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Projection on China’s Automobile Stock and Traffic Carbon Emissions

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Abstract—As a means of transportation, automobiles produce large carbon emissions. On the basis of analyzing the carbon emissions of automobile transportation in 2021, the ownership model, new car sales structure model and carbon emissions analysis model are constructed, and the carbon emissions of automobiles under the baseline scenario and dual carbon scenario in 2022-2060 are predicted. For dual carbon, the main technology path of automobile can be divided into four parts: popularizing new energy vehicles, energy-saving fuel vehicles, green transportation and zero-carbon fuels.

1. FOREWORD

In September 2020, Chinese President XI Jinping announced at the General Debate of the 75th Session of The United Nations General Assembly: "Strive to reach peak carbon dioxide emissions by 2030 and strive to achieve carbon neutrality by 2060." In order to do a good job in achieving emission peaking and carbon neutrality, the "Opinions of the Central Committee of the Communist Party of China and the State Council on Completely, Accurately and Comprehensively Implementing New Development Concept and Doing a Good Job in Emission Peaking and Carbon Neutrality" was printed and issued in 2021. Emission peaking and carbon neutrality have become important tasks in all walks of life in all regions. Automobile is an important means of transportation, transportation sector is an important area for emission reduction, Therefore, it is necessary to scientifically define and conduct comprehensive in-depth research and analysis on automobile carbon emissions, so as to identify major contributors to automobile carbon emissions and clarify low-carbon development paths.

2. DEFINITION OF AUTOMOBILE CARBON EMISSIONS

The carbon emissions of automobiles are relatively complex. There are not only carbon emissions caused by the production of automobiles, but also carbon emissions generated by burning gasoline and diesel for vehicles as a means of transportation. There are both annual carbon emissions and full-life-cycle carbon emissions. In order to facilitate understanding, we define automobile carbon emissions from the perspective of annual analysis. The annual carbon emissions of automobiles is automobile driving carbon emissions, which can also be called traffic emissions.

TABLE I. DEFINITION, COMPOSITION AND EMISSION ACTIVITIES OF AUTOMOBILE TRAFFIC

Scope Category	Definition	Composition	Greenhouse gas emissions activities
Carbon emissions from automobile driving	Carbon emissions generated by burning gasoline, diesel and other fuels when vehicles are used as means of transportation	Passenger vehicle driving carbon emissions	Private car driving Taxi driving, ride-hailing Official vehicles
		Commercial vehicle driving carbon emissions	Commercial truck driving Commercial bus driving

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3. AUTOMOBILE CARBON EMISSION ACCOUNTING METHOD

Automobile carbon emission consists of three main modules: demand forecast, scenario setting and emission analysis .The main analysis method is to estimate the annual carbon dioxide emissions from automobile driving based on the analysis of automobile ownership (total quantity and structure), quantity of scrapped automobiles and annual production of new cars (total quantity and structure).

