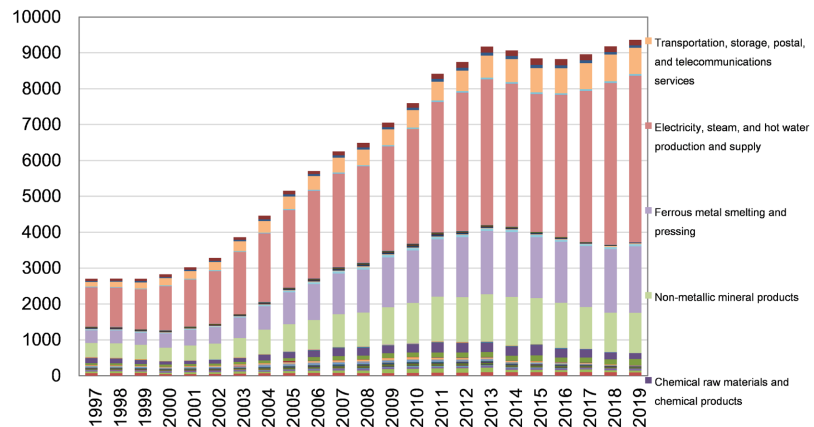


Figure 3. Carbon emissions of 43 industries in China (million tons), 1997-2019. Note: Data sourced from the CEADs database. For brevity and clarity, only the top 5 industries with the highest carbon emissions are listed in the legend.

2.1.3. Regional Distribution of Carbon Emissions in China

As one of the world's most populous countries and largest carbon emitters, China has experienced rapid urbanization over the past few decades, significantly impacting carbon emissions across its cities. The regional distribution of these emissions reflects differences in economic development, industrial structure, and consumption patterns.

Firstly, carbon emissions are highest in China's eastern coastal cities, such as Beijing, Shanghai, Guangzhou, and Shenzhen. These cities, serving as economic engines and major transportation hubs, are characterized by advanced manufacturing sectors, dense populations, and extensive transportation networks, leading to higher emissions from industrial production, energy consumption, and transportation.

Secondly, the western regions of China exhibit relatively lower carbon emissions. These regions are less developed and have a lower degree of industrialization compared to the eastern coast. Additionally, the western regions are home to vast agricultural lands and natural resources, with lower population densities. However, as economic development in the western regions accelerates, carbon emissions are on the rise.

Thirdly, large and medium-sized cities generally have higher carbon emissions. Cities such as Chongqing, Chengdu, and Wuhan, which are major economic centers and transportation hubs, have substantial emissions primarily stemming from industrial production, energy consumption, and transportation.

Fourthly, the distribution of urban carbon emissions in China is closely linked to the level of economic development. Highly developed regions, such as the Pearl River Delta and the Yangtze River Delta, with their advanced manufacturing and service industries, produce higher carbon emissions. In contrast, less developed regions, such as the western and northeastern areas, have lower emissions due to their economic structure and energy consumption patterns.

Lastly, the Chinese government has been actively working to reduce carbon emissions and enhance environmental protection. Policies and measures promoting energy conservation, clean energy, green transportation, and increased energy efficiency in industry and construction have been implemented. While these efforts have succeeded in slowing the growth of urban carbon emissions, significant challenges remain.

2.2. Challenges in China's Low-Carbon Transition

Despite the proactive measures taken by the Chinese government since the early 21st century—such as initiating carbon emissions trading pilots, increasing investments in clean energy, and promoting renewable energy—rapid economic growth, industrialization, and urbanization continue to drive up carbon emissions.

The first major challenge is China's industrial structure and energy dependency. The economy has long relied heavily on heavy industry and fossil fuels, particularly coal. This high-carbon development model is not easily shifted in the short term. As urbanization continues, the growing demand for energy in infrastructure construction and real estate development further complicates efforts to curb emissions.

Secondly, the slow pace of technological innovation and industrial upgrading is a significant obstacle. While China has made strides in clean and renewable energy, it still lags behind developed countries in critical areas such as energy-efficient technologies and carbon capture and storage. Moreover, the slow progress in industrial upgrading and transformation hinders the establishment of a low-carbon, circular economy.

