Energy and environmental impact of banning the sale of traditional fossil fuel vehicles

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Abstract

This study investigates the energy and environmental impacts of banning the sale of traditional fossil fuel vehicles in China. By using the Logistic model, the dynamic evolution of China's vehicle market under different timing of banning the sale of traditional fuel vehicles was simulated. Based on this, the fossil energy saving and greenhouse gas emission reduction potential of promoting new energy vehicles under different energy development scenarios was further explored from the life cycle perspective. The results show that under China's current electricity mix, the life cycle GHG emissions intensity and fossil energy consumption intensity of battery electric vehicles are about 40.94% (120.04 g CO2-eq/km) and 45.90% (1.68 MJ/km) lower than those of gasoline-powered vehicles, respectively. As the proportion of renewable electricity generation continues to increase, by 2050, replacing traditional fuel vehicles with battery electric vehicles can reduce GHG emissions and fossil energy consumption by up to 58.26% and 53.03%, respectively. In addition, if China plans to ban the sale of traditional fuel vehicles between 2040 and 2060, the cumulative fossil energy savings and GHG emissions reductions during the period of 2020~2050 can reach approximately 32.54~129.10 million TJ and 2.70 ~ 9.32 billion tons of CO2-eq, respectively.

Keywords: Battery Electric Vehicle, Ban Sales of Fossil Fuel Vehicles, Fuel Life Cycle, Fossil Energy Consumption, Greenhouse Gas Emissions, Logistic Equation

I. INTRODUCTION

Traditional fossil fuel (e.g., diesel and gasoline) vehicle (TFV) have become the major source of GHG emissions and fossil energy consumption around the world[1–3]. As a promising way to promote the transition of the energy and environment to sustainability, the development and promotion of new energy vehicle (NEV) has become an irreversible global wave and trend [4–6]. However, the academic research on NEVs mainly focuses on relevant industrial policies, consumer behavior, vehicle and fuel technology, and their competitive advantages over TFVs in terms of energy and environmental sustainability [7–11], few studies discuss the energy and environmental impacts of the medium-and long-term development of NEVs for a country or region. In addition, the development of NEVs industry is not isolated, but closely linked with the coordinated development of other industries. The market evolution of NEVs and the corresponding energy and environmental impacts depend on regional energy planning and the level of development of vehicle and fuel technologies. In turn, promoting NEVs can also affect the development of these related aspects to a certain extent. Currently, many countries around the world have drawn up timetables for the withdrawal of traditional fossil fuel vehicles from the market (i.e., plans to ban the sales of TFVs), which will exert a complex and great impact on the energy, environment and the development of related industries. Therefore, it is of great significance to study the impact of medium and long-term development of NEVs on energy and the environment in the context of banning the sale of traditional fossil fuel vehicles, which can provide valuable insights for policy formulation and industrial planning to promote healthy and sustainable development in an all-round way. Taking China as an example, this paper systematically and deeply analyzes the energy and environmental impact of banning the sale of traditional fossil fuel vehicles on the basis of fully considering the energy development scenario, vehicle and fuel technology and market evolution. It attempts to provide a forward-looking reference for authorities to formulate reasonable and effective industrial planning, so as to better promote the coordinated and orderly development of energy, environment, automobile and other related industries.

II. MATERIALS AND METHODS

This study investigates the energy and environmental impacts of banning the sale of traditional fossil fuel vehicles in China from a life cycle perspective. Life cycle assessment (LCA) is a standardized method to measures the impact of products and services throughout its life cycle, covering the phases of resource extraction, manufacture, distribution, use, and disposal [12,13]. Considering that nearly 90% of cars in China are light-duty gasoline passenger cars, and battery electric vehicles (BEV) are the main direction of the development of the new energy vehicle industry, this study selects light duty passenger vehicles as the research object for comparative analysis.The system boundary of this study is shown in Figure1. The fuel types involved in the LCA analysis are gasoline

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and electricity. In this article, relevant data are derived from the statistical reports of China's transportation and energy industries, peer-reviewed journal articles, and other scientific and technical literature. The vehicle life cycle inventory data are mainly based on the Ecoinvent database.

