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Development Strategies of Low-Carbon Transportation in Guangzhou

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Abstract: Transportation is the main source of the growth in carbon emissions. To explore the route to the peak of transportation carbon emissions in Guangzhou, this paper adopts the bottom-up method and develops a transportation carbon emission inventory in Guangzhou, according to the Global Protocol for Community-Scale GHG Emissions. The inertial scenario analysis results show that the transportation carbon emissions will peak after 2020. Through quantitative assessment of the important short-term urban transportation plan in Guangzhou, the results show that the intervention scenario can reduce carbon emissions by 8.92 million tons compared with the inertial scenario. Finally, the paper proposes three strategies for the low-carbon transportation development in Guangzhou during "the 13th Five-Year Plan", including travel mode shift, optimization of freight transportation organization, and promotion of the construction of national multimodal transportation infrastructure. **DOI:** 10.13813/j.cn11-5141/u.2018.0410-en

Keywords: transportation policies; low-carbon transportation; emission inventory; Guangzhou City

In November 2014, China set the goal to reach the peak of carbon dioxide emission around 2030. Cities are the foundation and key to implement this national strategy. Guangzhou, as one of the national low-carbon pilot cities, pledged to reach the peak of carbon emission by 2020 at the China–US low-carbon city summit in 2015. Construction, transportation and industry are the three main sectors of urban carbon emission control. Compared with the other two, transportation sector shows different characteristics in terms of the development trend and path of carbon reduction. In the past 20 years, many cities around the world have carried out a series of emission reduction actions and achieved a reduction in the total urban carbon emissions. However, the carbon emissions from the transportation sector are increasing year by year, and their proportions among the total carbon emissions also keep increasing. In most developed cities, the carbon emissions from the transportation sector still account for more than 20% of the total carbon emissions [1]. The urban transportation systems of developed cities in the world are already relatively mature, but Guangzhou is still in the stage to develop its urban transportation system rapidly. Therefore, the development path of low-carbon transportation may show different characteristics. In 2014, led by the Chinese Academy of Sciences–Guangzhou Institute of Energy Conversion, the Guangzhou National Low-carbon Pilot Research Project was jointly conducted by Guangzhou Transport Planning Research Institute, Guangzhou Institute of Building Science Co., Ltd. and Guangzhou Emission Exchange. Based on the research in this project, the carbon emission inventory of the transportation sector in Guangzhou was calculated in this paper, and the key areas and reasonable ways of low-carbon development in Guangzhou were actively explored.

1 Transportation carbon emission inventory of Guangzhou

1.1 Method

Carbon emissions in the transportation sector are mainly calculated by counting the energy activities of mobile sources [2], which can be estimated from the energy consumed in the transportation sector. With the top-down inventory accounting method, carbon emissions from mobile sources are calculated by adding up total energy consumptions of all modes of transportation. With the bottom-up inventory accounting method, carbon emissions are calculated according to the annual activity level (such as mileage) of each mobile source and its energy consumption level. Therefore, the calculation is related to the emission factors of all modes of transportation and the activity data of all mobile sources.

This paper adopts the bottom-up inventory accounting method and selects corresponding vehicles as carbon emission accounting carriers for each mode of transportation in a

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city, including taxi, urban bus, highway passenger transport, highway freight transport, subway, railway passenger transport, railway freight transport, air passenger transport, air freight transport, waterway passenger transport, waterway freight transport, city ferry, car and motorcycle. All modes of transportation are accounted for separately. The calculation equation is as follows.

$$E=\sum_{a} F_{a}\times Q_{a}\times EF_{a}\times 10^{-9}, \quad (1)$$

where E is the greenhouse gas (GHG) emissions for a mode of transportation (unit: kg); F is the fuel consumption (unit: kg or m^3); Q is the fuel's average lower heating value (unit: $kJ\cdot kg^{-1}$ or $kJ\cdot m^{-3}$); EF is the emission factor (unit: $kg\cdot tJ^{-1}$); and a is the fuel type, such as gasoline, diesel, natural gas.