Thirdly, the underdeveloped policy framework and market mechanisms pose additional challenges. Although the government has introduced various low-carbon policies, their implementation and effectiveness need strengthening. The carbon market mechanism is still incomplete, with unresolved issues in pricing, trading, and regulation of carbon emissions rights, limiting the market's role in resource allocation.

Finally, public awareness and participation in low-carbon practices need to improve. The transition to a low-carbon economy is not solely the government's responsibility; it requires broad societal engagement. However, public awareness and adoption of low-carbon lifestyles are still low, and practices such as low-carbon consumption and green transportation are not yet widespread. This lack of public engagement slows the progress of the low-carbon transition.

3. International Insights into Urban Low-Carbon Transition

3.1. The UK's Approach to Low-Carbon Transition

The UK government has implemented several pioneering low-carbon policies and regulations. A notable example is the introduction of a climate tax, which applies to all non-residential electricity consumption while exempting basic residential use. Additionally, companies utilizing certified clean energy qualify for partial tax exemptions. These measures have proven effective, with numerous companies surpassing their emission reduction targets. Building on this success, the UK government established legally binding requirements for energy conservation and emissions reduction, including the enactment of the Climate Change Act and the creation of the Department of Energy and Climate Change (DECC). These actions were complemented by a suite of policies that have significantly advanced the UK's low-carbon economy.

Technologically, the UK has placed strong emphasis on the development and deployment of low-carbon technologies, with substantial investment in R&D and the application of these technologies across various sectors. This focus has been instrumental in driving the transition to a low-carbon economy. The UK has directed significant funding towards the development and utilization of clean and low-carbon energy, including renewable energy, low-carbon transportation, energy-efficient power generation, energy-saving heating, energy storage, and carbon capture. Moreover, the UK has sought to elevate its research capabilities through international collaboration, establishing alliances with EU member states to fund cutting-edge research in areas such as low-carbon fuels, bioenergy, nuclear technology, offshore wind power, and hydrogen fuel cells.

3.2. Germany's Approach to Low-Carbon Transition

Germany's "Energiewende" (Energy Transition) policy has been the central strategy for restructuring its energy system. Under this long-term policy, Germany has gradually decoupled economic growth from energy consumption. The country has long supported the development of renewable energy, starting with legislation in the 1990s, including the Electricity Feed-In Act and the subsequent Renewable Energy Sources Act.

The introduction of an energy tax has been another key element in Germany's low-carbon transition, using price signals to guide greenhouse gas emissions. Germany has developed a comprehensive legal and regulatory framework for its carbon trading market, serving as a model for other nations. Companies are required to purchase emission allowances, with penalties for exceeding their limits. Additionally, Germany has implemented tiered tax rates for motor vehicles, incentivizing low-emission cars with lower taxes while restricting the sale and use of high-emission vehicles. These economic measures have been effectively and efficiently enforced.

Raising public awareness about low-carbon living is a cornerstone of Germany's low-carbon strategy. The German government has emphasized environmental

education, fostering a culture of environmental responsibility through a coordinated approach involving schools, societal resources, and grassroots initiatives. This strong governmental advocacy has ingrained the concept of a low-carbon society deeply into public consciousness.

3.3. Japan's Approach to Low-Carbon Transition

Japan has prioritized funding for critical technological policies through its science and technology budget, while also aggressively promoting the development of new energy sources. Offshore wind power has been identified as a key clean energy source, with plans to expand wind capacity to 45 million kilowatts over the next 20 years, equivalent to 45 nuclear reactors. Additionally, Japan is focusing on developing new fuel sources, such as ammonia and hydrogen, and has made substantial investments in the hydrogen energy sector to create a low-cost hydrogen supply chain. By 2019, the Japanese government had invested \$300 million in hydrogen energy research and development.

International cooperation on low-carbon transition is a global imperative, and Japan has made it a focal point of its diplomatic efforts. Japan leverages its technological expertise to host significant international events such as the G8 Summit, the Tokyo International Conference on African Development, and ministerial meetings on science and technology, positioning itself as a leader in addressing global climate challenges.