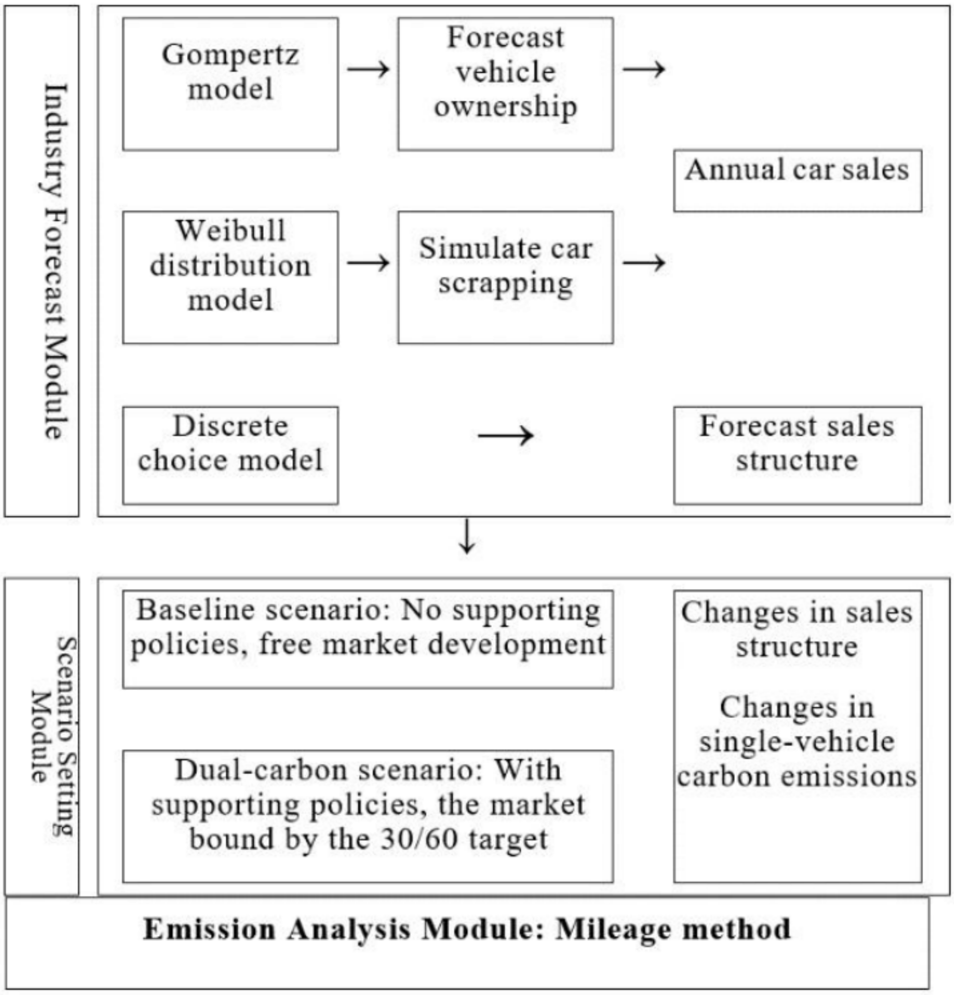

Figure 1. Automobile carbon emission analysis models

3.1 Automobile stock forecast module

1) Forecast vehicle ownership

It is the method adopted by most research institutions to analyze the total vehicle ownership in China from the population dimension based on the vehicle ownership per 1,000 persons. Gompertz curve is mostly used in the analysis on the research and development, maturity and decline of new products. It is more applicable for forecasting these commodities in the mature stage to obtain the saturation volume of market demand and sales. Judging from the current situation of China's automobile vehicle market, the automobile market has passed the peak growth stage and entered a stable growth stage, while the market growth trajectory will enter a relatively stable stage. It is consistent with the characteristics of Gompertz curve, which is suitable for the analysis on the research and development, maturity and decline of new products and more applicable for forecasting these commodities in the mature stage. Therefore, this paper selects the Gompertz curve to forecast the vehicle ownership from 2022 to 2060.

According to statistics from the Ministry of Public Security, as of September 2021, vehicle ownership in China has reached 297 million cars, while the vehicle ownership per 1,000 persons has reached 205 cars. With the continuous increase of residents' income, continuous upgrading of consumption and gradual advancement of urbanization in the future, there is still a large space for growth in the vehicle ownership per 1,000 persons in China. After collecting and sorting out the results of existing major research institutions, it is found that the peak vehicle ownership per 1,000 persons in China will be between 300-500 cars and the corresponding peak value of the overall vehicle ownership will be between 420-650 million cars in the future.

2) Forecast total annual sales of automobiles

Weibull distribution is a random variable distribution, which reflects the wear residual of items under the condition of natural decay.

