Transportation Carbon Emissions Assessment of Low-Carbon Eco-Park: A Case Study in Pingdi, Shenzhen

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***Abstract*-Urban carbon emission has sharply increased owing to the rapid urbanization and motorization. Since transportation is a main source of carbon emission, it is urgent to build a low-carbon transport mode with characteristics of environment-friendly, high efficiency, low energy cost and safety. With the IPCC's methods and spatial analysis, transportation carbon emission of Pingdi international low-carbon eco-park in Shenzhen was evaluated. Road vectorization was operated on arcgis10.0, while traffic distribution based on the dual-constrained gravity model was operated on transcad. Furthermore, by studying the structure of residents travel and the carbon emission per unit distance of each motor vehicle, the traffic carbon emission of the study area was evaluated. The total co_2emission was 127127.57 tons per year. The transportation emission structure shows that private cars, official cars and taxi account for the largest proportion of the emission, each for 42.9%, 18.2% and 16.5%, while the proportions of bus and motorcycles were less than 10%. The spatial distribution shows that the largest intensity appears in roads of heavy traffic, such as Huiyan express and Yanlong Avenue. On the contrary, districts of more slip roads have low carbon emission intensity. influencing factors of transportation carbon emissions, including land use structure, structure of travel, transport vehicle, traffic network and low-carbon consciousness, were deeply analyzed in order to provide some references for developing the transportation mode dominated by public transport and the implementation of energy saving policy.**

Keywords- Low-Carbon Eco-park; Transportation; Carbon Emission; Emission Structure; Spatial Analysis

I. INTRODUCTION

Urban traffic is the third major greenhouse gas emission sector following energy supply and industrial production, accounting for 13.1% of the global emission (IPCC, 2006). In the past dozens of years, along with the development of social and economic activities, urban space was gradually expanded and vehicle constantly increasing, the growth rate of traffic carbon emission is higher than any other sector (MA Jing et al, 2011).

In order to reduce the carbon emission, developed countries have made the emission reduction plans. Special attention is paid to the traffic sector to reduce the emissions, by improving traffic technology, adjusting traffic structure and stressing the public traffic. Britain puts forward the concept of low-carbon economy for the first time, whose Traffic Department issued Low-carbon Traffic Innovation Strategies in 2007 to put forward the practical technology of road, air, railway and water transport and the study direction of the future low-carbon traffic technology (SU Chengyuan et al, 2012). Study on Low-carbon Social Mode and Feasibility of Japan proposes to transform the urban traffic structure to the traffic mode oriented by the public traffic by elevating the land use rate and strengthening the urban function (SU Chengyuan et al, 2012). Singapore released the White Paper of Traffic Development-Build the First-class Land Traffic System in 1996 to keep balance between cars and public traffic and draft strict measures about the traffic demand management (ZHANG Liang et al, 2011). Traffic Planning, the third generation of urban traffic planning developed by France in 1990s, expands the target to slowdown traffic and focuses on the complementary integration of walking, non-motorized vehicle, car and public traffic, and transits from the pursuit of the technical solution of traffic system to overall organization and the quality of urban mobility service (ZHUO Jian et al, 2010).

Along with the significant growth of traffic carbon emission, studies on the carbon accounting, emission structure and the construction of low-carbon traffic also gradually increase. International studies on the traffic carbon emission mainly focus on two aspects: one analyzes the existing traffic carbon emission reduction plan to discuss the low-carbon traffic mode of the city and the macro regulation strategy of the traffic, while the other quantitatively analyzes the characteristic of the traffic carbon emission structure and spatial distribution. International quantitative studies are quite mature and some institutions have transformed the theoretical study to the practical planning evaluation software. For example, INDEX (U. S.), I-PLACE3S (U. S.) and Tool for Evaluating Neighborhood Sustainability (Canada) (GAO Yang et al, 2012) evaluates the traffic carbon emission of the study area by establishing the correlation model between automobile mileage and urban characteristic (e.g. mixed land utilization extent, accessibility of public service facility, etc.).

Domestic studies on traffic carbon emission mainly focus on the emission structure, influencing factors and spatial characteristics of carbon emissions. Existing studies indicate that private cars account for a quite large proportion of CO_2 emission in the urban traffic (SU Chengyuan et al, 2012). Urban population and vehicle capacity significantly influence the urban traffic carbon emission by influencing the volume of passengers and cargo transport, and the proportion of bus negatively influences the urban traffic carbon emission (SU Taoyong et al, 2011). Influenced by the long-distance travel of the rural residents, the average traffic carbon emission per household gradually increases from downtown to suburbs (GAO Yang et al, 2012).

