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Green Transportation Development Strategies Under the Carbon Neutrality Goal

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Abstract: Transportation has long been one of the major contributors to greenhouse gas (GHG) emissions. Setting the carbon neutrality goal will profoundly affect transportation development. This paper presents an analysis of major dilemmas and challenges in the transportation sector with respect to carbon emissions reduction, including the discussion of diversified impacts of transportation demand, travel modes, land use development, and other factors. The paper proposes strategies to address the challenges from several aspects, such as new energy for vehicles, transportation mode share optimization, and residents' travel mode change. For vehicles, it is necessary to consistently enhance the utilization of new energy in private cars. For transportation mode share, the paper highlights the development of a green multimodal logistics system that relies on electrified railways as the backbone. For residents' mobility, the paper proposes to promote residents' travel mode change from private cars to public transit, walking, and biking through measures such as transportation and land development integration and carbon credits for green mobility. **DOI:** 10.13813/j.cn11-5141/u.2021.0503-en

Keywords: carbon neutrality; transportation sector; carbon emissions reduction; public transit; green development

1 The "Carbon Neutrality" goal boosts new momentum for green development in the transportation sector

China has been consistently and actively participating in various global activities to address climate change issues. At present, China has become the largest country worldwide in terms of using new and renewable energy. In September 2020, President Xi Jinping of China announced at the seventy-fifth UN General Assembly that "China will strive to reach peak carbon dioxide emissions by 2030 and achieve carbon neutrality by 2060." As a responsible big country, this announcement not only demonstrates China's determination to address climate change with green and low-carbon development but also boosts new momentum of transformation in various economic sectors to green development.

Following General Secretary Xi Jinping's guiding concept of "Lucid Waters and Lush Mountains Are Invaluable Assets", the sustainable development in the transportation sector of China is constantly progressing. The ecological civilization system of transportation has been improving, the concepts of "green, low-carbon, and environmentally friendly" have been well followed, and the increasingly strict dual control system of total energy consumption and intensity has also been implemented. The railway electrification rate in China increased to 71.9% by the end of 2019. In aviation, Auxiliary Power Unit (APU) replacement work is fully launched and promoted throughout the country, which will effectively reduce carbon emissions generated by aircraft. In terms of road transportation, the numbers of new-energy buses and new-energy trucks are growing to reach 400,000 and 430,000, respectively, by the end of 2019. For express delivery and logistics, the proportion of new-energy and clean-energy vehicles in postal and express fleet has also increased steadily [1].

In recent years, the green development of the transportation sector has been highlighted in relevant documents issued by the CPC Central Committee, the State Council, and certain state departments. In 2019, the "Outline for the Construction of Nation with Strong Transportation System" emphasized that China would take specific measures to strengthen energy conservation and emissions reduction in the transportation sector, including the structure optimization of transportation energy, the promotion of new and clean energy use, the improvement of energy conservation and emissions reduction in road freight, and the promotion of vehicle electrification and utilization of new energy and clean energy for all urban public transit and logistics distribution[2]. In 2020, the "Green Commuting Creation Action Plan" clarified that China would improve the green commuting level of cities by implementing green commuting creation actions, promoting a simple,

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green, and low-carbon lifestyle, and encouraging green commuting modes such as public transit, walking, and biking to reduce the total number of passenger car trips[3]. In 2021, the "Outline of the National Comprehensive Multidimensional Transportation Network Planning" specifically pointed out that China would accelerate the green and low-carbon development to reach the peak of carbon dioxide emissions in the transportation sector as soon as possible; the planning document also proposed to reduce the emission intensity of pollutants and greenhouse gases (GHG), focus on the protection and restoration of ecological environment, and promote harmonious development between transportation and the nature[4]. It is clear that green development will continue to be the main theme in the transportation sector in the future. Under the "3060" target, more in-depth research and discussions are needed in the transportation sector for enhancing top-level design and system planning of energy conservation and emissions reduction, as well as effectively promoting low- or zero-carbon development.

2 Main dilemmas and challenges for green development

The transportation sector has been a major contributor to carbon emissions for a long time. Although countries and regions around the world have achieved positive results through great effort in reducing transportation carbon emissions and promoting the green development transformation, it is still a long way to go for further mitigation of energy consumption and emissions. Under the "carbon neutrality" goal, constraints in green development transformation in the transportation sector continue to grow.