It is widely used in reliability engineering research, especially for describing the wear residual of electromechanical products. For the research on the prediction of vehicle scrapping volume, most researchers use the Weibull distribution to describe the car survival rate. There is a close relationship among car sales, scrapping volume and ownership. vehicle ownership and scrapping volume are converted into the sales of the current year, that is, the sales of passenger cars in the current year is equal to the difference between the vehicle ownership in the current year and the vehicle ownership in the previous year plus the number of scrapped passenger cars in the current year, which is expressed by the sales export formula:

$$N_t = S_t - S_{t-1} + R_t$$

Where, N_t is the sales of cars in year t, S_t is the vehicle ownership in year t, and R_t is the number of scrapped cars in year t.

3) Forecast automobile sales structure

Based on the forecast of the total annual sales of automobiles, combining with the main factors that affect consumers to purchase cars, the discrete choice model is used to analyze the changes in various factors (such as policy impact and cost changes), quantitatively analyze the comprehensive cost of vehicles with different fuel types (such as Battery Electric Vehicles, plug-in hybrid vehicles, fuel-driven vehicles and fuel cell vehicles), analyze the probability of consumers' choices for purchasing cars and forecast the market share of vehicles by fuel type.

3.2Scenario design module

There are two development scenarios. One is baseline scenario, which is a scenario without dual-carbon requirements. The industry follows the current natural development trend, technological progress and market share of new energy vehicles; the carbon emission of single car, carbon emission factor of electricity and others will evolve at the decline rate of the previous year; the fiscal and tax incentive policies for new energy vehicles will no longer be implemented after the end of 2022, while other policies will be set by the industry's own development needs. The other is dual-carbon scenario. Based on the requirements of carbon peaking ahead of schedule by 2030 and carbon neutrality ahead of schedule by 2060, it is required to continue to implement certain fiscal and taxation support policies, while the requirements for industrial technological progress, market share of new energy vehicles, low carbon emissions of single car and green development of electricity are more radical. In these two scenarios, there is the difference in the policy strength for fuel-driven vehicles and new energy vehicles. In the baseline scenario, subsidies for new energy vehicles and vehicle purchase tax concessions will not be implemented from 2023, while restrictions on fuel-driven vehicles will not continuously enhanced (such as Traffic restrictions and purchase restrictions). In the dual-carbon scenario, vehicle purchase tax concessions will be continuously implemented in 2023, while restrictions on fuel-driven vehicles will be enhanced, thus affecting consumers' choice of purchasing cars.

TABLE II. CHANGES IN POLICIES AND MAIN PARAMETERS IN THE BASELINE AND DUAL-CARBON SCENARIOS

	Policies, market conditions	Main parameter changed
Baseline scenario	The vehicle purchase tax preferential policy will no longer be implemented for new energy vehicles since 2023.	1. Vehicle electrification ratio; 2. Average fuel consumption of fuel-driven vehicles;
Dual-carbon scenario	In 2023, continue to implement vehicle purchase tax preferential policies, improve the support for charging infrastructure	

3.3 Carbon emission analysis module

(Automobile driving carbon emission sub-module)

According to different statistical sources of key data, the main transportation carbon emission calculation methods can be divided into "top-down method" with energy consumption as the core and "bottom-up method" with mobility data as the core.