The overall analysis framework of this study is as follows. Based on the energy planning and vehicle technology, it first compared and analyzed the fossil energy consumption intensity and the GHG emission intensity of BEV and TFV by using the life cycle assessment methods. Then, it uses Logistic equation to obtain the evolution of China automobile market under different scenarios of banning sale of TFV. Finally, combined with the fossil energy consumption intensity and the GHG emission intensity of BEV and TFV, and the market evolution of automobile in China under different scenarios of banning the sales of TFV, it investigates the energy and environment impacts of the medium-and long-term deployment of BEV.

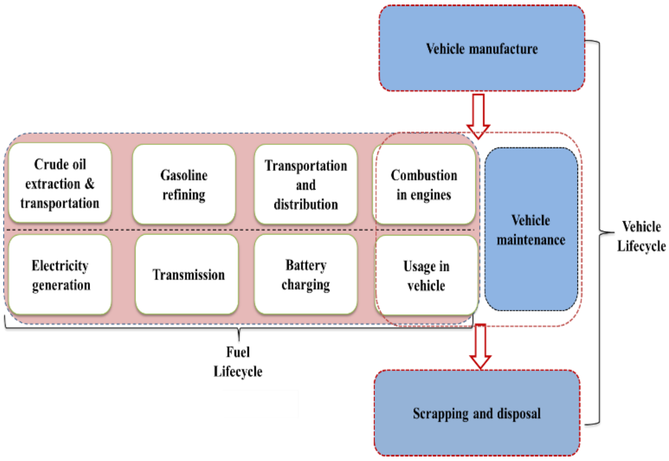

Figure 1. System boundary of the life cycle assessment

The Logistic equation was used to simulate and predict the growth trend of China's automobile market[14–16], as shown in Eq. (1).

$$M(t) = \frac{A}{1+Be^{-Ct}} \tag{1}$$

Where A refers to the maximum capacity of China's automobile market. $M(t)$ refers to the car ownership at time t. B and C are the two parameters of the logistic equation to be estimated.

In order to cooperate with the development of BEV industry, China has formulated relevant energy development plans to better ease the pressure on energy and environment. In this study, two energy scenarios were used to further explore the potential of BEV in energy saving and GHG emissions reduction: high-proportion thermal power scenario and low-proportion thermal power scenario, the details are shown in Figure 2 and Figure3.

For high-proportion thermal power scenario, the proportion of the coal-based thermal power generation is expected to drop to about 60% in 2030 and about 45% in 2050 [17,18]. As to the low-proportion thermal power scenario, the proportion of the coal-based thermal power generation is expected to drop to about 45% in 2030 and about 11% in 2050 [19,20] . At the same time, the fossil energy consumption of the coal-based thermal power generation is expected to drop to 8.50 MJ/kWh in2030, and 8.06 MJ /kWh in 2050[19,21]. In addition, the fuel economy of vehicles on road in China are presented in Figure 4.