2.1 High carbon emissions from the transportation sector is the main challenge faced by countries all over the world

According to data from the International Energy Agency, the 2019 global CO_2 emissions generated by the transportation sector were approximately 8 billion metric tons, which accounted for nearly 1/4 (24.2%) of the total global CO_2 emissions. Road transportation generated approximately 6.5 billion metric tons, which accounted for 81% of the CO_2 emissions from the transportation sector. High carbon emissions from the transportation sector have become a common challenge faced by countries all over the world. Data from the EU also suggest that 22.3% of the EU's total GHG emissions (in CO_2 equivalent) come from the transportation sector, of which the proportion of GHG emissions generated by road transportation (passenger cars, vans, heavy-duty trucks, buses, and motorcycles, etc.) has reached 21.1% (see Fig. 1). Road transportation has become the dominant source of carbon emissions in the entire transportation sector.

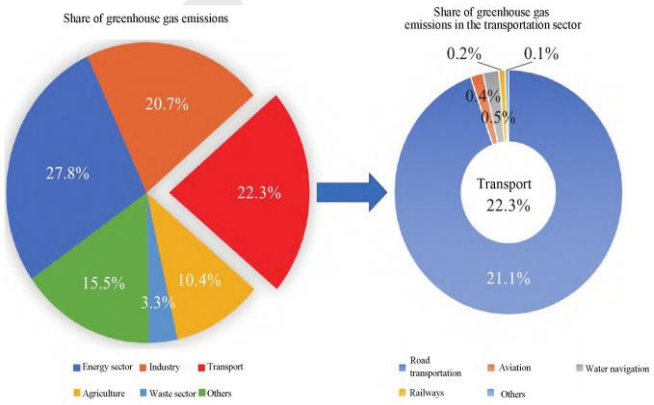

Fig. 1 Distribution of greenhouse gas (GHG) emissions in different sectors in the European Union

Source: Reference [5].

The movement of people and goods usually relies on four modes: road transportation, railways, water navigation, and aviation. In recent years, the utilization of new and clean energy in transportation has been promoted worldwide; however, the major transportation modes continue to heavily rely on fossil fuels, especially oil (see Table 1). Data from the Republic of Korea suggested that 32% of the country's total oil consumption in 2017 was used in the transportation sector. GHG emissions in the transportation sector accounted for 14% of the Republic of Korea's total GHG emissions, which increased by 2.8 times compared with the 1990 level; road transportation dominated the transportation sector in terms of accounting for 97% of the sector total energy consumption.

Table 1 Transportation energy usage and consumption in the Republic of Korea in 2017

Item	Road			Train	Ship	Plane
	Passenger vehicle	Truck	Bus			
Fuel	Gasoline (37%) Diesel (53%) LPG (10%)	Diesel (99%) LPG (1%)	Diesel (54%) CNG (46%)	Diesel (29%) Electricity (71%)	Heavy oil (51%) Diesel (49%)	Jet fuel (100%)
Energy use (Unit: 10^4 oil equivalent)	4,279.6 (Passenger 78%, Truck 13%, Bus 9%)			34.3	45.4	61.3

Source: Reference [6].

The energy conservation and emissions reduction in the transportation sector in China are also not satisfying. Data from the International Energy Agency indicated that total energy-related CO_2 emissions of China in 2017 were approximately 9.3 billion metric tons, with the transportation sector's 890 million metric tons CO_2 emissions accounting for nearly 10% (Fig. 2). Road transportation contributed 730 metric tons of CO_2 emissions, which accounted for 82% of total carbon emissions in the transportation sector.

