Research on Energy Consumption, Pollutant Emission and Carbon Emission of Passenger Vehicles in the Whole Life Cycle

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Abstract. Passenger cars are an important field of energy consumption, pollutant emission and carbon emission. Strengthening vehicle pollution reduction and carbon reduction is of great significance for China to achieve peak carbon neutrality. Based on the previous management measures of motor vehicle energy consumption and pollutants, this paper firstly conducted a quantitative study on the management effect of motor vehicle energy consumption, pollutants and carbon emissions in the whole life cycle. Secondly, it analyzed the ratio of motor vehicle energy consumption, pollutant emission and carbon emissions in each link of the whole life cycle. Finally, this paper puts forward the policy suggestions of cooperative reduction of vehicle energy consumption, pollutants and carbon emissions.

Keywords: Passenger Car · Carbon Emissions · Energy Consumption · Pollutant Emission

1 Introduction

The transportation industry is an important sector in global energy consumption, pollutant emission and carbon emission. According to the latest study report of IEA, in 2018, the global transportation sector accounted for 52% of the world's final energy consumption [1], and the carbon emission accounted for 25% of the world's total carbon emissions. The transportation industry has become one of the key areas to mitigate and address climate change because of its significant energy consumption and carbon emissions [2].

The transport sector is one of the country's major emitters, accounting for nearly 9 percent of the country's total carbon emissions, which have doubled in the past decade. Of this, road transport emissions grew rapidly, by 127%, from 69% to 77.4% (IEA and ONS). In 2019, the total life cycle carbon emission of passenger vehicles in China was 620 million tCO2e. With the development of vehicle electrification, the proportion of vehicle cycle carbon emissions will increase from 20% of fuel vehicles to 45%, and the carbon emissions of vehicle life cycle will also transfer from the use stage to the

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upstream and downstream of the industrial chain. The challenge of "carbon neutrality" and the corresponding international competitive pressure of the automobile industry will increase sharply [3–5].

Motor vehicle pollutant emission has become one of the important fields of pollution emission in China and even the world. "China Mobile Source Environmental Management Annual Report (2021)" shows that in 2020, the total amount of four pollutants discharged by motor vehicles is 15.93 million tons. The emissions of the four pollutants, hydrocarbon (HC), nitrogen oxide (NOx) and particulate matter (PM) were 7.697 million tons, 1.902 million tons, 6.263 million tons and 68,000 tons respectively. Motor vehicle pollution has become an important source of air pollution in Chinese large and medium-sized cities, as well as an important cause of fine particulate matter and photochemical smog pollution. The urgency of prevention and control of motor vehicle pollution has become increasingly prominent [6, 7].

In the early stage, China mainly strengthened the management of motor vehicle energy consumption and pollutants, and introduced a large number of policies and standards to promote the significant reduction of motor vehicle energy consumption and pollutants. Under this background, automobile carbon emissions have been controlled to a certain extent, but mainly in the use stage. With the proposed goal of "double carbon", carbon emission management is gradually transforming from the use stage to the full life cycle in order to avoid pollution transfer. Based on the previous management measures of motor vehicle energy consumption and pollutants, this paper will conduct a quantitative study on the management effect of motor vehicle energy consumption, pollutants and carbon emissions in the whole life cycle, explore the relationship between motor vehicle energy consumption, pollutant emissions and carbon emissions, and on this basis analyze the policy suggestions for collaborative reduction of motor vehicle energy consumption, pollutants and carbon emissions.

2 First Research Scope and Methods

2.1 Functional Units and System Boundaries

A functional unit is a quantitative reference for all relevant inputs and outputs (raw materials, energy inputs and pollutant emissions required for production) of each production process, which defines the content of the study, and all analyses in the study are based on this functional unit. According to the requirements of ISO14040 standard [8], this study determined the transportation service provided by a passenger vehicle traveling 1 km as the functional unit of evaluation. In this study, the life cycle mileage of passenger vehicles was set at 150,000 km.

