DOI 10.15302/J-SSCAE-2021.06.008

Paths for Carbon Peak and Carbon Neutrality in Transport Sector in China

Li Xiaoyi[1,2], Tan Xiaoyu[1,2], Wu Rui[1,2], Xu Honglei[1,2], Zhong Zhihua[3], Li Yue[1,2], Zheng Chaohui[1,2], Wang Renjie[1,2], Qiao Yingjun[4]

1. Institute of Environment and Resources, Transport Planning and Research Institute, Ministry of Transport, Beijing 100028, China
2. Laboratory of Transport Pollution Control and Monitoring Technology, Transport Planning and Research Institute, Ministry of Transport, Beijing 100028, China
3. Chinese Academy of Engineering, Beijing 100088, China
4. Center for Strategic Studies, Chinese Academy of Engineering, Beijing 100088, China

Abstract: Peaking carbon dioxide emissions and achieving carbon neutrality is a major strategic decision made by China and it brings significant pressure and challenges to the transport sector. Peaking carbon emissions is an important direction for the realization of the high-quality development and green transformation of the transport sector. This study analyzes the status quo of green development and carbon emissions in China's transport sector and identifies the existing challenges toward achieving the carbon peak and carbon neutrality goals in the transport sector. The overall idea is to actively and steadily peak carbon emissions by implementing categorized policies, combining short- and long-term goals, controlling carbon emission increments, and adjusting the current emission structure. An overall carbon reduction path in the transport sector at different stages is proposed. Furthermore, we summarize several key measures to achieve carbon peak and carbon neutrality in the transport sector as follows: (1) optimizing the transport structure, (2) promoting the energy efficiency of transport equipment, (3) popularizing low-carbon transport equipment, (4) improving the traffic organizing efficiency, and (5) encouraging low-carbon travel modes.
Keywords: transport sector; carbon emission projection; carbon peak; carbon neutrality; development path

1 Introduction

Transportation is a key fossil fuel consumption sector and a major source of greenhouse gas (GHG) emissions. In recent years, it has become one of the fastest growing fields in China in terms of GHG emissions [1]. Presently, China's transport sector is still dominated by fossil fuel consumption, and the proportion of clean energy is still low. Based on the current situation and long-term development, it is difficult for the transport sector to peak carbon dioxide emissions. On one hand, the total transportation demand is increasing, and residents' demand for better travel services in terms of shortened travel time and improved convenience is increasing, thereby posing huge challenges for the control of total carbon emissions. Reducing carbon intensity hits a glass ceiling. On the other, clean energy has not been widely used in the transport sector, which largely depends on technological breakthroughs in equipment. Without active and sustained mitigation policies, the increase in carbon emissions would outpace that of other energy

Received date: October 12, 2021**; Revised date:** November 16, 2021
Corresponding author: Xu Honglei, senior engineer of Institute of Environment Resources, Transport Planning and Research Institute of Ministry of Transport. Major research fields include green and low-carbon development of transportation and technologies and policies for addressing climate change. E-mail: xuhl@tpri.org.cn
Funding program: CAE Advisory Project "Research on Carbon Peaking and Carbon Neutralization Strategies and Paths in China" (2021-HYZD-16)
Chinese version: Strategic Study of CAE 2021, 23(6): 015–021
Cited item: Li Xiaoyi et al. Paths for Carbon Peak and Carbon Neutrality in Transport Sector in China. *Strategic Study of CAE*, https://doi.org/10.15302/J-SSCAE-2021.06.008

end-use industries, probably making the transport sector the largest contributor to carbon emissions [2].