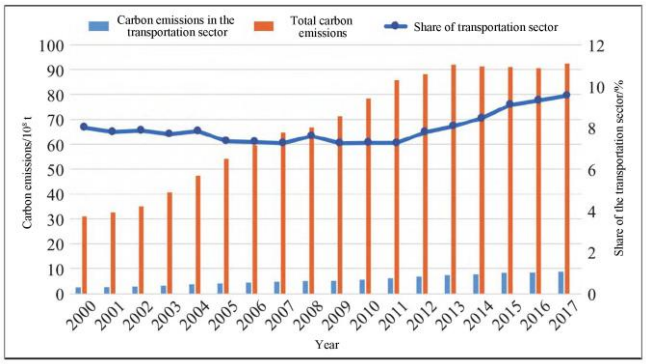

Fig. 2 Carbon emissions in the transportation sector in China (2000–2017)

Source: International Energy Agency (IEA)

2.2 The continuous growth of car ownership puts tremendous pressure on energy conservation and emissions reduction in the transportation sector

Road transportation is the dominant contributor of carbon emissions in the transportation sector; carbon emissions from road transportation are largely generated by vehicles. Although the government has been implementing policies to promote the development of new energy automobile industry and the number of new energy vehicles has also been increasing, new energy vehicles are still less popular than conventional fossil fuel vehicles. Data from the Traffic Management Bureau of the Ministry of Public Security suggested that, by the end of 2020, the number of new energy vehicles in China was 4.92 million, which only accounted for 1.75% of the total number of vehicles. The consistent growth in car ownership and the uncontrolled use of private cars put unprecedented pressure on energy conservation and emissions reduction in the transportation sector. China's car ownership was less than 20 million in 2001 but exceeded 200 million by the end of 2017. In the meantime, the International Energy Agency had data showing that carbon emissions in China's transportation sector increased from 254 million tons in 2001 to 890 million tons in 2017 (see Fig. 3).

2.3 Continuous growth of transportation demand offsets the improved automobile fuel economy

With increasingly stringent automobile emission standards worldwide and continuous improvements in automobile emissions technology, the fuel consumption level of new cars has been going down in general. Since the implementation of Phase III of automobile fuel economy standards in 2012, the consumption reduction process of the automobile industry in China has accelerated. Compared with 7.42 L hm^{-1} in 2012, the average fuel consumption level of Chinese passenger cars in 2019 was 6.45 L hm^{-1}, with an overall 13.07% reduction[7]. The automobile industry has achieved good results in promoting energy conservation and emissions reduction through technical improvements. However, with the development of society and economy, the overall passenger and freight movement demand in the transportation sector continues to grow. The increased transportation demand not only offsets the improved fuel consumption reduction of new cars due to advanced automobile engine technology over the years but also accelerates the growth of carbon emissions in the transportation sector to a certain extent.

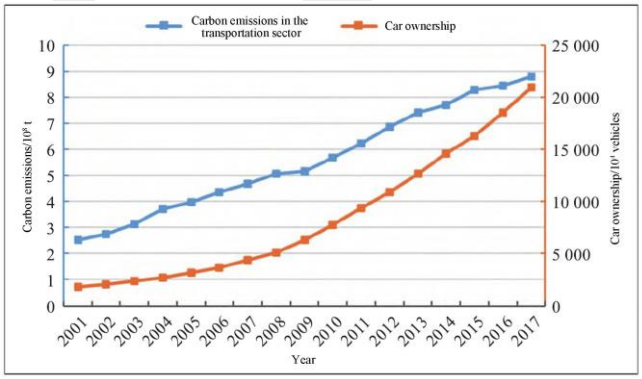

Fig. 3 Car ownership and carbon emissions in the transportation sector in China (2001–2017)

Source: The 2001–2017 carbon emissions data are from the International Energy Agency. The 2001–2015 car ownership data are from the "China Automobile Industry Yearbook". The 2016–2017 car ownership data are from the "Statistical Bulletin of National Economic and Social Development".

Taking the EU as an example (see Table 2), the average CO_2 emissions of new automobiles in the EU in 2000 were 172.2 g hm^{-1}. With the improved automobile engine technology, average CO_2 emissions decreased by 31.2% to 118.5 g hm^{-1} in 2017. Over the same period, the demand for road freight in the EU increased by 23.9% and the demand for passenger cars increased by 14.0%. Due to the growing demand for passenger and freight transportation, the total annual carbon emissions of EU road transportation increased from 849 million tons to 885 million tons.