4. Conclusion and Policy Implications

In recent years, the escalating global climate crisis has made greenhouse gas reduction and low-carbon transition a critical concern worldwide. As the world's largest developing country and leading carbon emitter, China's low-carbon transition is essential not only for its own sustainable development but also for global climate governance. To manage the pressures from rapid economic growth, the Chinese government has implemented various measures, including promoting clean energy development, launching carbon emissions trading, and enhancing energy efficiency. However, challenges such as a heavy industrial structure, reliance on a singular energy source, and lagging technological innovation continue to hinder China's progress toward a deeper low-carbon transition.

This study offers a comprehensive overview of China's current low-carbon transition, highlighting China's role and trends in the global carbon landscape by comparing international carbon emission data. It then delves into the key challenges and obstacles China faces in its low-carbon efforts. To provide valuable insights, the study examines successful low-carbon strategies from three representative countries: the United Kingdom, Germany, and Japan. Finally, it proposes targeted recommendations for China's urban low-carbon transition, offering policymakers scientific evidence to further China's low-carbon development.

Our findings indicate that since the early 21st century, China has made substantial progress in its low-carbon transition, notably through carbon trading pilots,

increased clean energy investments, and the promotion of renewable energy. These efforts have slowed the growth of carbon emissions and led to significant achievements in the renewable energy sector. However, China's heavy reliance on industries dependent on fossil fuels like coal, combined with a narrow energy mix, presents significant barriers to further progress. Additionally, the pace of technological innovation and industrial upgrading has been slow, especially in crucial areas such as energy efficiency and carbon capture and storage, where China lags behind developed countries. The policy framework and market mechanisms also remain underdeveloped, with enforcement and market-based approaches requiring further enhancement. Public awareness and participation in low-carbon practices are also low, with limited adoption of low-carbon lifestyles further impeding progress.

To address these challenges, this study emphasizes that the successful strategies of developed countries like the UK, Germany, and Japan—comprehensive policy frameworks, advanced low-carbon technology R&D, robust market mechanisms, and heightened public awareness—offer valuable lessons for China. These strategies are crucial for optimizing and accelerating China's future low-carbon transition.

To address the challenges in China's urban low-carbon transition, it is essential to promote the development of high-tech industries, services, and modern agriculture, reducing reliance on traditional heavy industries through policy guidance and financial support. Implementing stricter environmental standards and carbon emission limits can drive industries toward low-carbon and environmentally friendly practices. Increased investment in clean and renewable energy will further reduce dependence on fossil fuels. Setting ambitious renewable energy development targets can serve as a strategic priority in this transition.

Dedicated budgets should be allocated to support research, development, and the application of key technologies such as energy efficiency and carbon capture and storage. Enhancing international scientific collaboration will be crucial for importing, adapting, and innovating advanced technologies. An industrial upgrading strategy should be developed to encourage companies to achieve energy savings and emission reductions through technological renovation and upgrades. Establishing a green supply chain system will promote resource sharing and recycling among enterprises, thereby creating a low-carbon circular economy.

China should also focus on formulating and refining its low-carbon policy and regulatory framework, setting clear emission reduction targets and timelines to strengthen legal enforcement. Supporting policies such as tax incentives and subsidies will encourage both corporate and individual participation in the low-carbon transition. Enhancing the carbon trading system to ensure fair pricing, trading, and regulation of carbon emission rights will be vital. A comprehensive legal and management framework for carbon markets will be crucial for effective market oversight and enforcement.

To raise public awareness and participation in low-carbon practices, a collaborative

approach involving school education, social resources, and grassroots initiatives is recommended. Increasing public knowledge and acceptance of low-carbon lifestyles should be a priority. Media and online platforms should be leveraged to actively participate in low-carbon awareness campaigns, fostering a positive societal atmosphere. Policy guidance and market mechanisms can be used to incentivize low-carbon consumption and green transportation, such as offering tax breaks or subsidies for purchasing new energy vehicles and using public transportation. Expanding the development of bicycle lanes and pedestrian paths will further facilitate green travel.

Finally, active participation in global climate governance through enhanced exchanges and cooperation with other countries in low-carbon technologies, financing, and policies will enable China to jointly address global climate challenges and share successful experiences and practices in the low-carbon transition.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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