Presently, China's energy consumption in transport is dominated by fossil fuels, which emit large amounts of GHG and pollutants. This has worsened haze, acid rain, and greenhouse effects, as well as aroused attention from academia to the development path toward green transformation. Zhang et al. [3] drew advanced experiences from developed countries to promote low-carbon transport development and proposed accelerating carbon reduction by improving fuel efficiency and promoting clean energy. The shift to low-carbon fuels is expected to play an important role in mitigating climate change during transportation. Lu [4] proposed a phased low-carbon development path, that is, in the short term, to focus on energy conservation and emission reduction in transport equipment and technologies; in the medium term, to promote the use of non-fossil fuel in the transport sector; and in the long term, to promote the market application of hydrogen fuel. He also pointed out that the energy conservation and emission reduction of private cars will be the focus of low-carbon transportation research in China. Liu et al. [5] proposed a medium- and long-term development path for low-carbon transport transformation in China. The research pointed out that we should give full play to the emission reduction potential of urban public transport, pay attention to improving fuel economy, and promote new energy vehicles. Thus, the transport sector can realize low-carbon transformation in a technically feasible way. Yuan et al. [6] reviewed China's low-carbon transportation measures and pathways and pointed out that to peak carbon dioxide emissions in the transport sector, it was necessary to formulate more stringent fuel economy standards, promote alternative fuels, and encourage the use of low-carbon transport modes.

In a carbon peak and carbon neutrality context, the transport sector is facing mounting pressure on emission reduction. To peak carbon emissions and promote in-depth emission reduction in the transport sector is of great significance to achieve carbon peak and carbon neutrality goals for the whole country [7]. In light of international and domestic requirements for addressing climate change and high-quality development of the industry, it is urgent to accelerate the energy conservation and carbon reduction process in the transport sector and put forward a development pathway toward achieving carbon peak and carbon neutrality. This study reviews the current status of carbon emissions in the field of transportation, identifies the problems and challenges, determines the phased pathways, and proposes key measures to achieve carbon peak and carbon neutrality in the transport sector.

2 Current status of green development and carbon emission in the transport sector

Carbon emissions from transportation primarily emanate from vehicular fuel combustion. Based on energy consumption in the transportation field [8], this study calculates the direct carbon dioxide emissions from China's transport sector in 2019, excluding that of international shipping and aviation, as well as the indirect emissions from the use of electricity. In 2019, China's carbon dioxide emissions in the transportation field accounted for approximately 11% of the national total. The emission proportions from different modes of transport are shown in Fig. 1.

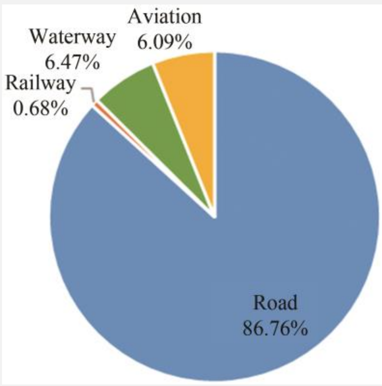

Fig. 1. Carbon emission proportions of different modes of transport in China.

The carbon emissions of specific transport modes differ significantly. Road transport, including private cars and business vehicles, is the major source of carbon emissions, accounting for 86.76% of the total. Waterway transport, civil aviation, and railway transport account for 6.47%, 6.09%, and 0.68%, respectively.

The carbon emissions from heavy trucks constitute the most significant share in road transport, accounting for 54% of the total emissions (Fig. 2). The second-largest emitters are passenger vehicles. In recent years, the scale of China's passenger vehicle market has expanded. In 2019, the ownership of passenger vehicles in China exceeded

DOI 10.15302/J-SSCAE-2021.06.008

220 million, leading to carbon emissions of 33.7% of the total road transport. The proportion of carbon emissions from other types of vehicles did not exceed 6%. It can be seen that heavy trucks and passenger vehicles hold the key to energy conservation and emission reduction in China's road transport in the future, as well as for the transport industry as a whole.

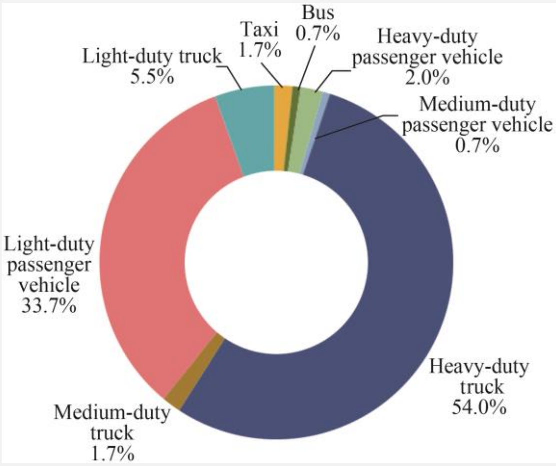

Fig. 2. Carbon emissions of different types of road transport vehicles in 2019.