Global observation suggests that carbon emissions in the transportation sector have been growing in recent years. Although the average energy consumption and GHG emissions of new automobiles have been significantly reduced due to continuous improvement of emission standards and engine technology for oil-fueled automobiles in various countries and regions, carbon emissions in the transportation sector are still increasing. The development of the economy and society not only stimulates the growth of automobile

sales but also stimulates the continuous growth of passenger and freight movement demand. As the main source of carbon emissions in the transportation sector, road transportation has significant potential for energy conservation and emissions reduction while facing substantial challenges.

Table 2 Carbon emissions growth in the transportation sector with increased passenger and cargo transportation demand in the European Union

Item	Freight transported in EU (10^9 t·km^{-1})	Distance traveled by EU cars (10^9 passengers·km^{-1})	CO_2 emissions of new cars (g·km^{-1})	Total CO_2 from road transport (10^4 t)
2000	15 090	43 010	172.2	84 900
2017	18 700	49 010	118.5	88 570
Change/%	+23.9	+14.0	−31.2	+4.3

Source: Reference [5].

3 Strategies for green development

Energy conservation and emissions reduction of the transportation sector are important for global carbon neutrality development. Road transportation with car dependency is the dominant contributor of carbon emissions in the transportation sector and demands significant energy conservation and emissions reduction. The forecast data from the International Energy Agency indicate that, based on the current policy scenario, carbon emissions in the global transportation sector will reach 9.4 billion tons by 2030 and 10.6 billion tons by 2040. This trend is clearly off track from the carbon neutrality goal. Energy conservation and emissions reduction in the transportation sector are complex and need to be addressed with systematic engineering. The achievement of green development and carbon neutrality goal in the transportation sector requires continuous efforts from several perspectives, such as using new energy for private cars, optimizing transportation mode share, and changing residents' travel modes.

3.1 Consistently enhance the utilization of new and cleaning energy and vehicle electrification

The rapid growth and uncontrolled use of fossil fuel vehicles have become a key obstacle to energy conservation and emissions reduction in the transportation sector. The utilization of new energy, cleaning energy and electrification for passenger cars is critical to save energy and reduce emissions, balance energy supply and demand, and improve the environment. With the strong promotion of new energy vehicles, it is necessary to reduce carbon emissions from existing vehicles using technical approaches and recognize its urgency for green and low-carbon development in the transportation sector.

In recent years, vehicle electrification and the utilization of new or cleaning energy in public transit have been promoted with certain achievements in China. For example, the proportion of new- and clean-energy buses in Beijing has exceeded 90%; other cities are also following up with policy implementation for retrofitting or replacing buses. The proportion of new energy buses continues to increase. Complete electrification and new- or clean-energy utilization in public transit are expected within the next few years. The utilization of new energy in public transit will bring positive effects on energy conservation and emissions reduction in the road transportation sector, but such an effect is still insufficient. Most carbon emissions in the road transportation sector are from private cars, especially fossil fuel cars. The utilization of new energy, cleaning energy, and electrical energy in cars are the top priorities of carbon emissions reduction in road transportation. It is necessary to consider the energy saving and emissions reduction in terms of both vehicle fleet increment and stock. For fleet increment, it is necessary to significantly increase the proportion of new energy vehicles in newly registered vehicles. For inventory stock, a substantial reduction of carbon emissions from existing vehicles is needed.

Promoting the utilization of new energy, cleaning energy, and electrical energy for passenger cars is a long-term arduous task. Comprehensive coordination and joint promotion are needed in various dimensions, such as economy and society, for various interest subjects including government, enterprises, and consumers. 1) In terms of economy, on the one hand, the government can appropriately increase subsidies for new energy vehicles so that consumers can afford to buy them to replace old vehicles at a reasonable price. This can meet the psychological expectation of consumers. At the same time, economic compensation and other measures can help speed up the elimination and retrofitting of old vehicles with high emissions. On the other hand, the government can offer special funds for energy conservation and emissions reduction to provide positive incentives for enterprises' research and development with breakthroughs of traditional vehicle technologies. This can not only boost the enthusiasm of enterprises in energy conservation and emissions reduction, but also promote the low-carbon technological progress of automobiles, and further enhance the low-carbon development of automobile industry. 2) At the social development level, it is necessary to further improve the layout of supporting facilities for new energy vehicles and accelerate the construction progress of supporting facilities, such as charging piles for new energy vehicles to improve their convenience and reliability and enhance users' acceptance. 3) In terms of technology, it is necessary to promote the use of waste gas treatment technologies, such as the Selective Catalytic Reduction, in existing fossil fuel vehicles. At the same time, it is needed to enhance the research and development of low-carbon biofuel and accelerate low carbonization of fuel to reduce carbon emissions from the existing vehicle fleet. 4) With respect to enterprises, it is necessary to strengthen their social responsibility and the sense of ownership. The government can quantify social responsibility indicators of