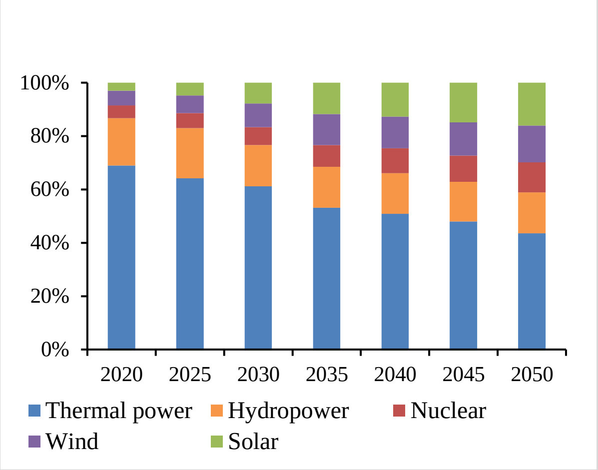

Figure2. High-proportion thermal power scenario in China

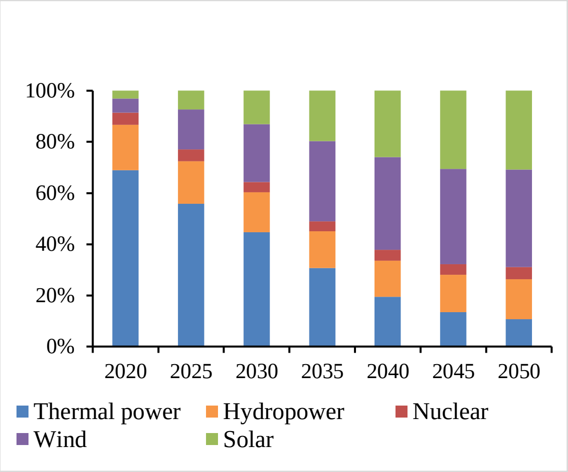

Figure 3. Low-proportion thermal power scenario in China

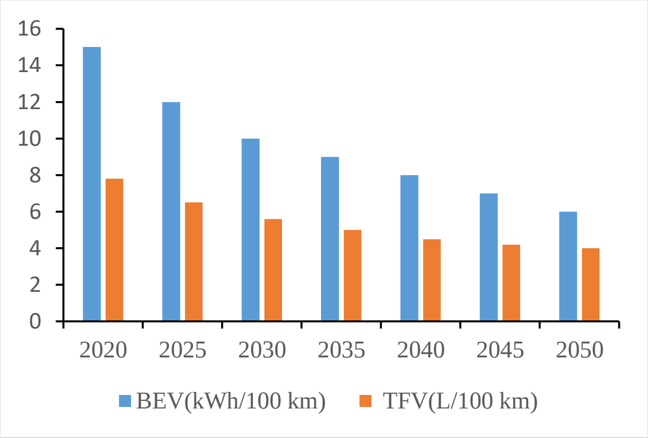

Figure 4. The fuel economy of vehicles on road in China [22–24]

III. RESULTS

A. Fossil Energy Consumption Intensity and GHG Emission Intensity of BEV and TFV

Based on the above energy planning and assumption, we compared and analyzed the fossil energy consumption intensity and the GHG emission intensity of BEV and TFV, as shown in Figure 5 and Figure 6.

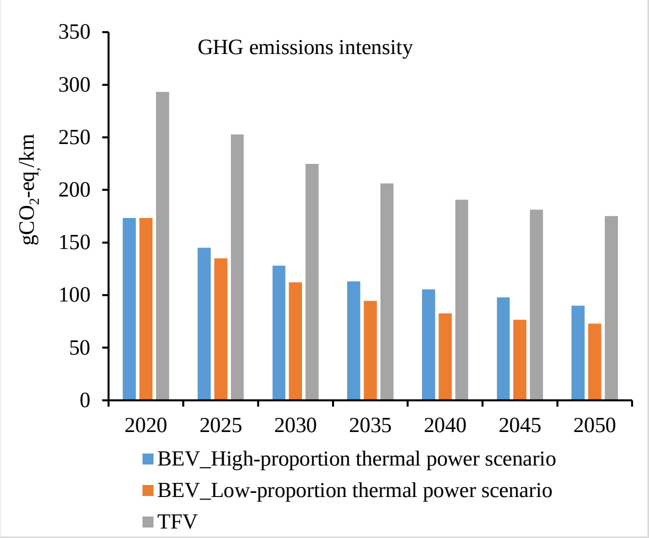

Figure 5. Comparison in GHG emissions intensity of TFV and BEV under different scenarios