Fuel data can be estimated based on vehicle mileages. The calculation equation is as follows.

$$F=\sum_{i,j}\left[V_{i,j}\times S_{i,j}\times C_{i,j}\right], \quad (2)$$

where F is the total fuel consumption estimated from the travel distance (unit: L or kg or m^3); V is the number of vehicles (unit: veh); S is the annual mileage that each type of vehicle travels with using a certain type of fuel (unit: km); C is the average fuel consumption (unit: $L\cdot km^{-1}$ or $kg\cdot km^{-1}$ or $m^3\cdot km^{-1}$); i is the vehicle type; and j is the fuel type.

Carbon emissions are difficult to account for, because mobile sources may generate carbon emissions across regional boundaries. The *Global Protocol for Community-Scale GHG Emissions* (GPC) defines three accounting areas for all mobile sources to distinguish emission inventories (see Fig. 1). Area 1 refers to direct energy consumption within urban boundaries, such as urban cars and motorcycles; Area 2 refers to indirect energy consumption within urban boundaries, such as electricity consumption by urban subways; Area 3 refers to urban-related emissions outside urban boundaries, such as air and waterway transport. GHG emission inventories from each mobile source should indicate the emission area, so that the total inventories within a certain area or area groups can be calculated.

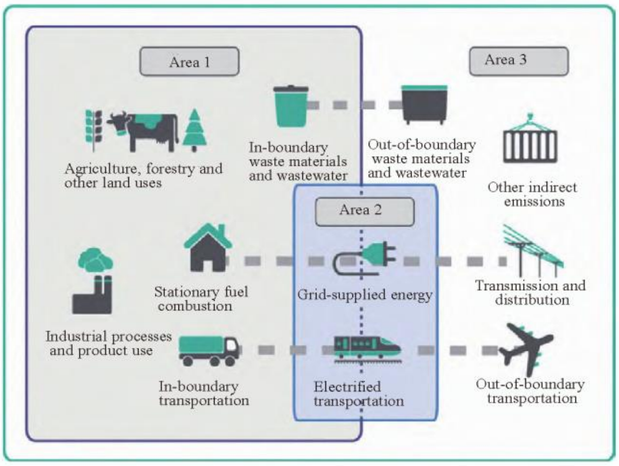

Fig. 1 Emission range of urban greenhouse gas

Source: Reference [2].

1.2 Parameters

1.2.1 Energy consumption coefficient

The buses and taxis driven by liquefied petroleum gas (LPG) have been popularized in Guangzhou. Based on relevant literature, the energy consumption coefficient is set to be 62 $L\cdot 10^{-2} km^{-1}$ for LPG buses, and 11.5 $L\cdot 10^{-2} km^{-1}$ for LPG taxis in this paper. The energy consumption coefficients for other transportation modes are determined by referring to the corresponding national values, which are listed in Tab. 1. It is worth noting that the efficiency of highway passenger transport in Guangdong Province has been improved in the past decade, and its energy consumption coefficient has been reduced as compared with Tab. 1. Referring to the energy consumption ratio of railway and highway freight transport, the energy consumption coefficient of railway passenger transport is set to be 50% of highway passenger transport. Similarly, referring to the energy consumption ratio of railway and waterway freight transport [5], the energy consumption coefficient of waterway passenger transport is set to be 10% of railway passenger transport.

Tab. 1 Energy consumption coefficients of various transportation modes in Guangzhou

Transportation mode	Standard coal equivalent [passenger transport / $(tce\cdot 10^{-4} per^{-1}\cdot km^{-1})$; freight transport / $(tce\cdot 10^{-4} t^{-1}\cdot km^{-1})$]	Gas or fuel consumption $/(L\cdot 10^{-2} km^{-1})$	Electricity consumption $/(kW\cdot h\cdot 10^{-2} km^{-1})$
Taxi		11.5	
Bus		62	
Subway			264.9
Highway passenger transport	0.121 0		
Highway freight transport	0.726 3		
Railway passenger transport	0.605 0		
Railway freight transport	0.455 2		
Air passenger transport	1.02 0		
Air freight transport	5.180 7		
Waterway passenger transport	0.060 5		
Waterway freight transport	0.045 0		
City ferry	0.060 5		
Car		8.8	
Motorcycle		2.0	

Source: References [\1–\2].