In recent years, energy consumption and carbon emissions from the transport sector have received considerable attention, and administrative departments have introduced a package of measures to shift to low-carbon transport. In 2020, the number of city buses powered by new energy reached 466 thousand, with taxis and logistics vehicles reaching 132 thousand and 430 thousand, respectively [9]. The promotion of standardized ships for waterway transport has been facilitated, and the use of clean energy has improved. In 2020, 20 liquefied natural gas (LNG) stations were built for inland ships and more than 290 LNG-powered ships were built.

In addition, the administrative department has set up a series of targets to support the realization of energy conservation and emission reduction. (1) In terms of vehicle fuel consumption standards, the national mandatory standard *Fuel Consumption Limits for Passenger Cars* issued in 2021 stipulates that the average fuel consumption of new passenger vehicles will drop to 4 L/100 km (CO_2 emission is approximately 95 g/km) by 2025. (2) In terms of transport restructuring, the 14th Five-Year Plan for Green Transportation states that bulk cargo transportation as well as medium- and long-distance freight transportation should gradually shift to railway and waterway transportation. (3) In terms of green travel, it is pointed out in the *Action Plan for Promoting Green Travel* and the 14th Five-Year Plan for Green Transportation that the environment for green travel will be improved to encourage more urban residents to choose green travel. By 2025, the proportion of green travel is expected to reach 70% for more than 60% of cities participating in green travel action plans. (4) In terms of new energy vehicle equipment, it is proposed in the *New Energy Industry Development Plan (2021–2035)* and *Energy Conservation and New Energy Vehicle Technical Roadmap 2.0* that the sales of new energy vehicles will reach approximately 20% of the total, and the average power consumption of new pure electric passenger vehicles will be reduced to 12.0 kwh/100 km; by 2035, pure electric vehicles will become the mainstream in the new vehicle market, and vehicles in the public domain will be fully electrified.

3 Challenges for carbon reduction in the transport sector

3.1 Transport demand will continue to grow

Transportation provides basic support for travel and logistics. With the rapid socioeconomic development and ever-increasing improvement of people's living standards, transport demand is also increasing, thereby complicating the control of total carbon emissions. According to the *Guidelines on Developing Comprehensive Transport Network*, travel demand is expected to grow steadily, mostly in the form of high-quality, diversified, and personalized services. The average annual growth rate of passenger travel (including private cars) from 2021 to 2035 is estimated to be approximately 3.2% [10]. The proportion of travel by high-speed railway, civil aviation, and private cars will continue to increase, and the travel demand in city clusters is more vigorous. The eastern region of China will continue to face the fastest growing travel demand, and the growth rate of travel demand in the central and western regions will accelerate. The demand for freight transportation has increased steadily, while the demand for highvalue, small-batch, and time-efficient travel has increased rapidly. It is estimated that from 2021 to 2035, the average annual growth rate of the freight volume of the whole society will be approximately 2%, and the average annual growth rate of the express mail service will be approximately 6.3%. The transportation of foreign trade goods will maintain a growing trend in the long run, and the volume of bulk cargo will remain high for some time. The freight transport demand in the eastern region remains high, and the growth rate in the central and western regions will be faster than that in the eastern region. An increase in total transportation demand will lead to the continuous growth of carbon emissions.

3.2 Emission reduction from transport restructuring is time consuming and the effect declines

Presently, there is limited capacity for the main railway lines and special railways. It is time-consuming for the construction of railway infrastructure and the development of the railway freight market. It is difficult for railway freight to usher in explosive growth in a short time, which requires joint efforts from network construction, supporting facilities, quality of services, market development, and production efficiency. Constrained by the capacity of railway and waterway transport and appropriate freight types, the marginal benefits from transport restructuring will decrease in the long run, which means that its short-term contribution to carbon reduction is greater than that in the long term.