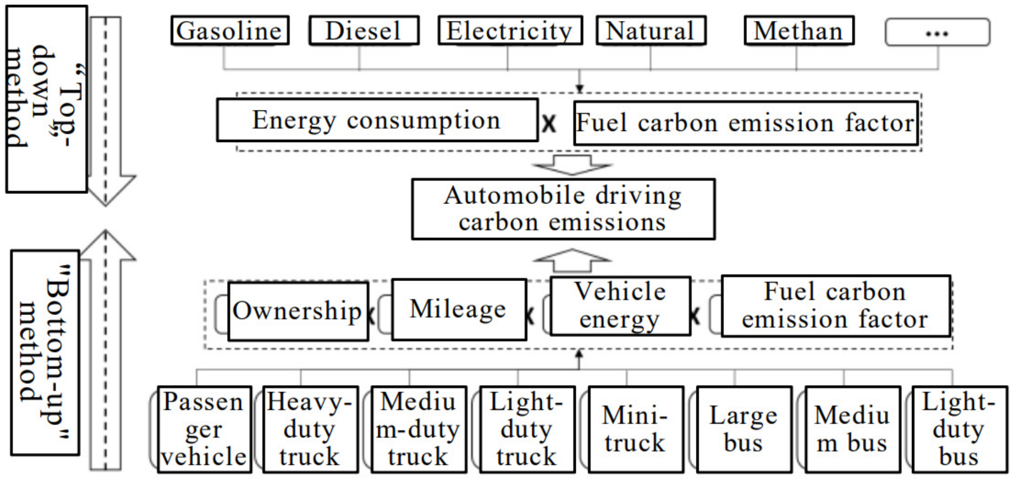

Figure 2. Schematic diagram of "top-down method" and "bottom-up method"

The "top-down" method, based on energy consumption, is the most commonly used method for calculating transportation carbon emissions now. The principle is to obtain the total volume of carbon emissions by multiplying fuel consumption by the carbon emission factors of various fuels. The "bottom-up" method takes mobility data as the core and obtains the total volume of carbon emissions by multiplying the movement distance of various vehicles by the carbon dioxide emission factor per unit movement distance. The research uses the "bottom-up" method for calculation. The "bottom-up" method is used to calculate the carbon emissions during automobile driving, which is mainly affected by four elements including ownership of each model (Battery Electric Vehicles, energy-saving vehicles, Fuel Cell Electric Vehicles and Plug-in Hybrid Electric Vehicles), fuel consumption perunit of each model, annual mileage of each model and fossil fuel carbon emission conversion factor.

$C_{automobile\ driving}$ = Carbon emissions from passenger cars driving + Carbon emissions from commercial vehicles driving

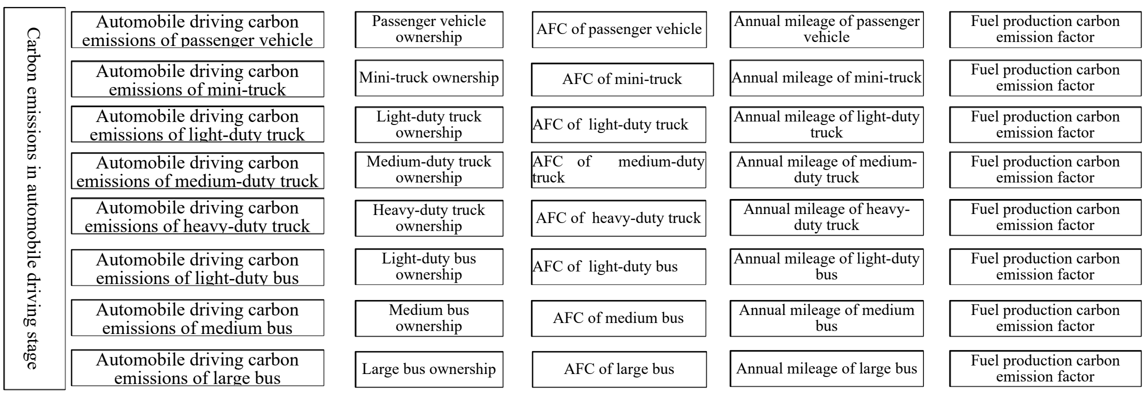

Chart Notes：AFC is short for Average Fuel Consumption.