1.2.2 Emission factor

Guangzhou's energy statistics shows that the emission factor of standard coal in Guangzhou is 2.456 7 $t\ CO_2e\cdot tce^{-1}$. According to the *General Rules for Calculating Comprehensive Energy Consumption* (GB/T 2589—2008) and the *Guidelines for Provincial Greenhouse Gas Compilation*, the CO_2 emission factors from energy consumption by various transportation modes in Guangzhou are determined as shown in Tab. 2. Some transportation modes, such as subway and tramcar, use electricity supplied by the Southern Power Grid. Their unit energy consumption is about 0.331 6 kgce·kW^{-1}·h^{-1}, and the CO_2 emission factor is 7.14 tCO_2e·$10^{-4}kW^{-1}$·h^{-1}.

Tab. 2 Energy consumption emission factors in the transportation industry of Guangzhou

Fuel type	Average lower heating value (unit: kJ·kg⁻¹)	Conversion coefficient of standard coal	CO_2 emission factor
Gasoline	430 70	1.471 4	2.925 1
Kerosene	430 70	1.471 4	3.017 9
Diesel	426 52	1.457 4	3.095 9
Fuel oil	418 16	1.428 6	3.170 5
LPG	501 79	1.714 3	3.101 3

1.3 Calculation results

Calculations were performed based on the method and parameters discussed above. The results showed that the total emissions of Area 1 and Area 2 in Guangzhou increased from 15.57 million tons in 2010 to 24.42 million tons in 2014, with an average annual growth of 11.7%. Over the same period, the total emissions of Area 3 increased from 35.49 million tons to 60.15 million tons, with an average annual growth of 14.1% (see Fig. 2).

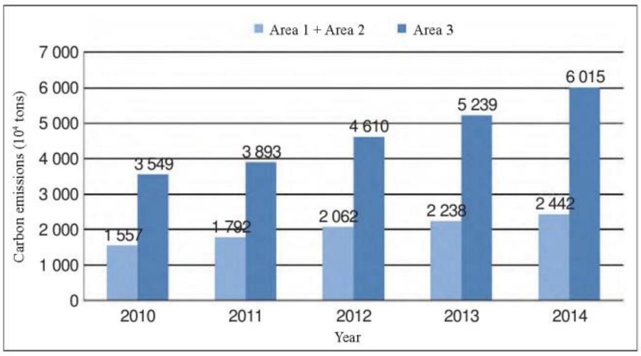

Fig. 2 Annual transportation carbon emissions in Guangzhou

According to the calculation results, the vast majority of transportation carbon emissions in Guangzhou were from Area 3, that is, the emissions from passenger and freight transport by air, waterway and railway. Since the energy consumption of Area 3 was not active within the urban boundary, Area 3 was generally not included in the calculation of urban carbon emissions.

Among the transportation carbon emissions in Area 1 and Area 2, the carbon emission from highway freight transport accounted for more than 50%, and this proportion was increasing year by year, which is closely related to the development of economy, commodity trade and logistics industry in Guangzhou. The carbon emission from cars ranked the second, whose proportion has been stable at 19% in the past five years. This was closely related to the car purchase restriction policy (see Fig. 3).

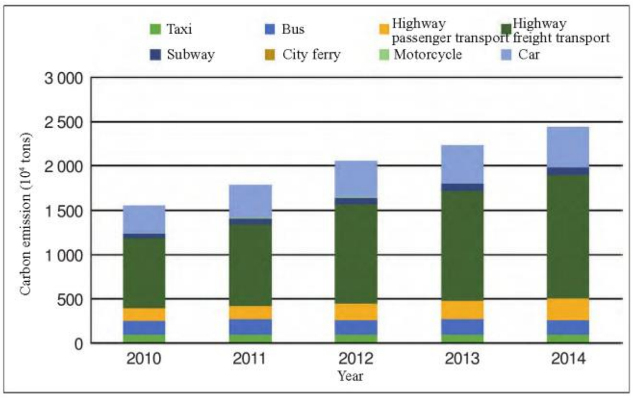

Fig. 3 Composition of transportation carbon emissions in Area 1 and Area 2 of Guangzhou

1.4 Lateral comparison

In terms of per capita transportation carbon emission, it was 1.87 t in 2014 in Guangzhou, which is higher than that in Tokyo, London, New York and other developed cities, but lower than that of Shanghai (see Tab. 3). Considering the level of motorization, New York, London and Tokyo had far more cars than Guangzhou do, but their per capita transportation carbon emissions were lower. This shows that there was still a large room for reduction in transportation carbon emissions with Area 1 and Area 2 of Guangzhou.