Currently, most studies of the traffic carbon emission focus on the whole city or the comparison of several cities but few focus on the scale of park. Eco-park is an experiment of low-carbon eco-city and an important part of the low-carbon urban traffic. Studies on the traffic carbon emission of the park are helpful in decomposing influencing factors of the urban traffic carbon emission in the meso perspective and put forward corresponding strategies. Therefore, this paper regards Shenzhen Pingdi International Low-carbon Eco-park as the object, constructs the meso-scale carbon emission computation model, and conducts spatial processing of the park. Taking the structure of residents travel and the carbon emission per unit distance of each motor vehicle into account, this study accounts the total volume, structure and spatial distribution of the traffic carbon emission of the park, and analyzes influencing factors, by which we provide a theoretical basis for developing the transit oriented development (TOD) mode and the implementation of energy saving policy was supplied.

II. METHODS AND CALCULATION

A. Methods

In traditional studies, the traffic carbon emission is mainly measured by the emission factor method of *National Guidelines for Greenhouse Gas Emission of IPCC 2006* (IPCC, 2006), i.e. it is achieved by the fuel consumption of each vehicle multiplied with the emission factor of each kind of fuel. This method applies to the area with large space (e.g. city) but is quite limited in the data availability in the park. Besides, this method may only obtain the regional carbon emission but may not study the spatial characteristic of the traffic carbon emission.

Therefore, for the purpose of computing the traffic carbon emission of the park/city with small space and analyzing the distribution of the carbon emission space, this study computes the carbon emission per unit distance of each vehicle as the emission factor with reference to the empirical value of existing studies.

1) Accounting Model:

$$E_{CO_2 \cdot day} = \sum_{j=1}^{n} \sum_{i=bus}^{subway} Q_j \times P_{ij} \times L_j \times EF_i$$

Where:

$E_{CO_2 \cdot day}$-Traffic carbon emission, unit: kgCO_2/day;

j-Code of road section independently measured in the space;

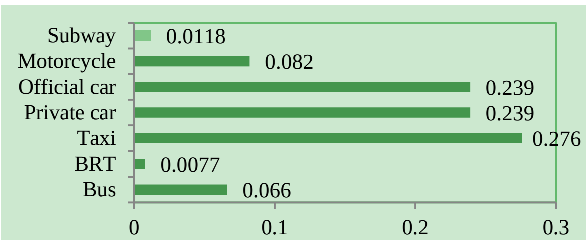
i-Motorized travel mode (including bus, taxi, private car, official car, motorcycle, truck and subway);

Q_j-Total traffic flow of road j, unit: person/day;

P_{ij}-Share rate of travel mode i on road j, unit: % (see 2.2);

L_j-Length of road j, unit: km;

EF_i-Emission per unit distance of travel mode i, unit: kgCO_2/ (km person-time), see Fig. 1.



Unit: kg CO_2/ (person km)

Fig. 1 Carbon (CO_2) emission factor per unit distance per capita of each motorized travel mode

Source: Heidelberg Research Institute: *Chinese Traffic: Energy Consumption and Emission of Different Transportation Modes* (with reference to CO_2 emission of per unit distance per capita of Shanghai in actual loading 2005[1]).

Annual carbon emission of the traffic department is computed by the daily traffic carbon emission (unit: ton CO_2/year):

[1]Carbon emission per unit distance per capita is reduced when the load rate is higher by car sharing.

$$E_{CO_2 \cdot a} = E_{CO_2 \cdot day} \times 365/1000$$

2) Flow Computation Model:

Traffic distribution by dual-constraint gravity model: determine the travel distance between traffic zones by Multiple Shortest Path of TransCAD, take the distances as the impedance matrix, and determine the inverse power function as the impedance function. Model of the flow between zones is:

$$\begin{cases} T_{ij} = P_i \times \dfrac{A_j \times f(d_{ij})}{\sum_z A_z \times f(d_{iz})} \ (constraint\ of\ travel\ flow) \\ T_{ij} = A_j \times \dfrac{P_j \times f(d_{ij})}{\sum_z P_z \times f(d_{iz})} \ (constraint\ of\ attraction\ flow) \end{cases}$$

Where:

T_{ij}-Estimated flow attracted to zone j produced by zone i;

P_i-Estimated travel flow produced by zone i;

A_j-Estimated travel flow attracted to zone j;

d_{ij}-Resistance from zone i to zone j.