The setting of the system boundary defines which unit processes are part of the whole process of passenger car production and use. In this study, the system boundary is defined from "cradle" to "gate". The boundary includes the fuel cycle of passenger car (fuel production, The whole life cycle includes fuel use -- the passenger vehicle use stage -- and vehicle cycle (material production, components and materials production, vehicle production and vehicle maintenance). In the downstream process, vehicle abandonment and recycling are not considered.

2.2 Research Methods and Data Sources

Based on ISO14040 series standards, this paper adopts the life cycle assessment (LCA) research method to quantitatively analyze the energy consumption, pollutants and carbon emissions of passenger vehicles in the whole life cycle. Life cycle assessment is the compilation and evaluation of the input and output of a product system and its potential environmental impact during its life cycle. Life cycle assessment, as the main theoretical basis and analysis method of industrial ecology, has been widely used by automobile enterprises and government management departments since the late 1960s, after more than 50 years of development, for the research and development and design of automobile products, the formulation of automobile environmental protection policies and the consumption of environment-friendly automobile products. The International Organization for Standardization defines life cycle assessment as the compilation and evaluation of the input, output and potential environmental impact in the life cycle of a product system. ISO 14040 stipulates that the technical framework of LCA consists of four stages: determination of purpose and scope, inventory analysis, impact assessment, and result interpretation to be carried out at each stage.

In terms of passenger cars, the data of their reconditioning quality and historical fuel consumption come from the average value of passenger cars sold in China in 2020 [9]. The material composition of passenger cars is calculated by the China Vehicle Life Cycle Evaluation Model (CALCM). Carbon emission factors, energy consumption and pollutants (carbon monoxide, hydrocarbon, particulate matter and nitrogen oxide are mainly considered) of the vehicle production process and various fuels and materials are derived from the China Vehicle Life Cycle Evaluation Database (CALCD) and EcoInvent database [10]. Emission parameters for fuel cycle single Vehicle (China 0~Country V) from Technical Guide for Compilation of Air Pollutant Emission Inventory of Road Motor Vehicles (Trial), The emission of CO and HC shall be reduced by half, NOx by 40% and PM by one third according to Emission Limits and Measurement Methods for Light Vehicle Pollutants (China Stage 6) and Emission Limits and Measurement Methods for Heavy Diesel Vehicles (China Stage 6).

3 Analysis Results of Energy Consumption, Carbon Emissions and Pollutant Emissions

In order to clarify the current situation of energy consumption, carbon emission and pollutant emission of passenger cars, this study studied the average energy consumption, carbon emission and pollutant emission in the whole life cycle of newly sold passenger cars in 2020, and analyzed the proportion of energy consumption, pollutant emission and carbon emission in each link in the whole life cycle of vehicles.

$$C = C_m + C_p + C_u + C_{om} + C_{ou} \tag{1}$$

where, C——Carbon emission of vehicle life cycle.
C_m——Carbon emissions in the production of vehicle materials.
C_p——Carbon emissions in vehicle production.
C_u——Carbon emissions in vehicle maintenance.
C_{om}——Carbon emissions in fuel production.
C_{ou}——Carbon emissions in fuel use.

$$E = E_m + E_p + E_u + E_{om} + E_{ou} \tag{2}$$

where, E——Life cycle energy consumption of vehicles.
E_m——Energy consumption of automobile material production.
E_p——Energy consumption in vehicle production.
E_u——Energy consumption in vehicle maintenance.
E_{om}——Energy consumption in fuel production.
E_{ou}——Energy consumption at the fuel use stage.

$$P_i = P_{mi} + P_{pi} + P_{ui} + P_{omi} + P_{oui} \tag{3}$$

where, P_i——Emission of pollutant i in vehicle life cycle.
i——Pollutants CO, HC, Nox, PM.
P_{mi}——Emission of pollutant i in the process of automobile material production.
P_{pi}——Emission of pollutant i in vehicle production.
P_{ui}——Emission of pollutant i in automobile maintenance link.
P_{omi}——Emission of pollutant i in fuel production.
P_{oui}——Emissions of pollutant i from fuel use.