3.3 Technological uncertainty exists in transport energy adjustment

Substituting for clean energy in transport equipment is key to carbon reduction. Although the technology for new energy vehicles and light logistics vehicles has matured in recent years, there is still a lack of mature energy alternatives for heavy trucks and ships in the short term. For example, new energy heavy trucks encounter technical bottlenecks in terms of driving range and effective load, and hydrogen and ammonia fuel ships are still in the initial stages in terms of equipment research and development (R&D), supporting energy infrastructure construction, risk prevention and control, and standards development. Based on the current development status of new energy vehicles in China [11], approximately one million heavy trucks should shift to new energy if the transport sector is to attain the carbon peak target by 2030. From a technological development perspective, it is still uncertain whether new energy heavy trucks can be widely applied. Greater efforts are required to promote the use of new energy vehicles in passenger transport. The same emission reduction effect will be achieved to realize the carbon peak goal by 2030 if an extra of approximately 30 million new energy passenger vehicles can be promoted in 10 years. Therefore, the in-depth adjustment of energy use in the transport sector depends on the joint efforts of the whole society, industries, and departments to forge a new energy transport system featuring mature equipment, enhanced production capacity, stable energy supply, strong consumption demand, and improved infrastructure.

3.4 Carbon reduction funds are in huge demand

According to the IPCC Sixth Assessment Report [12], the cost of carbon reduction in the transport sector is significantly higher than that in the industrial and building sectors. The available reduction measures include a shift from road transport to railway and waterway transport, the elimination of old diesel trucks, and the development of a supporting energy supply system. As these measures require a large amount of capital investment with low economic benefits, it is difficult to encourage the engagement of local governments, transport enterprises, and business owners.

3.5 Carbon reduction involves multiple stakeholders

Transport involves a wide range of fields that are closely related to China's carbon peak goal. These fields include business vehicles, ships, railways, civil aviation, and private cars. It also needs to coordinate departments of railway, civil aviation, environment, industrial and information technology, and public security, with the working mechanism further improved and coordination strengthened. Carbon emissions from private cars account for more than one-third of the total transport emissions, and room for the growth of ownership is also large. Owing to the uncertain large-scale application of new energy heavy trucks, reducing emissions from private cars is particularly important [13], which depends on factors such as ownership, energy efficiency, and alternative new energy. The administrative measures available to the government to address these factors are rather limited [14]. Concerted efforts are needed from departments of environment, industry and information technology, public security, and transport to strengthen data sharing, conduct equipment R&D, and develop standards, thereby jointly contributing to carbon reduction for

DOI 10.15302/J-SSCAE-2021.06.008

private cars.

4 Roadmap for realizing carbon peak and carbon neutrality targets in the transport sector

The carbon peak and carbon neutrality targets bring challenges for transport development, as well as opportunities for the green transformation of the industry. The sense of urgency and enthusiasm for the transportation sector to reduce carbon emissions have been significantly enhanced. Achieving the carbon peak goal is closely related to the scale of transport development and intensity of carbon reduction measures. In the short term, transport will maintain a medium- to high-speed growth, while the promotion and application of the technology are time consuming. Therefore, the scale of transport growth is the main cause of carbon emissions. In the medium- and long-term periods, the transport growth rate will decelerate while the application of technologies improves; therefore, technologies and policies will play a major role in emission reduction.

This study follows the concept of “classifying policies, combining near and far, starting from easy and then difficult, controlling incremental and adjusting stock, and actively, steadily, and orderly reaching the carbon peak”. The general principle is to respect objective laws, seek truth from facts, pursue economic efficiency, and proceed in an orderly manner to meet the overall strategic arrangement of the country, satisfy the diversified travel needs of people, and achieve high-quality development of the transport sector. The core roadmap should focus on the wide use of electrified energy and green and efficient passenger and freight transportation to move toward carbon peak and carbon neutrality targets.

From 2021 to 2030, growing transport demand will lead to an increase in carbon emissions. The focus of carbon emissions in the transport sector is to strengthen the top-level design, introduce various action plans and guidelines, and improve statistics to optimize the transport structure, enhance energy efficiency, promote the use of clean energy, and encourage the green travel. Preparatory work also needs to be initiated to conduct R&D on low- or zero-carbon equipment technologies.

From 2030 to 2035, with the deceleration of transport growth and the promotion of carbon reduction measures, carbon emissions will enter a stable period. At this stage, carbon reduction is expected to rely on the large-scale use of new energy and energy efficiency improvement, with a focus on deepening carbon reduction in road transport.