$f(d_{ij})$-Fraction Factor between Zone i and Zone j.

B. Calculation

Currently, there is no subway in the study area. This study mainly considers the contribution of the road traffic within the park to the traffic carbon emission, and motor vehicles in this study mainly refer to the bus, taxi, private car, official car, motorcycle and truck.

1) Vectorization of Road Network:

Traffic road network is mainly obtained by vectorization in ArcGIS, according to the aerial image of Pingdi and the traffic survey of Pingdi. Traffic data generating the complete road network and nodes is used to establish the topological relation of the vectorized traffic data generates the complete road network data.

2) Travel Demand Computation:

Import the road network data established in ArcGIS to TransCAD. The road network of Pingdi is divided into 483 sections and classified by the road level as shown in Fig. 2. Every road section is numbered and attached with the detailed information.

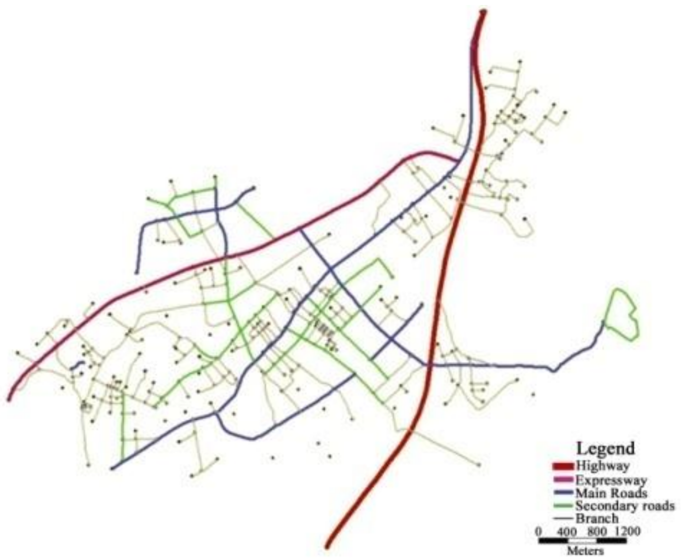


Fig. 2 Topological Map of Road Traffic Network of Pingdi

According to experience, the travel time per capita of a city is quite stable (ZHANG Shuwei, 2006). In view of the survey data of Longgang District and various streets, it is estimated that the current motorized travel rate per capita is 1.4 person time/day. In 2011, the total population of Pingdi is about 175 thousands, so the motorized traffic flow is estimated to be 245,000 person-time /day.

3) Traffic Zones Division:

Traffic zones are mainly divided according to the following principles:

- Land use, economic characteristic and social characteristic within zones shall be consistent with each other;
- The administrative area shall be kept complete as much as possible to utilize the existing statistical material of the administrative area;
- Mass center of the zone is the node in the road network;
- Quantity of zones shall be appropriates that it shall neither increase the load of planning nor reduce the analysis accuracy;
- Principle of uniformity and gradual increase outwards. Traffic zones within the study area shall be kept with proper uniformity in acreage, population and traffic attraction. Due to the lowered requirement on accuracy, traffic zones outside the study area shall be gradually enlarged as the distance from the study area is becoming farther.

According to the land use property, 154 traffic zones are divided in Pingdi, as shown in Fig. 3, where round areas are traffic zones. These traffic zones are basically surrounded by main and subsidiary roads, and some important branch roads.

Fig. 3 Traffic Zone Map

4) Freight Volume:

Computation of freight volume: The demand for internal freight volume of Pingdi is 5,000pcu/day and the demand for external freight volume is 14,000 pcu /day, which mainly flows to Pinghu, Henggang, Pingshan, Dongguan and Huizhou. Transit freight volume is 21,000pcu/day, which is mainly the freight volume between downtown and eastern Pearl River Delta and Yantian Port.

5) Traffic Flow Distribution:

The traffic flow for each road is estimated according to the gravity model, in combination with current traffic survey data. The traffic flow is distributed in TransCAD by the Stochastic User Equilibrium (SUE) method. Freight volume, bus traffic flow and motor vehicle traffic flow are respectively distributed and the traffic flow of each road section is added to obtain the motorized travel distribution of Pingdi.

6) Motorized Travel Structure:

Current travel modes of Pingdi's residents mainly include walking, bicycle, bus, taxi, private car, official car and others (mainly motorcycle). According to the travel situation, roads in Pingdi are not completely covered by the bus routes, thus the motorized travel structure of Pingdi shall be respectively distributed according to the road with bus and without bus (Table I).