Tab. 3 Comparison of transportation carbon emissions between Guangzhou and several cities in the world in Area 1 and Area 2

City	Year	Population (unit: 10^4)	Method	Emissions (unit: 10^4t)	Per capita carbon emissions of transportation sector (unit: t·per⁻¹)
New York	2013	834	ICLEI US	1 098.8	1.32
London	2011	781	IPCC 2006	886.1	1.17
Tokyo	2010	1 300	Ministry of the Environment, Japan	1 179	0.91
Shanghai	2007	1 910		4 795	2.51
Guangzhou	2014	1 303	ICLEI	2 442	1.87

Source: References [3–5, 8–9].

Experience showed that the higher the level of urbanization, the higher the proportion of transportation carbon emissions. The proportion of transportation carbon emissions in Guangzhou increased from 25% to 31% between 2010 and 2013, showing an upward trend year by year. In other cities of China, it increased from 20% to 26% in Shanghai between 2005 and 2012, and from 15% to 30% in Beijing over the same period. It was more than 20% both in London and New York. Considering the construction of the international shipping center and logistics center in Guangzhou, the transportation infrastructure would be further improved, and the total traffic demand would grow substantially. Therefore, the proportion of transportation carbon emissions in Guangzhou would increase further.

2 Effect evaluation of urban transportation carbon emissions of Guangzhou in 2020

Retrograde tracing (see Fig. 4) is the main method currently used to analyze the trend of future carbon emissions and to determinate low-carbon goals. This method established feasible and reasonable future scenarios according to the desired targets, and then deduced the current scenario from the future scenario, in order to find the best path to achieve the future scenario. In this paper, the retrograde tracing method was used to analyze the transportation carbon emissions in 2020 in the inertia scenario according to the current transportation carbon emission inventory. It was also used to analyze the transportation carbon emissions after adopting effective emission reduction measures that can be realized with current policies and technologies, and these emissions were set to be the control goal.

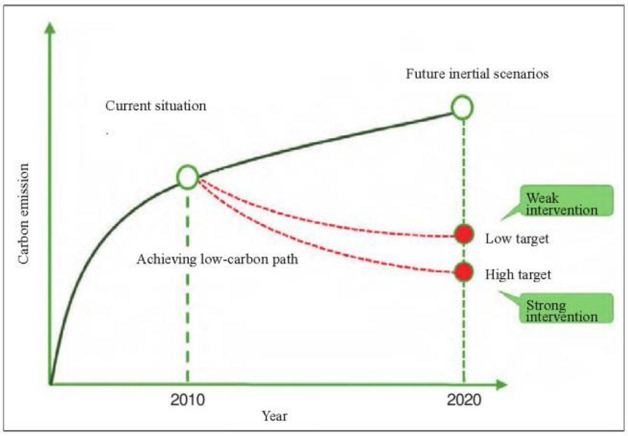

Fig. 4 Schematic of retrograde tracing

2.1 Assessment of total carbon emissions

According to the calculation, the total transportation carbon emissions of Guangzhou in 2020 would be 34.96 million tons in the inertial scenario, an increase of 125% from 2010. It would be 26.64 million tons in the intervention scenario, an increase of 67% from 2010, and a decrease of 8.92 million tons as compared with the inertial scenario (see Fig. 5). The comparison of the two scenarios showed that the potential of reducing carbon emissions came from highway freight transport, highway passenger transport and cars. This comparison also showed that the carbon emissions of city ferries, taxis, buses and motorcycles would not change much, and the carbon emission of subways would increase significantly. In addition, although a goal was set to reach the peak carbon emissions by 2020 in Guangzhou, the peak carbon emissions for the transportation sector of Guangzhou would be delayed.

2.2 Implementation plan and effect evaluation

The bottom-up calculation method was adopted in this paper to evaluate the major transportation facility projects in Guangzhou during the "13th Five-Year Plan" period. The results showed that these projects can reduce transportation carbon emissions by 8.82 million tons in 2020 and the emission reduction target can be basically achieved. The implementation plan and the emission reduction effect of each project are as follows.