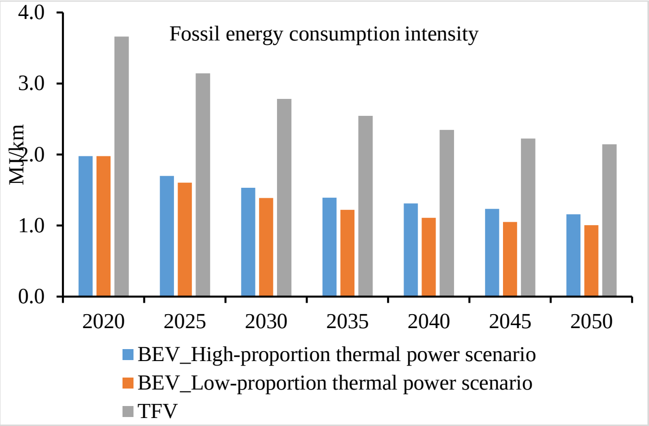

Figure 6. Comparison in fossil energy consumption intensity of TFV and BEV under different scenarios

As can be seen from Figure 5 and Figure 6, with the increase in the proportion of renewable electricity generation and the power generation efficiency of coal-fired thermal power stations, the advantages of BEV in energy conservation and emission reduction will become more and more significant. Under the high-proportion thermal power scenario, the GHG emission intensity of BEV will drop to 128.02 g CO2-eq/km in 2030 and 90.07 g CO2-eq/km in 2050, while the fossil energy consumption intensity of BEV could also be reduced to 1.53 MJ/km in 2030 and 1.16MJ/km in 2050. This means that replacing TFV with BEV can reduce GHG emissions and fossil energy consumption by up to 48.55% and 46.08%, respectively. If China's energy development follows the low-proportion thermal power scenario, the GHG emission intensity of BEV will drop to 112.11g CO2-eq/km in 2030 and 73.07 g CO2-eq/km in 2050, while the fossil energy consumption intensity of BEV could also be reduced to 1.39MJ/km in 2030 and 1.09MJ/km in 2050. Under this energy development scenario, replacing TFV with BEV can reduce GHG emissions and fossil energy consumption by up to 58.26% and 53.03%, respectively. Therefore, promoting BEV has great prospects in reducing fossil energy consumption and GHG emissions.

B. Dynamic evolution of China's auto market

This paper uses the Logistic equation to obtain the development trend of BEV and TFV under scenarios of banning the sale of TFV by 2040, 2050, and 2060 in China, respectively. The detailed results are shown in Figures 7–9. It can be seen that if China bans the sale of TFV from 2060, the market scale of BEV will exceed 100 million around 2042 and surpass the market scale of TFV by 2049. If China bans the sale of TFV from 2050, the number of BEV will reach 100 million around 2037 and then surpass the market scale of TFV around 2041. In particular, If China plans to ban the sale of TFV from 2040, the market scale of BEV will exceed that of TFV by around 2035.