TABLE I MOTORIZED TRAVEL STRUCTURE OF RESIDENTS OF PINGDI (UNIT: %)

Traffic Mode	Road with bus	Road without bus
Regular Bus	34	0
Taxi	10	16
Private Car	30	48
Official Car	16	26
Motorcycle	10	10

7) Spatial Display of Data:

Traffic carbon emission result of Pingdi computed by the traffic carbon emission model was imported to ArcGIS. Maps of traffic carbon emission and emission intensity of Pingdi were established by map symbol system of ArcGIS.

III. RESULTS

A. *Traffic Carbon Emission Assessment*

1) Amount and Structure of Traffic Carbon Emission:

According to the computation, traffic departments of Pingdi altogether emit *127,127.57* tons of CO_2 per year. Carbon emission structure of traffic departments is shown in Fig. 4, from which it can be seen that the private car, official car and taxi account for the largest proportion of emission, occupying 42.9%, 18.2% and 16.5% respectively; the bus and motorcycle account for relatively small proportion of emission, occupying less than 10% of the traffic carbon emission.

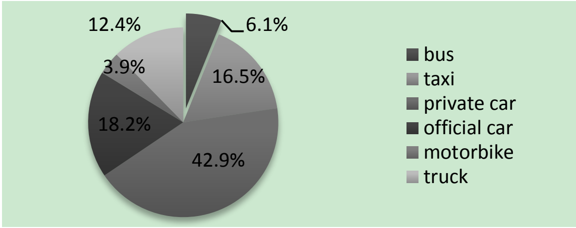


Fig. 4 Carbon Emission Structure of Traffic Departments

2) Comparison of Traffic Carbon Emission Structure:

Studies differ from each other in the motor vehicle structure when accounting the traffic carbon emission, as shown in Fig. 5. It can be seen from the picture that the proportion of the private car's carbon emission of Pingdi is less than that of Shanghai and Xi'an, but the carbon emission of the official car and taxi of Pingdi is 4.6% and 12.8% higher than that of Shanghai and Xi'an respectively. On the contrary, the carbon emission of bus is 9.1% and 6.6% lower than that of Shanghai and Xi'an respectively. It indicates that Pingdi shall take measures as soon as possible to adjust the travel mode of residents to elevate the ridership of the public traffic and optimize the traffic carbon emission structure.

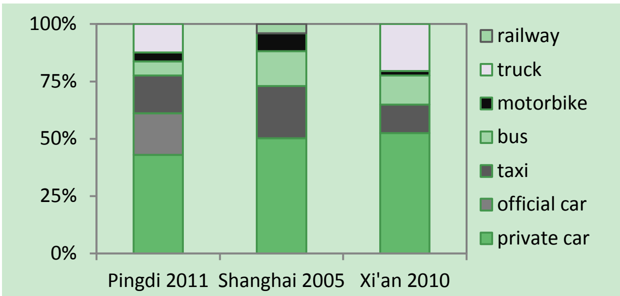


Fig. 5 Comparison of Pingdi, Shanghai and Xi'an in Carbon Emission Structure

Source: Shanghai-*Heidelberg Energy and Environment Research Institute*, 2008; Xi'an-*Study on Urban Traffic Carbon Emission Basing on Scenario Analysis*, 2012.

3) Spatial Distribution:

Spatial distribution of the traffic carbon emission of Pingdi is shown in Fig. 6. Sections with large-quantity of carbon emission include Huiyan Highway, Yanlong Avenue and Shenhui Road while the carbon emission of branch roads is relatively low.