From 2035 to 2050, carbon emissions in the transport sector are expected to decline with the replacement of new energy sources. Alternative fuels will start to play a key role, private cars, buses, taxis, and railway locomotives will be gradually electrified, vehicle energy efficiency will continue to improve, and mature automatic driving technologies will be applied.

From 2050 to 2060, the transport sector will enter a period of deep decarbonization, mainly relying on the large-scale use of new energy equipment and full integration of transport and energy. The focus will be on the carbon reduction of aviation and waterway transport to strive to realize near-zero emissions.

5 Policy recommendations for achieving carbon peak and carbon neutrality goals in the transport sector

5.1 Optimizing the transport structure

Optimizing the transport structure is one of the key measures toward realizing carbon peak goals. This includes facilitating a shift from road transport to railway and waterway transport for bulk cargo and medium- to long-distance freight transportation. Specific measures include the following:

It is advisable to make railway and waterway infrastructure more accessible and convenient; accelerate the construction of port rail transformation projects; connect port railways, main railway lines, and storage yards; and accelerate the construction of railway loading areas and supporting facilities in the port area. By 2030, China’s bulk cargo and major container ports in coastal and main inland port areas will be connected to port railways.

It is advisable to promote the development of multimodal transport and establish an efficient land–port–water coordination system. Efforts can be made to accelerate the planning and upgrading of railway logistics bases, railway container stations, port logistics hubs, air transfer centers, and express logistics parks, as well as facilitate the construction of multimodal transport hubs. The “one bill system” for multimodal transport should be promoted, standards and regulations aligned, and the use of a uniform electronic certificate for container multimodal transport facilitated. Efforts can also be made to promote the development of intermodal transport by linking railways with waterways, highways with railways, highways with waterways, and aviation with land transport, as well as by cultivating several leading multimodal transport enterprises with global influence.

It is advisable to increase the proportion of green transport in industrial enterprises and accelerate the construction of special railways for large industrial enterprises, such as coal, steel, electrolytic aluminum, electric power, coking, automobile manufacturing, cement, and building materials. For newly developed or relocated large industrial enterprises, special railway lines, ports, closed belt corridors, and other infrastructures should be planned and constructed simultaneously. It is also advisable to provide incentives to increase the proportion of green transport for bulk cargo delivery, including railways, waterways, closed belt corridor transport, and clean energy vehicles.

It is advisable to introduce financial subsidies and preferential policies for shifting from highway to railway, develop subsidies and loan preferential policies for the construction of special transit lines, adopt standardized charging policies for railway and waterway freight transport, and formulate a green transport support system.

5.2 Improving transport equipment efficiency

Improving the energy efficiency of transport equipment is an important means of achieving carbon peak and carbon neutrality targets in the transport sector. Priority should be given to improving energy efficiency standards, restricting market access, and accelerating the elimination of old vehicles and ships with high energy consumption and emissions. The specific measures are propounded as follows:

It is advisable to improve the energy consumption limit standards of vehicles, establish a vehicle carbon emission standards system, develop a fuel consumption detection system for business vehicles, and strengthen supervision. The elimination of backward technologies and high-consumption vehicles should be accelerated by means of economic compensation, strict supervision of excessive emissions beyond the standards, and enhanced vehicle detection and maintenance systems.

It is advisable to promote the implementation of the ship energy efficiency access system and establish energy efficiency indicators for new ships, phased implementation requirements, and verification mechanisms. Energy efficiency requirements should be regularly evaluated and adjusted, according to how energy-efficient technologies and alternative fuels are applied. It is also advisable to establish an energy consumption monitoring system, an energy efficiency verification mechanism, and assessment indicators for ships in operation, as well as formulate policies to restrict the use of old ships with high energy consumption. These ships are encouraged to be upgraded or withdrawn from the market ahead of schedule. The application of energy technologies, such as energy-saving appendages, drag reduction coatings, waste heat recovery, ship speed optimization, and trim optimization should be promoted, and greater efforts can be made to study and demonstrate how light materials, wind navigation, and photovoltaic power generation can be used on board.

It is advisable to promote vehicle energy-saving driving technology and ship best operation practices, incorporate energy-saving driving and navigation into training and examination, and increase the application of energy-saving technologies of on-site operation equipment in transportation hubs.