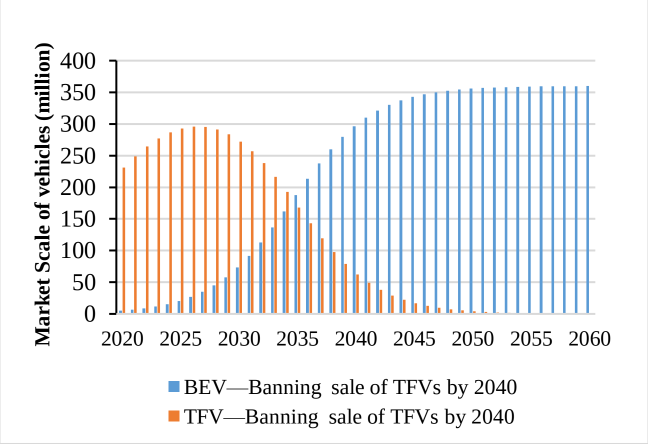

Figure 7. Market evolution under the scenario of banning the sale of TFV by 2040

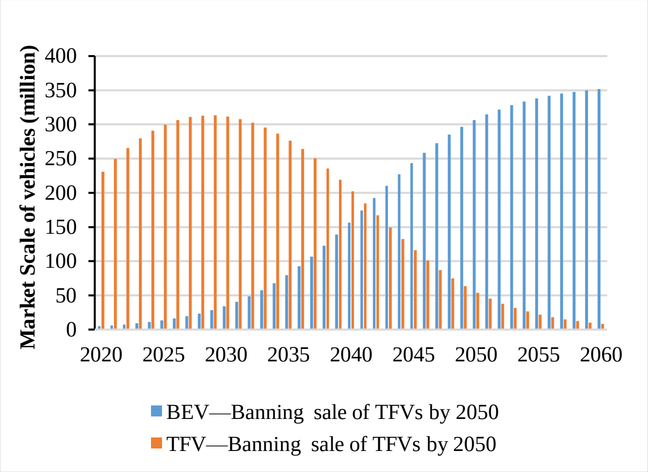

Figure 8. Market evolution under the scenario of banning the sale of TFV by 2050

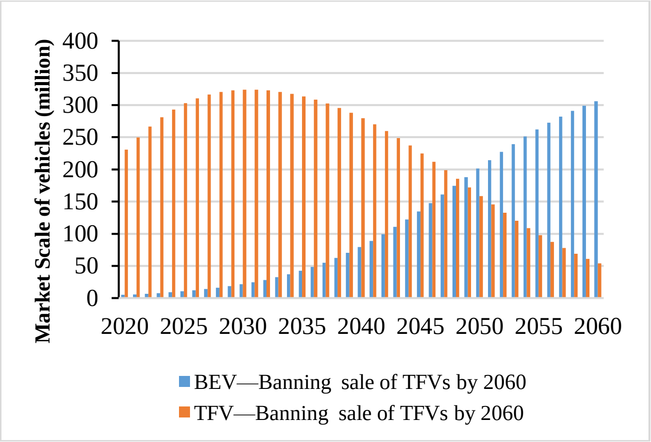

Figure 9. Market evolution under the scenario of banning the sale of TFV by 2060

C. The Energy and Environmental Impact of Banning the Sale of TFVs

In order to investigate the energy and environmental impacts of the medium-and long-term deployment of BEV, based on the BEV development trends and the energy planning scenario, we first calculated and compared the annual GHG emissions and energy consumption of the entire China automobile market with and without BEV, and then used 2020 as the starting point to calculate the cumulative fossil energy savings and GHG emission reductions brought about by the promotion of BEV during the period of 2020 ~ 2050. The detailed results are shown in Figure 10 and Figure11.