Figure 3. Factors affecting carbon emissions during vehicle driving

3.4 Basic data

For population data, please refer to the State Council's National Population Development Plan (2016-2030). The historical data of vehicle ownership mainly uses the relevant data provided by the National Bureau of Statistics. Passenger vehicle curb weight and fuel consumption per 100 kilometers are based on the data specified in the "Announcement on Average Fuel Consumption and New Energy Vehicle Points of Chinese Passenger Vehicle Enterprises in 2020" issued by the Ministry of Industry and Information Technology, Ministry of Commerce, General Administration of Customs and State Administration for Market Regulation. For the annual mileage of private cars among passenger cars, please refer to the "Research on Fuel Control Plans During the "14^{th} Five-Year Plan" Period in Transportation Sector" issued by the Planning and Research Institute of the Ministry of Transport. In addition, the annual mileage of operating taxis are obtained from survey data.

CO_2 conversion coefficient of direct combustion of vehicle energy: gasoline 2.37kgCO_2/L and diesel 2.6kgCO_2/L are the data specified in the standard GB 19578-2021 "*Fuel Consumption Limits for Passenger Cars*". The natural gas 2.16kgCO_2/m^3 is measured and calculated by the China Automotive Strategy and Policy Research Center, CATARC.

4. Analysis of Existing Circumstance of Automobile Carbon Emissions and Predictions

In 2021, the direct combustion of fossil fuels in vehicles released 900 million tons CO_2, where passenger cars and commercial vehicles accounted for 47% and 53% respectively.

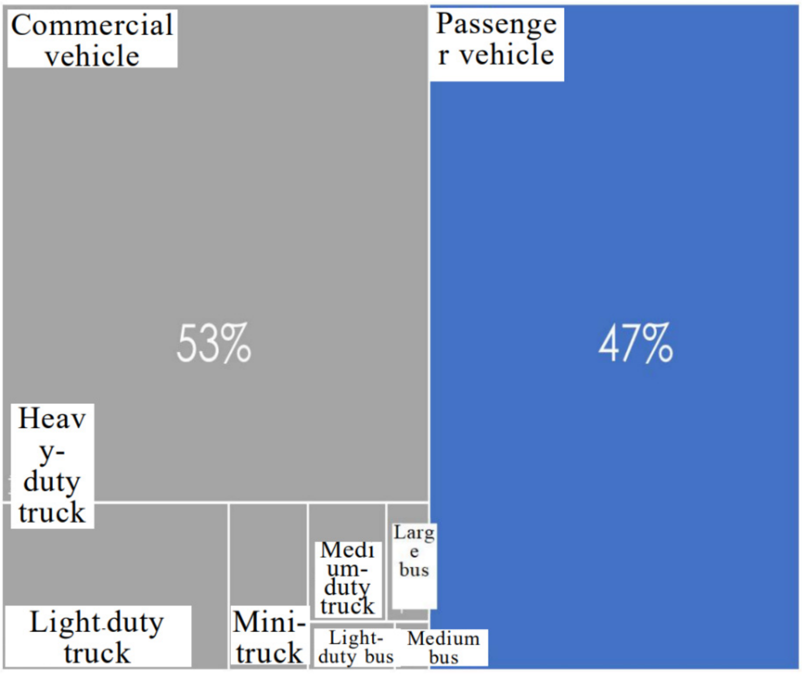

Figure 4. CO_2 emissions from vehicle driving in 2021 (100 million tons)