enterprises and combine them with positive incentive measures to encourage automobile enterprises to speed up technological breakthrough and stimulate their enthusiasm for energy conservation and emissions reduction.

3.2 Optimize transportation mode share and substantially promote multimodal green logistics system with electrified railways as the backbone

According to the "Outline of the National Comprehensive Multidimensional Transportation Network Planning" promulgated in 2021, China's overall freight demand will continue to grow in the future. Forecasted data have suggested an average annual growth rate of approximately 2% from 2021 to 2035 for the freight volume of the whole society. The postal express business volume will maintain an average annual growth rate of 6.3%. The current freight transportation in China is still dominated by road transportation. Data from the Ministry of Transport showed that road freight volume accounted for the highest proportion in the total national freight volume in 2019, reaching 77.91%. Road freight transportation mainly depends on traditional long-distance heavy-duty trucks, which consume a lot of energy and emit a lot of GHG emissions. With the development of economy and society, the growing freight demand and the increasing pressure on energy conservation and emissions reduction in the road transportation sector, the mode shift from road transportation to green and low-carbon railway transportation becomes inevitable. Such a shift can maximize the comparative advantages of railways, given that railway transportation is more sustainable and environment-friendly[8]. The multimodal green logistics system with trunk transportation relying on electrified railways and terminal distribution relying on new energy vehicles will offer huge potential for carbon emissions reduction. It will have significant positive impact on energy conservation and emissions reduction in the transportation sector.

1) Promote trunk transportation with electrified railways as the backbone

The carbon emissions per unit freight turnover of railway transportation are about 22 g $(t\ km)^{-1}$, which is only 1/6 of road freight transportation with traditional gasoline and diesel trucks. Railway transportation therefore has significant advantages in energy saving and emissions reduction. With the progress of railway electrification, it is necessary to take advantage of electrified railway transportation in terms of its intensity, high-efficiency, green and low-carbon features. Substantially increasing the proportion of railway freight in trunk transportation can help build a green logistics system based on electrified railways.

2) Promote the application of new energy vehicles for urban distribution terminals

It is necessary to promote and accelerate the use of new energy vehicles in urban distribution to achieve the energy cleaning progress in urban logistics (see Fig. 4). On one hand, the government can optimize the layout of new energy vehicles charging piles and accelerate the construction of new energy vehicle charging piles in logistics parks, industrial parks, and other areas to allow for convenient use of new energy vehicles and reduce dependence on traditional fossil fuel trucks. On the other hand, the government can encourage logistics enterprises to use more new energy vehicles for distribution through incentives such as car purchase subsidies and tax deduction.

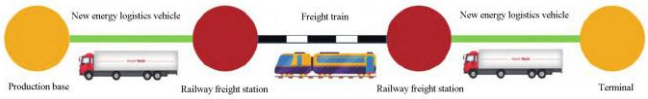

Fig. 4 Green logistics system with multimodal transportation

3.3 Implement multiple measures to guide residents in reducing car trips and switching to a green travel mode

With the growing urbanization process, urban space continues to expand and residents' travel distance continues to increase. Because passenger cars become popular and public transit is insufficient to meet travel demand, residents have increasing desire and need for car trips. With the rapid development of private motorization, the contribution of transportation to energy consumption and environmental pollution continues to grow and the pressure of energy conservation and emissions reduction in the transportation sector becomes stronger. Carbon emissions from the transportation sector are closely related to residents' travel behavior. The key measure for carbon emissions reduction in road transportation is to discourage people in taking car trips and instead choose green and low-carbon travel modes such as walking, biking, and public transit. The fundamental change of residents' travel modes requires a series of measures associated with planning and design, operation management, and policy incentives.