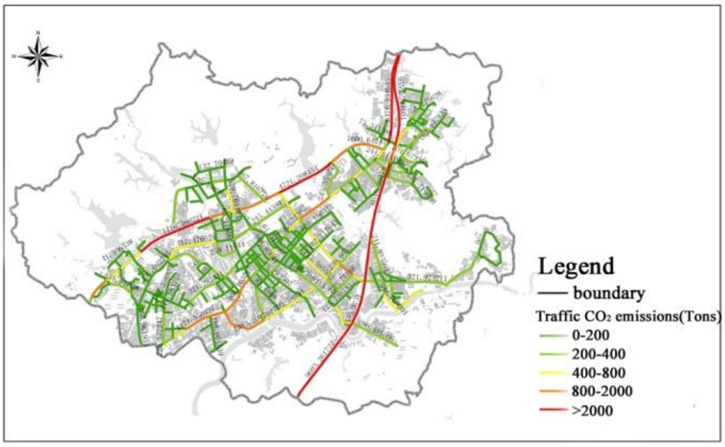


Fig. 6 Spatial Distribution of Traffic Carbon Emission of Pingdi

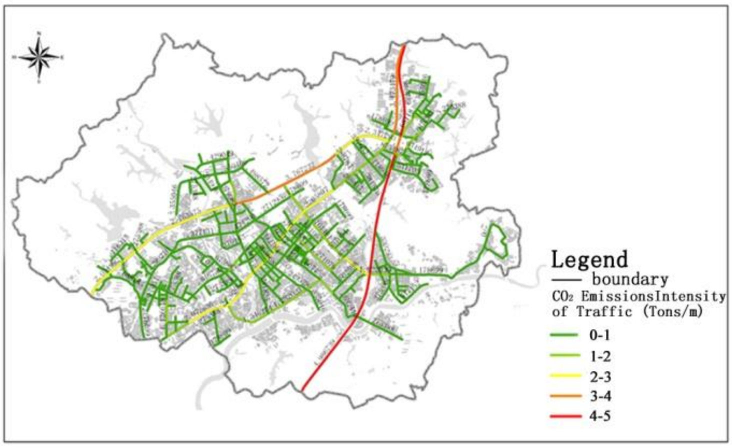


Fig. 7 Spatial Distribution of Traffic Carbon Emission Intensity of Pingdi

B. Influencing Factors

1) Land Use Structure:

Land use structure may influence the traffic demand, spatial distribution and travel distance, among which the traffic demand and travel distance are critical factors for the traffic carbon emission. Reasonable arrangement of urban land, adjusting regional proportion of commerce and residence, mixed development and transformation may meet the residents' demand for various services within the short distance, which can effectively reduce the demand for motorized travel and realize the carbon emission reduction of the traffic department.

2) Motorized Travel Structure:

Emission factor per unit distance of every motor vehicle differs from each other largely (Fig. 1): carbon emission factor per unit distance of the car is relatively high, while that of the Bus Rapid Transit (BRT), metro and bus is relatively low. For example, the carbon emission factor per unit distance per capita of BRT is less than 3% of that of the taxi. When the travel flow and travel distance are kept unchanged, adjustment of the travel structure may influence the traffic carbon emission. For example, in Pingdi, the carbon emission per unit distance of the road without bus is 0.227 kg/ (day ·km) while that of the road with bus is only 0.1473 kg/ (day ·km), 64.9% of the former one. It can be seen that it may effectively reduce the traffic carbon emission by increasing the proportion of vehicles with low emission factors, such as bus, metro and BRT.

3) Traffic Road Network:

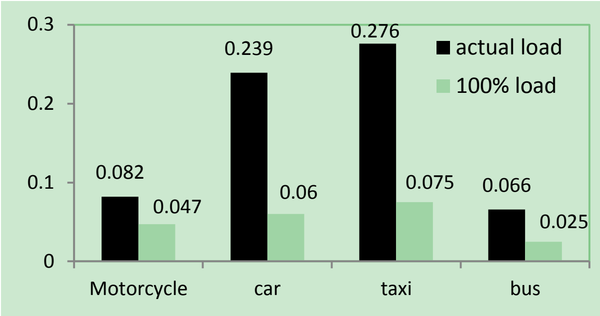
The carbon emission intensity of the highway and expressway is quite high, for they share the external transportation of Pingdi. The emission intensity of the park mainly comes from the main road, followed by the subsidiary road and branch road. As for the total emissions, the highway, main road and branch road emit much carbon while the expressway and subsidiary road emit less CO_2. The carbon emission intensity of the branch road is relatively low but the total emission is large. It's because the branch road network is quite dense, and it connects the subsidiary road and the residential area. Sometimes the roads take on large traffic flow and the vehicle speed is slow, so that their carbon emission is indirectly increased.