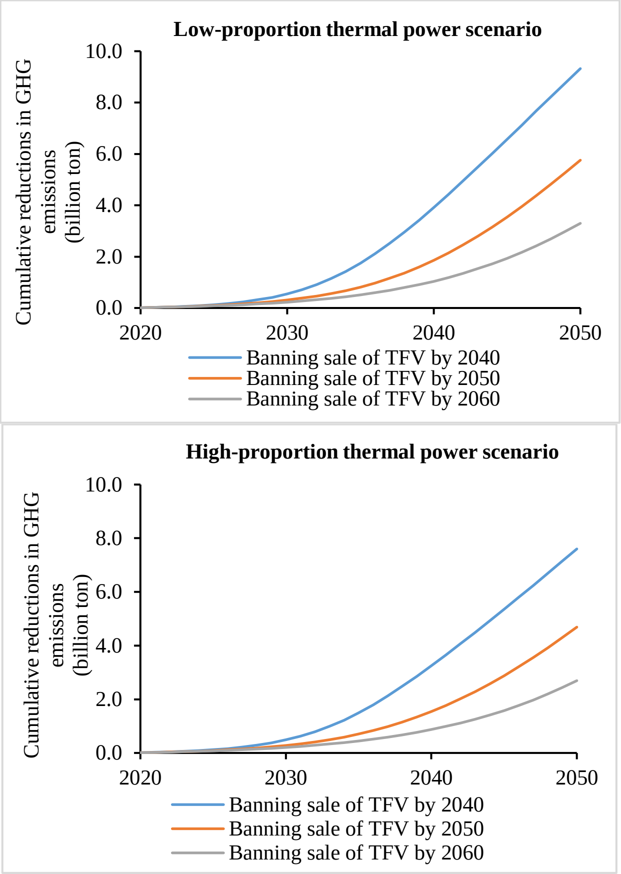

Figure 10. Cumulative GHG emissions reduction under different scenarios

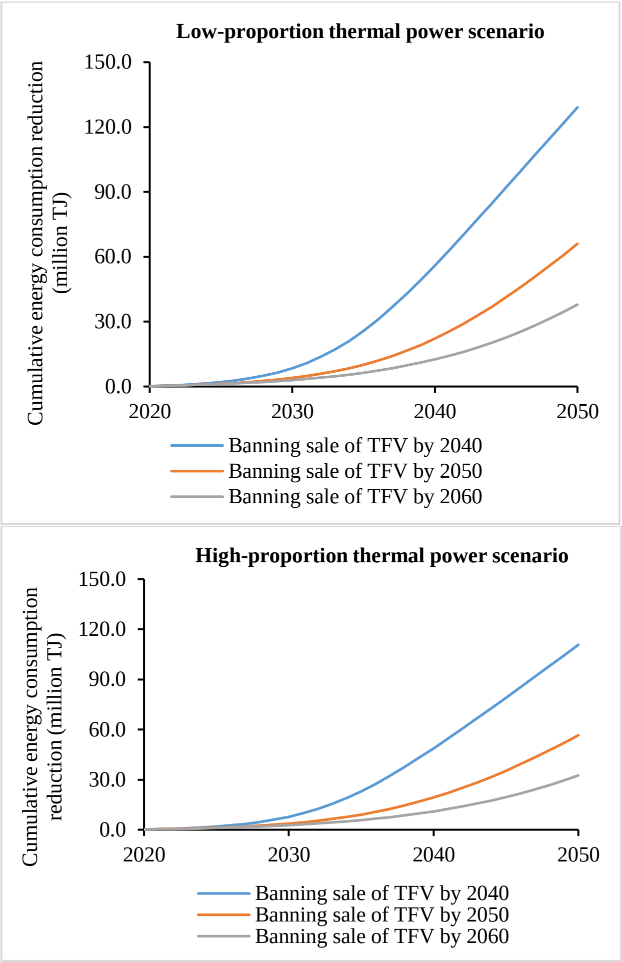

Figure 11. Cumulative energy consumption reduction under different scenarios

It can be seen from Figure 10 and Figure 11 that the promotion of BEV can significantly reduce the GHG emissions and fossil energy consumption of the automobiles market in China. If China plans to ban the sales of TFV from 2060, under the high-proportion thermal power scenario, a cumulative fossil energy savings of 2.74 million TJ and a cumulative GHG emissions reduction of 0.21 billion tons of CO2-eq can be achieved by 2030. By 2050, the cumulative energy-saving and GHG emissions reduction can reach 32.54 million TJ and 2.70 billion tons of CO2-eq, respectively. Furthermore, under the low-proportion thermal power scenario, the cumulative energy savings and GHG emissions reduction can reach 2.94 million TJ and 0.23 billion tons of CO2-eq by 2030 and 37.88 million TJ and 3.30 billion tons of CO2-eq by 2050. If the sale of TFV will be banned from 2050, with the continuous market diffusion of BEV, the cumulative energy savings by 2030 can reach 3.70 million TJ under high-proportion thermal power scenario and 3.99 million TJ under low-proportion thermal power scenario. In addition, the cumulative GHG emissions reduction by 2030 can also reach 0.28 billion tons of CO2-eq under high-proportion thermal power scenario and 0.31 billion tons of CO2-eq under low-proportion thermal power scenario. Furthermore, by 2050, the cumulative energy savings can reach 56.60 million TJ under high-proportion thermal power scenario and 66.05 million TJ under low-proportion thermal power scenario, and the cumulative GHG emissions reduction can also reach 4.69 billion tons of CO2-eq under high-proportion thermal power scenario and 5.76 billion tons of CO2-eq under low-proportion thermal power scenario.