1) Constantly promote the integration of urban transport and land use

The daily travel of urban residents is affected by land use patterns and development intensity. The industrial layout and job-housing relationship involved in land use planning are closely related to the number of trips, trip distance, and mode choice. Improper land use patterns such as single-function land use and extensive and inefficient land development will result in a significant separation between jobs and residential locations, which in turn will generate a large number of long-distance commuting trips. The rapid growth of car ownership will lead to substantial private motorization. Obviously, high ownership, usage, emissions, and parking demand of private cars have serious negative externalities for the entire society.

The high-density and compact land use and public transit-oriented urban development mode have positive impacts on energy conservation and emissions reduction in the transportation sector. The extensive and inefficient land use and development mode oriented by private motorization lead

to a huge amount of energy consumption and GHG emissions. Atlanta in the United States and Barcelona in Spain are good examples. The two cities have a similar population, but they have totally different land use and development patterns. Atlanta's development mode is a typical inefficient and urban sprawl development oriented by private motorization. Barcelona implemented public transit-oriented compact development. Research shows that Atlanta's per-capita traffic carbon emissions are five times that of Barcelona (see Fig. 5).

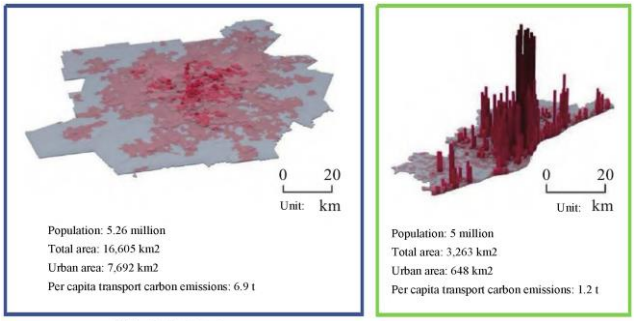

Fig. 5 Urban development mode and transportation carbon emissions

Source: https://www.reddit.com/r/MapPorn/comments/nho1vz/atlanta_vs_barcelona_urban_sprawl_environmental/.

The examples of Atlanta and Barcelona suggested a fundamental approach for energy conservation and emissions reduction through urban development oriented by green transportation based on improved public transit and integrated urban transport and land use. Compared with private cars, public transit has the advantage of reduced land occupation, less consumption, lower emissions, and high efficiency. The compact and transit-oriented development of urban agglomerations, metropolitan areas, and urban spaces can reduce travel demand and trip distance and encourage more people to choose public transit. The improvement of city operation efficiency, air quality, and environmental quality, as well as the reduction of energy consumption and carbon emissions resulting from the compact transit-oriented development represents a real healthy and sustainable high-quality development.

2) Focus on the construction of walking and biking systems to create a green, low-carbon, and sustainable "Walk-Ride-Bike" travel mode (Walking + Riding public transit + Biking).

The importance of walking and biking for energy conservation and emissions reduction in the transportation sector is obvious. However, the construction of walking and biking systems has not received enough attention in some cities. Certain cities are deeply influenced by the "car-oriented" development concept. In order to provide enough parking spaces for private cars along certain roads, some cities take the absurd approach of occupying sidewalks. As a result, the inadequate walking and biking space is further limited and it is difficult to walk and bike.

The walking and biking system is closely related to public transit. It is an indispensable link in the whole green and low-carbon travel chain. The quality of the walking and biking system directly affects residents' travel mode choice (Fig. 6). Poor travel environment, discontinuous walking and biking network, and limited walking and biking space will not only reduce residents' willingness to choose walking and biking but also increase residents' resistance to take public transit. The attractiveness of public transit is strongly supported by an improved walking and biking system connected with it. The construction of high-quality walking and biking system is the premise to promote residents' travel mode shifts and create a green, low-carbon, and sustainable travel mode.