3.1 Life-Cycle Energy Consumption and Emission Status

The results show that the life cycle energy consumption and carbon emission of newly sold passenger vehicles in 2020 are 3,286.74 kJ/km and 226.02 gCO2e/km respectively. The emissions of carbon monoxide, hydrocarbons, nitrogen oxides and fine particulate matter were 1.4 g/km, 0.17 g/km, 0.17 g/km and 0.47 g/km, respectively.

Figure 1 shows the life cycle average energy consumption and carbon emission structure of newly sold passenger cars in 2020. More than 60% of life cycle energy consumption and carbon emissions of passenger vehicles come from the fuel consumption process. The energy consumption and carbon emissions in the fuel production process accounted for 23.9% and 13.8% of the total life cycle energy consumption and carbon emissions, respectively. The energy consumption and carbon emission in the material production process accounted for 13.5% and 17.5% of the energy consumption and carbon emission in the whole life cycle, respectively. The maintenance process of passenger vehicles accounts for 7.1% of the total life-cycle carbon emissions.

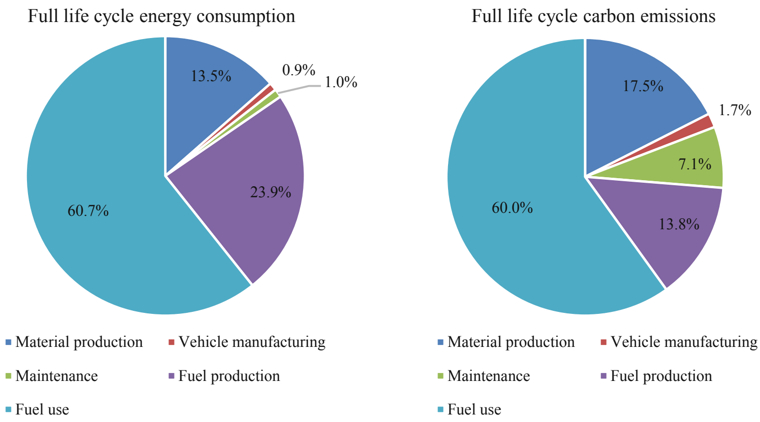

Fig. 1. Average energy consumption and carbon emission structure of newly sold passenger cars in the whole life cycle in 2020.

Figure 2 shows the average pollutant emission structure for the whole life cycle of newly sold passenger cars in 2020. As shown in the figure, CO and CH emissions mainly come from the material production and fuel consumption stage, while NOX emissions mainly come from the fuel production stage in addition to the material production and fuel consumption stage. Most of PM emissions come from the material production process. Therefore, controlling the pollutant emission in the process of material production and fuel consumption is the key to reduce the pollutant emission in the whole life cycle of passenger vehicles. However, for traditional fuel vehicles, pollutant emission in the process of fuel consumption is difficult to avoid, and can only be reduced by improving oil products and other measures, but the reduction effect is relatively limited. In contrast, promoting the development of new energy vehicles can greatly reduce pollutant emission in the fuel consumption stage.

3.2 Emission Status of Material Production Link

Since the material production stage occupies a large share of each pollutant emission, the traceability analysis of pollutant emission is carried out for the material production stage, and the analysis results are shown in Fig. 3. The emission of CO and PM in the material production stage mainly comes from the production of aluminum alloy, and most of the pollutants are discharged by thermal power generation in the upstream process of aluminum alloy production. The use of green electricity for aluminum smelting can greatly reduce the emission of CO and PM. CH emission mainly comes from iron and steel, and CH emission mainly comes from iron ore reduction process in iron and steel production, which is unrelated to energy structure but related to raw material structure. The most effective way to reduce CH emission in iron and steel production is to use green hydrogen instead of coke to participate in iron ore reduction process. NOX emissions mainly come from the production process of aluminum, steel and plastics.