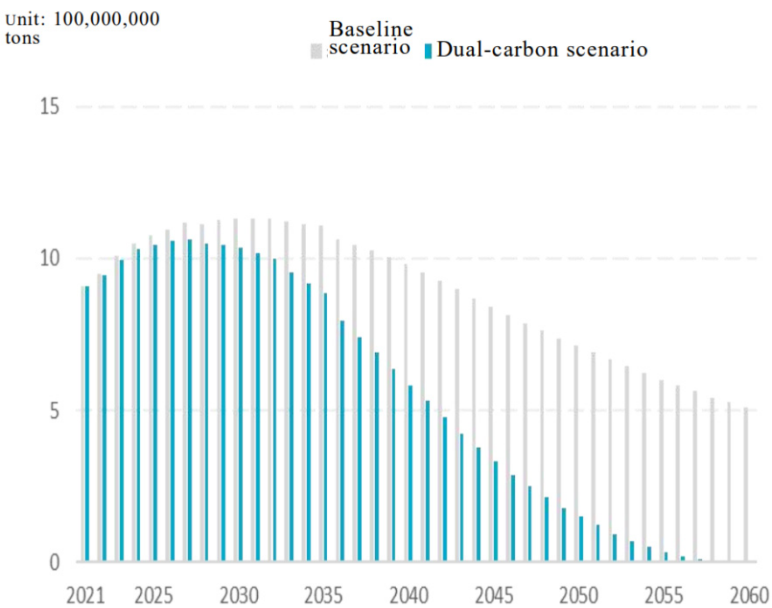

Figure 5. Prediction of CO_2 emissions from vehicle driving (100 million tons)

In the baseline scenario, automobile driving carbon emissions will peak at 1.134 billion tons in 2031; the peak value of vehicle ownership will be 560 million and the proportion of new energy vehicles in total vehicle ownership will reach 15% in 2030 and 70% in 2060.

In the two-carbon scenario, automobile driving carbon emissions will peak at 1.064 billion tons in 2027; the peak value of vehicle ownership will be 560 million and the proportion of new energy vehicles in total vehicle ownership will reach 22% in 2030 and 100% in 2060.

Automobile driving carbon emissions are mainly directly affected by the ownership structure of Battery Electric Vehicles, energy-saving vehicles, Fuel Cell Electric Vehicles and Plug-in Hybrid Electric Vehicles. The penetration rate of new energy passenger vehicles in new car sales is higher than that of new energy commercial vehicles. Therefore, the carbon emissions of passenger vehicles in the driving stage peak earlier than that of commercial vehicles. At the same time, it is more easy to achieve zero emissions of passenger vehicles in the driving stage than commercial vehicles. The price of new energy commercial vehicles is much higher than that of fuel-driven commercial vehicles, the electrification process of new energy commercial vehicles is slower than that of passenger vehicles, which is also affected by the development of the national economy and turnover.

5. Low carbon development technology path for automobile driving

The automobile driving carbon emissions are mainly the direct carbon emissions caused by the combustion of gasoline and diesel in traditional fuel-driven vehicles. Therefore, automobile driving carbon emissions can be significantly reduced by accelerating the popularization of new energy vehicles. Since the number of traditional fuel-driven vehicles is huge, it is difficult to achieve full electrification as soon as possible. At the same time, the energy-saving technology of internal combustion engines has not yet reached its peak and there is still a certain energy-saving potential. Therefore, promoting energy-saving of fuel-driven vehicles is still an important way to reduce carbon emissions in the automobile driving stage. In addition, changes in the total vehicle ownership (especially the total number of fuel-driven vehicles) and the driving characteristics of vehicle owners also have a greater impact on carbon emissions in the automobile driving stage. Therefore, it is also necessary to moderately control the total number of fuel-driven vehicles, guide green mobility and promote the development of green freight transport. Considering the realization of carbon neutrality in automobile driving stage in the future, it is also required to develop and apply more low-carbon and zero-carbon fuel-driven vehicles. To this end, the low-carbon development technology path in the automobile driving stage can be divided into four parts: popularizing new energy vehicles, energy-saving fuel vehicles, green transportation and zero-carbon fuels.

In terms of carbon peaking, more attention shall be paid to automobile driving carbon emissions. The improvement of the penetration rate of new energy vehicles can effectively reduce direct carbon emissions in automobile driving phase. To achieve carbon neutrality for vehicles before 2060, we shall not only focus on reducing automobile driving carbon emissions to zero emissions, but also pay more attention to carbon emissions neutralization in the production stage to achieve zero emissions in the entire life cycle.