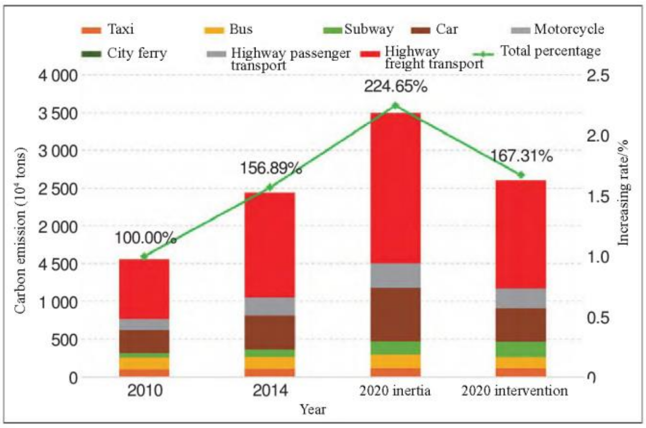

Fig. 5 Transportation carbon emission target of Guangzhou

1) To continue to improve the transport capacity of large and medium-capacity vehicles, such as subways, tramcars and bus rapid transits (BRTs)

Guangzhou will add 289-km subway lines by 2020. Passengers shifted to the newly built subway lines come from buses, cars and motorcycles, which accounted for 70%, 10% and 20% respectively. Because of this shift of travel modes, carbon emissions can be reduced by 404.8 thousand tons in 2020. Guangzhou has planned a 1 050.7-km tramcar system, and the 7-km pilot section of Pazhou Island has been open. Assuming that 100-km tramcar lines would be built by 2020, the average tramcar ridership was 1.2–1.5 million passengers per day, which would result in a total carbon emission reduction of 69.4 million tons in 2020. The well-operated Zhongshan Avenue BRT Line has brought a carbon reduction of 86 thousand t a^{-1} to Guangzhou [6]. If Guangzhou can promote the construction of two BRT lanes along Guangzhou Avenue and Sanyuanli Avenue according to the plan, it would reduce carbon emissions by about 90 thousand tons in 2020.

2) To transform and upgrade freight transport

During "13th Five-Year Plan" period, Guangzhou sets the development goal to build an international shipping center and logistics center, with the emphasis on optimizing the layout of logistics facilities, promoting the development of logistics parks in key areas, and promoting the innovation and development of modern logistics. By optimizing the layout of logistics facilities and building the new logistics park, the site selection and the development of supporting infrastructure will be optimized according to differentiated functional positioning to provide different services to the Pearl River Delta (PRD) region and Guangzhou; the freight transshipment sites will be moved outside of the urban area; and the highway freight transport will be shifted to railway and waterway. After the optimization, the efficiency of highway freight transport will be increased by about 15%. Promoting the innovation and development of modern logistics will further improve the efficiency of distribution, upgrade the distribution vehicles and improve the cargo load factors. If the highway freight efficiency in Guangzhou can be increased by 5%, the highway freight energy consumption can be reduced to 0.581 0 tce $\cdot 10^{-4} t^{-1} \cdot km^{-1}$ [5] in 2020. If 10% of the freight turnover by the highway freight transport can be shifted to other modes and the distribution efficiency can be improved, carbon emissions can be reduced by 4.833 6 million tons in 2020, given that the average transportation energy consumption can be reduced by 20%.

3) To continue to implement the car purchase restriction policy

Since the implementation of the car license plate restriction policy in 2012, about 120 thousand new passenger car license plates are issued in Guangzhou every year, and the growth rate of cars has been effectively controlled. The number of cars in Guangzhou will be about 2.43 million in 2020 with this restriction policy, and would be about 3.15 million without this policy. Based on the average annual driving distance of 13.575 thousand km for cars [7], a carbon reduction of 1.930 6 million tons will be achieved by 2020, comparing scenarios with and without this restriction policy.