As for the bus network, other than the highway and expressway, the number of bus routes in Pingdi is basically positively correlated to the traffic flow of the road, but there is larger improvement space: firstly, only 43.2% roads of Pingdi are covered by the bus route while some roads with large traffic flow has no bus; secondly, some sections covered by the bus route are insufficient in transportation so that bus routes shall be increased to share the traffic pressure; On the contrary, some traffic routes are too concentrated. For example, there are 17 bus routes on Shenhui Road, much more than 1.5-2.5[2] recommended by the *Traffic Engineering Manual*. It can be inferred from Fig. 8 that when the load rate of bus is 100%, the carbon emission per unit distance per capita may be reduced to 37.9% of the former carbon emission. As a result, it shall arrange the bus route reasonably to enlarge the coverage and reduce the repetition rate of the bus route based on the residents' travel demand on different roads, to elevate the load rate and utilize the bus to the maximum extent.

4) Energy Consumption Structure:

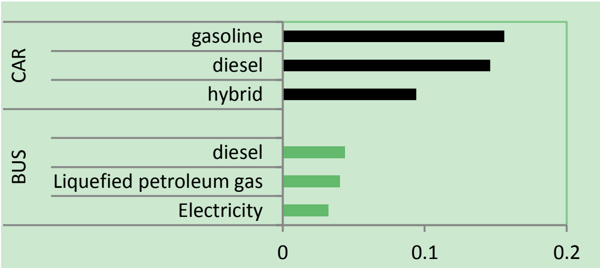
Energies differ from each other in the carbon emission per unit. It can be inferred from Fig. 9 that the CO_2 emission factor of the hybrid automobile is 39.7% lower than that of the gasoline automobile, and the CO_2 emission factor of the electric bus is 27% lower than that of the diesel bus. As a result, the promotion of the application of the low-carbon vehicle may effectively reduce the traffic carbon emission.

[2]Refer to Comprehensive Traffic Improvement Plan of Longcheng, Longgang and Pingdi-Pingdi Subdistrict.



Unit: kg CO_2/ (person ·km)

Fig. 8 Carbon emission per unit distance per capita under different load rates (Heidelberg Energy and Environment Research Institute, 2008)



Unit: kg CO_2/ (person ·km)

Fig. 9 Carbon (CO_2) emission factor per unit distance of various motor vehicles (QIULixun et al, 2008)

5) Green Travel Consciousness:

Other than improving the land use structure and traffic network and forming green traffic network, the residents' consciousness of green travel is critical for the traffic carbon emission reduction. For example, short-distance travel shall choose zero-carbon ways like walking and bicycle, the travel of 1 to 3 persons shall choose the low-carbon ways like bus and metro, so as to effectively reduce the traffic carbon emission within the region.

IV. CONCLUSIONS AND DISCUSSIONS

This paper constructs the park-scale computation model of the carbon emission to analyze the traffic carbon emission of Pingdi low-carbon eco-park of Shenzhen. Traffic flow distribution analysis of road is conducted in ArcGIS and TransCAD, and the traffic carbon emission structure and spatial distribution characteristic of Pingdi eco-park a reestablished. Furthermore, influential factors were analyzed. Result indicates:

(1) The private car accounts for the largest proportion of carbon emission in the park, followed by the official car, while bus and motorcycle account for relatively small proportion.

(2) Spatial distribution of the traffic carbon emission is basically consistent with spatial distribution of the traffic flow. Huiyan Highway and Yanlong Avenue with large traffic flows emit much CO_2.

(3) Important factors influencing the traffic carbon emission include land use structure, travel structure, traffic network, traffic vehicle and residents' travel consciousness.

According to the analysis above and the actual situation of traffic carbon emission of Pingdi, we suggest taking the following measures to reduce the carbon emission of traffic departments:

a. Optimize the land use structure and adjust the road network: Construct the mixing function area to avoid separated commerce and residence to reduce long-distance travel. Optimize road network structure and increase subsidiary roads to connect the main road and branch road to reasonably arrange the traffic flow. Construct the slow traffic system like bicycle lane and green lane for the convenience of the residents' zero-carbon travel instead of motorized travel.

b. Optimize the travel structure: Reasonably arrange the official car, and avoid private use of the official car. Reduce the utilization of the private car and encourage the travel by public transit. Improve the public traffic system to elevate the proportion of bus, metro and BRT in the travel structure to optimize the travel structure and reduce the intensity and flow of carbon emission of each motorized road section.

c. Use the green vehicle: Optimize the automotive power, strengthen the automotive technology and choose the clean-energy vehicle to reduce the carbon emission of the motor vehicle and enlarge the application of the clean-energy bus.

d. Strengthen the green travel consciousness: Encourage and publicize the green travel and reduce the demand for the motor vehicle. Meanwhile, strengthen the green travel consciousness by campus education and publicity to guarantee the green and low-carbon traffic.

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