It is advisable to strengthen the R&D and application of energy-saving technologies, actively promote the use of intelligent, light, energy-efficient, and low-carbon business vehicles, as well as continue to improve fuel consumption limits and emission standards, give full play to the role of the fuel consumption detection systems on business equipment, and improve the management of fuel consumption limits for vehicles in operation. Automatic driving technologies for cars should be promoted, and pilot projects should be conducted on smart and automatic driving technologies for ships in coastal areas.

It is advisable to study and upgrade the fuel consumption limit standards of vehicles, formulate the energy efficiency access and exit system of ships, develop a carbon emission inspection and evaluation system for vehicles in operation, as well as assess and verify the energy efficiency systems of ships.

5.3 Promoting low-carbon transport equipment use

Promoting the use of low-carbon equipment is key to achieving carbon neutrality in the transport sector. Research on new energy transport equipment should be facilitated and applications in different places should be promoted.

It is advisable to accelerate the application of new energy in public, short-distance transport, and light trucks first, and gradually extend this to private cars, heavy trucks, and long-distance transport nationwide. Efforts can be made to accelerate the electrification of official cars and urban buses and demonstrate the use of pure electric, hydrogen fuel cell vehicles, including electrified road systems in freight transportation.

It is advisable to improve the construction of supporting facilities, such as charging, gas, and hydrogen stations in expressway service areas, ports, passenger transport hubs, logistics parks, and bus stations, and conduct pilot

DOI 10.15302/J-SSCAE-2021.06.008

projects on self-consistent energy systems.

It is advisable to encourage ships to use various forms of energy, such as shore power and hybrid power, and continue to increase the proportion of electricity, solar, wind, tidal, and geothermal energy used in port production and operation.

It is also advisable to continue to support the R&D of low-carbon key technologies for heavy equipment, create a favorable market environment for the application of clean energy equipment by developing standards and regulations, reduce cost with fiscal and market measures, as well as improve charging, hydrogen, and maintenance services.

It is advisable to introduce subsidies to eliminate old vehicles and ships, incentives for the use of new energy vehicles and ships, and differentiated charging policies. Subsidy policies for the construction and operation of new energy facilities, such as charging, hydrogen stations, and shore power, are also needed. It is advisable to provide incentives for the electrification of vehicle equipment and machinery in airports, ports, and hub stations; formulate policies that restrict access to near-zero carbon emission control areas for urban transport and low-carbon navigation control areas for ships; establish standards for carbon emission management; and implement a pioneering system for those enterprises that take the lead in reducing carbon emissions.

5.4 Increasing transport operation efficiency

Improving transport efficiency is also crucial to promote the transport achieving carbon peak and carbon neutrality targets. Thus, the development of high-efficiency smart transport should be further promoted. The specific measures are presented as follows:

It is advisable to actively develop freight transport networks, integrate logistics resources, improve the intensive development of freight logistics, and effectively reduce the empty driving rate. Efforts can also be made to develop smart logistics; improve the efficiency of freight systems; and encourage transport enterprises, logistics parks, ports, and stations to apply the Internet of Things, big data, automation, and other technologies to promote the use of automatic three-dimensional warehouses, intelligent sorting, and loading equipment.

It is advisable to build an intensive, efficient, green, and intelligent urban freight distribution system that enables the unified and time-sharing delivery of goods, which can be operated in alignment with drop and pull transport in the main railway lines. Policies related to urban green freight transport should be improved and underground logistics should be explored.

It is advisable to improve the construction of a three-level network of rural logistics, develop new models such as low-altitude rail transport, and promote resource integration of existing passenger and freight transport stations, postal service centers, road maintenance facilities, transport management resources, e-commerce networks, and rural supply and sales systems to improve the efficiency and service quality of available resources.

It is advisable to fully utilize automatic driving, intelligent travel, and shared technologies to reshape future passenger and freight transport and considerably improve the efficiency of the transportation system.

5.5 Encouraging green travel

The best supporting policy to achieve carbon peak is to encourage green travel. A favorable environment for green travel needs to be created, and market signals should be sent to encourage low-carbon transport. The specific measures are iterated as follows:

It is advisable to prioritize public transport and build an urban public transport system with urban rail transit as the backbone and conventional public transport as the main part. It is also advisable to build bus rapid transit systems, micro-circle transport, and other public transport systems based on local conditions; facilitate the construction of slow traffic systems, including urban pedestrian and bicycles; reasonably allocate parking facilities; undertake sidewalk cleanup actions; build bike routes according to local conditions; and encourage green travel.