4) To encourage walking and bicycling

Guangzhou has recently planned a 557-km bicycle lane network based on subway and BRT stations to improve the bicycle trip conditions in the urban central area. The internet-based bicycle sharing systems, such as Mobai Bicycle Share and Xiaoming Bicycle Share, appeared in 2016, which solved the problems with rental, return and parking space, and significantly improved the share of bicycle trips made by urban residents. Because bicycles only have an advantage for short trips within 3 km, they cannot replace other transportation modes for long-distance commuting trips. Based on the experience of other cities, the carbon emission reduction for bicycles would be about 35 000 t a^{-1} [10].

5) Promote new energy vehicles

Guangzhou has gradually replaced LPG buses with pure electric buses since 2017, and is striving to fully realize bus electrification by the end of 2018 [11]. In 2016, Guangzhou had 14 095 normal buses [12], and the average daily service miles for each bus was 104.93 km $\cdot veh^{-1} \cdot d^{-1}$ [13] according to the historical data. Thus, the daily service miles for buses in Guangzhou is 1 478 988.35 km in 2020. Based on the power consumption rate of 120 kW $\cdot$ h $\cdot 10^{-2} km^{-1}$ [14], the power consumption of electric buses is 1.774 8 million kW $\cdot$ h and the carbon emissions are 1 267.2 tons, which would reduce carbon emissions by 1.352 2 million tons in 2020 as compared with the inertial scenario.

3 Transportation carbon reduction strategies in Guangzhou during the “13th Five-Year Plan” period

3.1 To focus on the shift of passenger trips to collective travel modes

The implementation strategy to reduce urban transportation carbon emissions basically concentrates on three aspects: prevention, shift and improvement. The prevention strategy is to avoid unnecessary traffic demand from the source through reasonable urban spatial form and diversified land uses, which mainly includes reducing the number of trips and trip distance, so as to reduce transportation carbon emissions. The shift strategy is to adjust traffic structure through various means to shift some passengers relying on private motorized travel modes to green travel modes, including public transportation, bicycling and walking. The improvement strategy aims at the vehicle energy efficiency, which is essentially the development and application of low-carbon vehicles. Relevant studies have shown that in urban passenger transportation, mode shift has the greatest potential to reduce emissions (see Fig. 6).

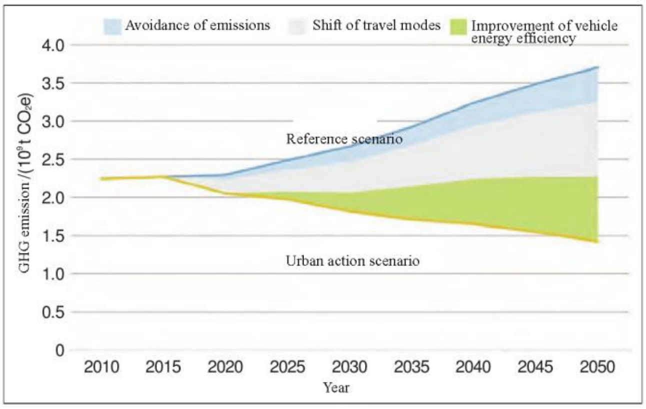

Fig. 6 Potentials of different carbon reduction schemes in urban passenger transportation

Source: Reference [8].

Guangzhou is in the rapid construction stage of rail transit, and the level of public transportation service will greatly improve. Therefore, the carbon reduction potential at this stage mainly comes from the shift of travel modes, followed by the improvement of vehicle energy efficiency. The strategy of reducing traffic demand through urban planning is relatively lagging behind in terms of the reduction of carbon emissions. Statistics shows the car license plate restriction policy, which is actually a policy to mandate the shift of travel modes, accounts for 24% of the carbon emission reduction. At the same time, the construction of subways, BRTs, bus lanes and other infrastructure increases the capacity of public transportation, improves the level of service, and ensures the travel quality after the mode shift. Therefore, during the "13th Five-Year Plan" period, the emphasis of low-carbon transportation in Guangzhou should be placed on the intensification of passenger transportation, and the strengthening of the car demand management. However, the regulations and control policies on car usages must match the service level of public transportation to ensure the travel quality of urban residents.