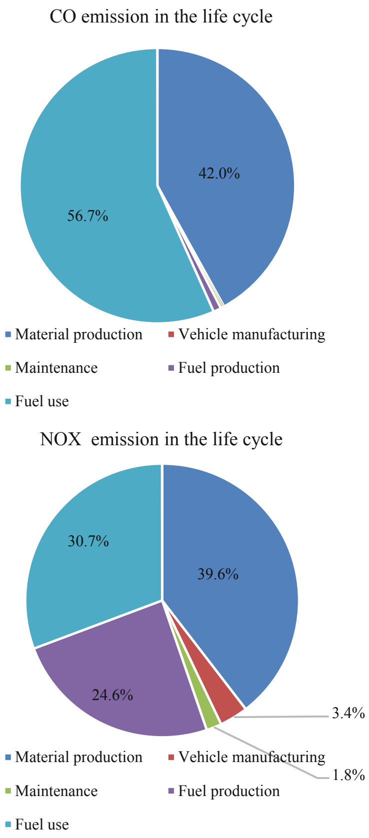

Fig. 2. Average pollutant emission structure of newly sold passenger cars in the whole life cycle in 2020

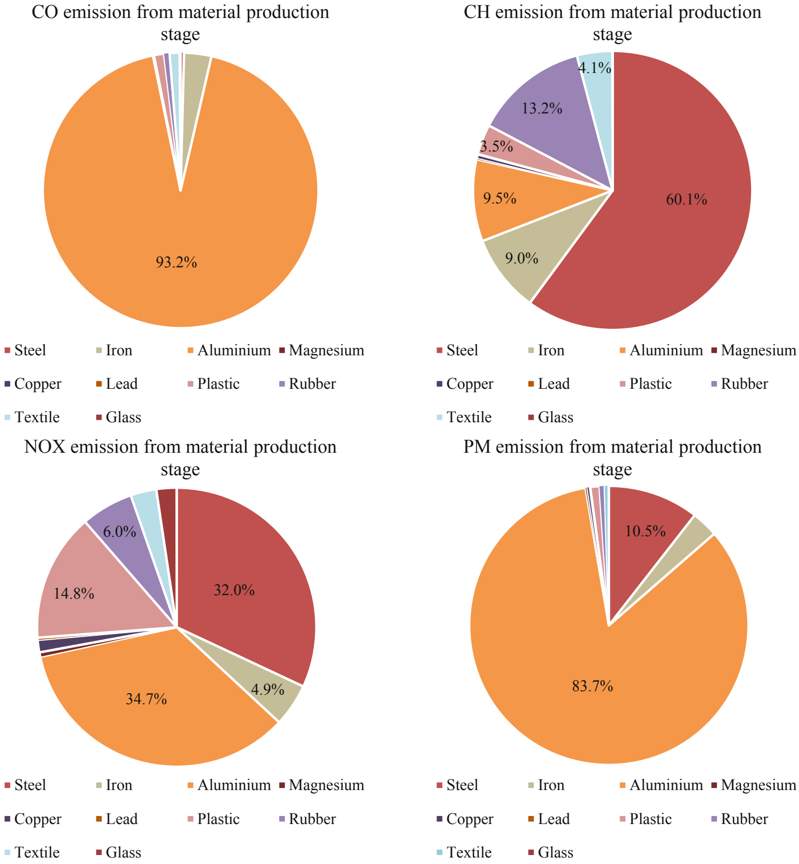

Fig. 3. Pollutant emission structure in the production stage of newly sold passenger car bicycle materials in 2020

4 Summary and Suggestions

From the above analysis, it can be seen from the above analysis that the current life cycle energy consumption and carbon emissions of passenger cars are mainly concentrated in the fuel consumption, fuel production and material production stages, while the pollutant emissions are mainly concentrated in the fuel consumption and material production stages. Through the traceability analysis of pollutant emission in material production, it is found that the pollutant emission mainly comes from the steel production and aluminum alloy production process. The key to reduce pollutant emission in material production stage is to take green electricity substitution in aluminum smelting process and green hydrogen substitution for coke in steel production process. With the increasing number of motor vehicles in China, in order to strengthen energy management and control and realize the collaborative management of pollutants and carbon emissions, it is necessary to constantly transition to the full life cycle management of vehicles based on the current energy consumption and exhaust management policies in the use stage of vehicles, and drive the whole life cycle of vehicles to reduce energy consumption and pollutant emissions by controlling carbon emissions throughout the life cycle based on carbon emission management.

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