It is advisable to promote the integration of main railway lines, intercity and urban (suburban) railways, and build an efficient and convenient city cluster rail transit network that connects central cities, surrounding cities (towns), and new towns. The integration of high-speed railway, rail transit, and urban public transport should be strengthened, a comprehensive transport hub concentrated by various traffic modes should be built, and an all-day-long integrated transfer system should be created to provide convenience to the intensive travel of the public.

Supported by the intelligent transport infrastructure network and management system, mobility as a service can be designed, and an integrated and convenient travel system dominated by public transport can be built to reduce dependence on private cars. Smart travel systems, such as reservation travel systems, can also be designed.

The market mechanism should be given full play to implement nationwide carbon incentives for green travel to get small- and medium-sized enterprises, communities, and individuals involved and ensure that they can obtain economic benefits with carbon credits. A household-based carbon account system can be gradually established to reduce high-carbon travel.

To ensure the continued implementation of emission reduction strategies in the transport sector, it is advisable to roll out action plans for achieving carbon peak at national and provincial levels, develop an efficient coordination mechanism between different departments, establish an energy consumption calculation system, introduce guidelines for compiling GHG emission inventories, and establish a monitoring, reporting, and verification system for energy consumption and carbon emissions. Efforts can also be made to actively explore market-based tools for diversified investment and financing and attract social capital to support the realization of carbon peak and carbon neutrality targets via green credit, green bonds, low-carbon transition funds, and emission trading systems.

References

[1] Oil Control Research Project Group. China's oil consumption scenario and peak analysis [J]. China Coal, 2019, 45(12): 20–26. Chinese.

[2] Tang B J, Li X Y, Yu B Y, et al. Sustainable development pathway for intercity passenger transport: A case study of China [J]. Applied Energy, 2019, 254: 113632.

[3] Zhang X L, Guo Q F, Chang S Y, et al. Resource and technical potential analysis of developing liquid biofuel in China [J]. China Energy, 2009, 31(3): 10–12. Chinese.

[4] Lu L. Traffic transformation and low carbon development: Focus, path and phase [C]. Guiyang: The 15th Annual Meeting of China Association for Science and Technology, 2013. Chinese.

[5] Liu J L, Sun Y H, Wang K, et al. Study on mid- and long-term low carbon development pathway for China's transport sector [J]. Climate Change Research, 2018, 14(5): 513–521. Chinese.

[6] Yuan Z Y, Li Z Y, Kang L P, et al. A review of low-carbon measurements and transition pathway of transport sector in China [J]. Climate Change Research, 2021, 17(1): 27–35. Chinese.

[7] Yu B J, Zhao G P, An R Y, et al. 2021. Research on China's CO_2 emission pathway under carbon neutral target [J]. Journal of Beijing Institute of Technology (Social Sciences Edition), 2021, 23(2): 17–24. Chinese.

[8] National Bureau of Statistics. Chinese energy statistical yearbook 2020 [M]. Beijing: China Statistics Press, 2021. Chinese.

[9] China Academy of Transportation Science. Sustainable development of transport in China [R]. Beijing: United Nations Global Sustainable Transport Conference, 2021. Chinese.

[10] Fu Z H, Sun Y F. Strategic research on transportation power [M]. Beijing: People's Communications Press Co., Ltd., 2019. Chinese.

[11] China Automotive Technology Research Center. Annual report on new energy vehicle industry in China (2021) [M]. Beijing: Social Sciences Academic Press, 2021. Chinese.

[12] Naik V, Szopa S, Adhikary B. 2021: Short-lived climate forcers [R/OL]. (2021-08-26)[2021-10-15]. https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Chapter_06.pdf.

[13] Feng Z H, Wang X C, Zhang H Y, et al. Path and policy of green transportation development from low carbon perspective [J]. Transport Research, 2019, 5(4): 37–45. Chinese.

[14] Wang H, Ou X, Zhang X. Mode, technology, energy consumption, and resulting CO2 emissions in China's transport sector up to 2050 [J]. Energy Policy, 2017, 109: 719–733.