In particular, if China plans to ban the sale of TFV by 2040, under the high-proportion thermal power scenario, the cumulative energy savings and GHG emissions reduction can reach 7.75 million TJ and 0.49 billion tons of CO2-eq by 2030. By 2050, the cumulative energy savings and GHG emissions reduction can reach 110.78 million TJ and 7.60 billion tons of CO2-eq, respectively. Furthermore, under the low-proportion thermal power scenario, the cumulative energy savings and GHG emissions reduction can reach 8.39 million TJ and 0.55 billion tons of CO2-eq by 2030 and 129.10 million TJ and 9.32 billion tons of CO2-eq by 2050.

IV. DISCUSSION AND CONCLUSIONS

This study investigates the energy and environmental impacts of banning the sale of traditional fossil fuel vehicles in China from a life cycle perspective. Combined with the development of China's energy sector and vehicle and fuel technology, the comparative advantages of BEV over the traditional gasoline-powered vehicle in terms of energy-saving and GHG emissions reduction was analyzed. In addition, the Logistic equation was used to simulate and predict the growth trend of BEV at different timing of banning the sale of TFV. Finally, on the basis of the market scale of BEV and TFV in China, the impact of the medium and long-term development of BEV on energy and the environment was further estimated. The main conclusions are shown as follows.

BEV has great potential in reducing fossil energy consumption and GHG emissions. Under China's current electricity mix, the life cycle GHG emissions intensity and fossil energy consumption intensity of BEV is about 40.94% (120.04 g CO2-eq/km) and 45.90% (1.68 MJ/km) lower than those of TFV, respectively. As the proportion of renewable electricity generation and the power generation efficiency of coal-fired thermal power stations continue to increase, the advantages of BEV in energy conservation and emission reduction will become more and more significant. By 2050, under the high-proportion thermal power scenario, replacing TFV with BEV can reduce GHG emissions and fossil energy consumption by up to 48.55% and 46.08%. In particular, if China's energy development follows the low-proportion thermal power scenario, replacing TFV with BEV can reduce GHG emissions and fossil energy consumption by up to 58.26% and 53.03%, respectively.

If China bans the sale of TFV from 2060, the market scale of BEV will exceed 100 million around 2042 and surpass the market scale of TFV by 2049. During 2020 ~ 2050, the cumulative fossil energy savings and GHG emissions reductions can reach 32.54~37.88 million TJ and 2.70 ~ 3.30 billion tons of CO2-eq, respectively. If China bans the sale of TFV from 2050, the number of BEV will reach 100 million around 2037 and then surpass the market scale of TFV around 2041. During the period of 2020~2050, a total of approximately 56.60~66.05 million TJ fossil energy savings and 4.69 ~ 5.76 billion tons of CO2-eq GHG emissions reductions can be obtained. In particular, if China plans to ban the sale of TFV from 2040, the market scale of BEV will exceed that of TFV by around 2035. During 2020 ~ 2050, the cumulative fossil energy savings and GHG emissions reduction can reach approximately 110.78~129.10 million TJ and 7.60 ~ 9.32 billion tons of CO2-eq, respectively.

Nowadays, China faces increasing pressure on energy and the environment in the process of economic development. Vigorously promoting new energy vehicles is one of the potential ways to effectively alleviate these problems. In order to better achieve sustainable and healthy development of China's new energy vehicle industry, authorities should formulate scientific and reasonable industrial strategies and policies, strengthen technological innovation, and accelerate the development of supporting industries. Since electricity production is the most important factor that can significantly affect the potential of BEV in reducing GHG emissions and fossil energy consumption in China, relevant national energy development plans such as increasing the proportion of green electricity, controlling the emission standards of the power plants, and continuously improving the generation efficiency of thermal power should be effectively implemented.

However, there also exist some limitations in the study. First, due to the lack of available data, this study selects passenger cars as the research object for comparative analysis and does not consider other components of the road transportation system such as transit buses, sanitation vehicles, and other types of heavy-duty vehicles. Furthermore, in terms of environmental impact, the LCA study only focuses on GHG emissions and does not include broader impacts on human health, ecosystems, and resource availability. All these need to be further supplemented and improved in the future.

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