The most direct way to shift travel modes is to shift from motorized modes to non-motorized modes. From public bicycles to shared bicycles, Guangzhou has ushered in the era of the full return of bicycles. Bicycles have gradually transformed from taking on the transportation function of connecting to public transportation and solving the last one-kilometer issue to taking on multiple functions of pursuing health and quality of life. Guangzhou also has many advantages that can provide more development space for walking, such as arcade blocks, multifunctional land development, riverside location and construction of greenways. Walking and bicycling are important additions to the collective transportation system. Therefore, Guangzhou's carbon reduction actions during the "13th Five-Year Plan" period should create walking and bicycling spaces with distinctive Lingnan characteristics that utilize the Pearl River system, mountain greenways and arcade blocks, fuse walking and bicycling as a way of travel with lifestyle, integrate the recognition of "Flower City" into travel experience, and achieve high-quality "zero carbon" travel.

3.2 To pay attention to the optimization of the provincial highway freight transportation organization and the overall optimization of the urban distribution system

The development of the highway transportation market is lagging behind in Guangzhou, and the organization mode is extensive. Data show that as high as 51.7% of logistics companies have an empty-truck rate of 30%–50% [15]. From the list of transportation projects to be implemented before 2020, it is shown that the most effective emission reduction project is the optimization of freight transportation, which accounts for 69%. In terms of the highway freight transport in the urban area of Guangzhou, 50% of the freight demand is to transship cargo originated in the PRD region through Guangzhou. Therefore, the optimization of freight transportation should consider how to improve the efficiency of highway freight transport from the level of urban agglomeration or the PRD region as a whole, which includes defining the location of freight hubs and freight corridors, guiding the freight transportation, reducing empty trucks and reducing unnecessary cargo transshipment through Guangzhou.

In terms of urban freight transport, attention should be paid to the urban distribution system, mainly on vehicle configuration and optimization of the distribution system. Relevant data show that trucks travel 8 hours per day in urban areas, while other passenger vehicles travel 2 hours on average [16]. Therefore, governments should develop policies to vigorously promote new energy vehicles in the urban distribution system. In the meantime, the information management platform for new energy vehicles should be promoted to optimize the structure of urban distribution to improve efficiency and reduce costs.

3.3 To promote the construction of national multimodal transportation infrastructure

Multimodal transportation is recognized by the international logistics industry as a modern mode of transportation with high efficiency, better safety, low cost and low emissions. It is also the main area of carbon emission reduction in Area 3. The proportion of container multimodal transportation is as high as 20% in the world. But it is only 2% in Guangzhou, and the sea-rail transportation, as a mode with the lowest carbon emissions, only accounts for less than 1%. This is largely due to the decline in the capacity of railway freight transport and the lag of railway freight facilities in recent years. At present, nine of the 18 railway container center stations planned by China have been built, and the construction of the container center station in Guangzhou is about to start. A port is the most important hub of container multimodal transportation, and a railway is one of the main means of large volume and long-distance ground transportation in a comprehensive transportation system. In the future, the focus of the construction of low-carbon transportation is to coordinate various modes of transportation around railway hubs and ports, give full play to the overall efficiency of comprehensive transportation, and build a large system of multimodal transportation.

4 Conclusions

Using the bottom-up inventory accounting method, this paper calculates the inventory of transportation carbon emissions in Guangzhou from 2010 to 2014, according to the GPC definition on the range of urban carbon emissions. The results show that 70% of the total emissions are from Area 3, that is, the carbon emissions from passenger and freight transport by air, waterway and rail. In Area 1 and Area 2, the highway freight transport accounts for the largest proportion of the urban transportation carbon emissions. According to the target forecast, transportation carbon emissions would not reach the peak in Guangzhou by 2020. The evaluation of the major transportation construction projects in Guangzhou during the "13th Five-Year Plan" period shows that the transportation carbon emissions can be reduced by about 8.9 million tons by 2020, and the emission reduction target can be basically achieved.

How to define urban boundaries to calculate the urban transportation carbon emissions is still a problem worthy of further discussion. In addition, achieving carbon reduction targets at the urban level is only one aspect of the implementation strategy. The organization of highway freight transport, which has greater potential for carbon reduction, should be considered at the provincial level (Guangdong) to achieve more effective control on carbon emissions. The multimodal transportation involving air, railway, waterway and highway transport also need to be considered at the national level to improve facilities, coordinate transportation organizations and break trade barriers, in order to control the overall transportation carbon emissions in Area 3.

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