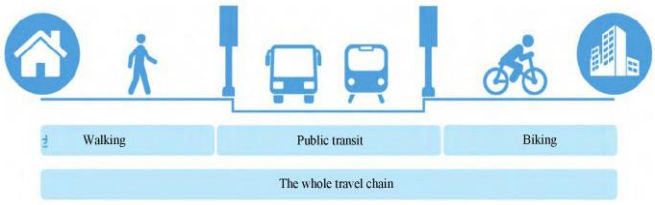

Fig. 6 Green, low-carbon, and sustainable ways of mobility: "walking, public transit, and biking"

The green, low-carbon and sustainable travel mode of "Walk-Ride-Bike" is the key to reducing traffic congestion and promoting energy conservation and emissions reduction in the transportation sector. While continuing to implement public transit-oriented strategies, cities must prioritize the construction of walking and biking systems. Conceptually, it is necessary to completely change the traditional "car-oriented" thinking and reserve more road space for pedestrians and cyclists. In terms of management, it is necessary to increase penalties for vehicles using sidewalks and non-motorized vehicle lanes to create a good environment for non-motorized transportation. With respect to facility construction, opening up the "dead end" of non-motorized transportation and building a continuous and barrier-free network of sidewalks and non-motorized lanes are needed to offer residents more favorable conditions for green and low-carbon travel.

3) Proactively promote the carbon credits mechanism for green travel to encourage residents to choose green travel modes

Based on the principle of "those who achieve emissions reduction receive benefits", personal green travel behavior can be quantified in the form of carbon emissions reduction. The quantified indicators are reflected in carbon credits and can be combined with production and consumption. Residents will be able to use carbon credits in exchange for shopping discounts or public services (see Fig.7). This positive incentive mechanism can cultivate the public's awareness of green travel, encourage the formation of good habits of green travel, guide residents to become practitioners and promoters of green travel and develop a new low-carbon travel mode guided by the government and participated by all people.

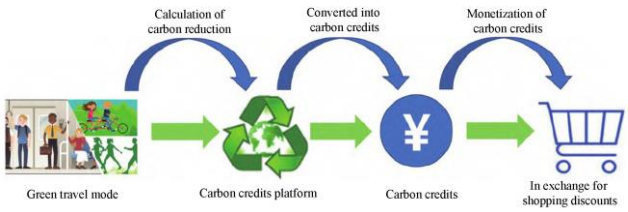

Fig. 7 Operation principle of carbon credits for green mobility

The carbon credits mechanism for green travel has been implemented as a pilot program in some cities in China and good results have been achieved. According to the data from Beijing Municipal Commission of Transport, since Beijing launched the green travel carbon credits incentive program in September 2020, 5.755 million green trips and 18.87 million tons of carbon emissions reduction have been made within just over four months. Other cities, such as Nanjing, Wuhan, Chengdu, and Guangzhou have also explored and practiced the carbon credits mechanism in the transportation sector with progress in policy system development, pilot operation, and platform construction as well as positive social effects. Under the carbon neutrality goal, it is necessary to promote the carbon credits mechanism of green travel nationwide to achieve energy conservation and emissions reduction in the transportation sector at the national level.

4 Conclusion

Collaboratively addressing climate change and continuously promoting green development is the only way for mankind to achieve sustainable development. With the proposal of carbon neutrality goal, the policy constraints and industrial changes will have a far-reaching impact on all economic sectors and also bring opportunities as well as challenges to the green development of transportation. With the effort for years, China's green and low-carbon development policy system has been substantially improved. The energy conservation and emissions reduction technology for vehicles has been continuously progressing. The transportation sector has a high potential for energy conservation and emissions reduction. However, high carbon emissions in the transportation sector has become a significant issue faced by all countries in the world. Road transportation dominated by automobiles has become the worst-hit area in terms of carbon emissions. Carbon emissions reduction in the transportation sector involves a wide range of issues and different stakeholders. The improvement of engine technology, the increased proportion of new energy vehicles, the optimization of transportation mode share in freight transportation, and the fundamental mode shift of residents' travel are all closely related to energy conservation, emissions reduction, and green development in the transportation sector. The achievement of carbon emissions reduction goal in the transportation sector needs to follow the criteria of technical feasibility, economic rationality, and social acceptability. The work needs to focus on cooperating and coordinating with multiple stakeholders to jointly promote the utilization of new energy of vehicles, optimizing transportation mode share, and changing residents' daily travel modes.

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