6. Some policy suggestions for promoting low-carbon development of automobiles

In order to guide government authorities, automobile manufacturers, automobile users to form a joint force to jointly promote low-carbon development of automobiles, it is recommended to introduce policy measures in the following four aspects to realize the low-carbon development of automobiles as soon as possible.

1) ***Improve policies to support the popularization of new energy vehicles.*** *Study the feasibility of continuing to reduce or exempt vehicle purchase tax for new energy vehicles before 2025, vigorously promote the demonstration application of Fuel Cell Electric Vehicles, encourage the electrification of vehicles in public sector and improve the fiscal and taxation policy support system. Revise the "Measures for Parallel Management of Average Fuel Consumption and New Energy Vehicle Credits of Passenger Vehicle Enterprises", accelerate the formulation of commercial vehicle credit management policies and guide automobile enterprises to launch more new energy vehicle models and expand sales. Encourage local governments to introduce subsidy policies for auto replacement to encourage consumers to replace high-energy-consumption and high-emission vehicles with new energy vehicles and energy-saving vehicles and reduce or exempt parking fees and tolls. Speed up the construction of charging and swapping infrastructure, establish a moderately advanced charging and swapping service network.*

2) ***Enhance the application of energy-saving technologies for fuel vehicles.*** *Establish a car tax system based on carbon dioxide emissions, guide the development of energy-saving, low-carbon and small vehicles for a long time, continuously improve energy efficiency standards for automotive products and improve fuel consumption standards for passenger vehicles and commercial vehicles.*

3) ***Encourage the research and development of low-carbon technologies for automobile products.*** *Support enterprises to undertake major national green and low-carbon science and technology projects, research and develop key core technologies such as power batteries, fuel cells, low-carbon energy, zero-carbon fuels and new materials. Cultivate national key laboratories, national technology innovation centers and major scientific and technological innovation platforms for research and development of low-carbon and zero-carbon fuels, new energy technologies and products, and promote the demonstration and application of low-carbon technologies for automobiles.*

4) ***Encourage the development of green and low-carbon mobility, green and efficient freight transport.*** *Firmly develop an urban transportation system featured with public transportation as the mainstay, encourage the development of the TOD model, increase the construction of new infrastructure, explore the mobility guidance mechanism in private sector, reward individuals for green mobility and encourage low-carbon mobility. Encourage to explore and implement low-emission driving area pilots in qualified places and increase the external cost of fuel-driven cars by establishing zero-emission areas, levying traffic congestion charges and collecting differentiated parking fees. Support the transfer from road transport to railway and water transport, reduce the sharing rate of road transport. Reduce the empty driving rate of road freight vehicles, increase the average single load of heavy-duty vehicles and improve transportation efficiency to effectively reduce freight carbon emissions. Actively introduce relevant measures to support the full electrification of road vehicles in public sector, encourage* *the replacement of fuel vehicles with Battery Electric Vehicles and hydrogen fuel vehicles by local conditions.*

7. Conclusions

In 2021, the direct combustion of fossil fuels in vehicles released 900 million tons CO_2, where passenger cars and commercial vehicles accounted for 47% and 53% respectively.

Automobile driving carbon emissions are mainly directly affected by the ownership structure of Battery Electric Vehicles, energy-saving vehicles, Fuel Cell Electric Vehicles and Plug-in Hybrid Electric Vehicles. The penetration rate of new energy passenger vehicles in new car sales is higher than that of new energy commercial vehicles.

For dual carbon, the main technology path of automobile can be divided into four parts: popularizing new energy vehicles, energy-saving fuel vehicles, green transportation and zero-carbon fuels. Some policy measures should be taken,

1) Improve policies to support the popularization of new energy vehicles.

2) Enhance the application of energy-saving technologies for fuel vehicles.

3) Encourage the research and development of low-carbon technologies for automobile products.

4) Encourage the development of green and low-carbon mobility, green and efficient freight transport.

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