Research on Key Factors of the Life Cycle Carbon Emission for Battery Electric Vehicles

Lixin Yao[1]*, Naifeng Ma[1], Bin Liu[1] and Hong Shi[1]

[1] China Automotive Technology and Research Center Co., Ltd., Tianjin 300300, China

Abstract. With the ever increasing energy crisis and environmental issues globally in recent years, China is enhancing the processes of automobile electrification. Compared with traditional fuel vehicles, Battery Electric Vehicle (BEV) has lower carbon emission level during the whole life cycle, which is one of important technical routes for the low-carbon development of the automotive industry. Based on the main influencing factors of carbon emission for BEVs, this paper focuses on the correlation between the five key factors and carbon emission, including vehicle mileage, power grid cleaning, energy consumption level, battery energy density and utilization rate of renewable materials, and proposes development suggestions for carbon reduction ways for BEVs.

1. Introduction

Carbon neutralization in automobile industry is a systematic project, involving multiple fields of energy, industry and transportation information, as well as multiple links of R&D, production, use and recycling. In order to achieve the goal of carbon peaking and carbon neutralization in the automobile industry, not only do we need to make technological breakthroughs, but also other relevant industries need to accelerate the research and development of low-carbon technologies, accelerate the energy conservation and emission reduction in the whole life cycle of automobiles and the whole industrial chain, and jointly promote the green development of the automobile industry.

In the past year, the dual carbon target has become an important driving force to promote the rapid development of new energy vehicles and accelerate the low-carbon transformation of the automobile industry. Thanks to the technological innovation of battery structure and battery materials, the driving range of models equipped with lithium iron phosphate battery system continues to increase, which can meet the daily travel needs of consumers. At present, the installed capacity of lithium iron phosphate battery has gradually increased.

Research results at home and abroad [1-2] show that the full life cycle perspective is an important method to study the resource consumption and environmental impact of automotive products. The overall carbon emissions of automobile product life cycle consist of fuel cycle and vehicle cycle. According to research and calculation, although the carbon emission of battery electric vehicles in the vehicle cycle is higher than that of traditional fuel vehicles, the total carbon emission in the life cycle of battery electric vehicles is lower than that of traditional vehicles because they can achieve zero emissions in the operation phase, and the future emission reduction potential is greater [3].

This paper selects the representative models of the battery electric passenger vehicle market, quantitatively analyzes the relationship between key influencing factors and carbon emissions, and puts forward development suggestions on carbon reduction approaches of battery electric passenger vehicles.

2. Models and Inputs

2.1. Life cycle model

Life Cycle Assessment (LCA) is an assessment method to analyze the resource consumption and environmental impact of automotive products in the stages of raw material acquisition, parts production and manufacturing, vehicle production and manufacturing, fuel production, fuel transportation, fuel use and scrap recovery from the perspective of the entire life cycle. Considering the availability of input data and its contribution to the overall carbon emissions of the vehicle model, this paper only considers the four upstream stages [4-5] of traditional component raw material acquisition, battery raw material acquisition, vehicle production and manufacturing, and vehicle driving process power for the calculation of carbon emissions of battery electric passenger vehicles, and other stages are ignored. The calculation formula is shown in Formula (1).

$$C_{BEV} = C_M + C_{BM} + C_P + C_F \quad (1)$$

Where, C_{BEV} is the total carbon emission of BEV; C_M is the carbon emission in the raw material acquisition stage of traditional components; C_{BM} is the carbon emission in the battery raw material acquisition stage; C_P

*Corresponding author: yaolixin@catarc.ac.cn

is the carbon emission in the production and manufacturing stage of the whole vehicle; C_F is the carbon emission upstream of the electric power during vehicle driving.

The carbon emission of traditional components in the raw material acquisition stage (C_M) is calculated according to formula (2).

$$C_M = \sum_{i=1}^{n}(W_i \times E_i)/L \quad (2)$$

Where, n is the number of material types of BEV traditional parts; W_i is the ith material quality of traditional components; E_i is the carbon emission factor of the ith material of traditional components; L is the life cycle mileage of BEV.

The carbon emission in the battery raw material acquisition stage (C_{BM}) is calculated by formula (3).

$$C_{BM} = \sum_{i=1}^{n}(BW_i \times BE_i)/L \quad (3)$$

Where, n is the number of BEV battery material types; BW_i is the mass of the ith material of the battery; BE_i is the carbon emission factor of the ith battery material; L is the life cycle mileage of BEV.

Carbon emissions in the production and manufacturing stage of the whole vehicle (C_P), the calculation formula [6] is shown in Formula (4).

$$C_P = [\sum_{i=1}^{n}(FC_i \times FE_i) + EC_p \times EP]/L \quad (4)$$

Where, n is the amount of fossil energy consumed in the production and manufacturing process of BEV vehicles; FC_i is the consumption of the ith fossil energy; FE_i is the carbon emission factor of the ith fossil energy use process; EC_P is the power consumption in the whole vehicle production process; EP is the carbon emission factor in the power production process; L is the life cycle mileage of BEV.

The calculation formula of carbon emissions upstream of the electric power during vehicle driving (C_F) is shown in Formula (5).

$$C_F = EC \times EP \quad (5)$$

Where, EC is the power consumption per unit mileage during BEV driving; EP is the carbon emission factor of power production process.

2.2. Correlation analysis method

Correlation analysis is a method used to evaluate the impact of input factors on output results in life cycle research. It can be subdivided into single factor correlation analysis and multi factor correlation analysis. Single factor correlation analysis is used to measure the impact of a single input factor on output results, and multi factor correlation analysis is used to measure the impact of two or more input factors on output results. In this paper, single factor correlation analysis is used to study the impact of different factors on carbon emissions.

2.3. Impact factors

It can be seen from the life cycle model that the carbon emissions of battery electric passenger vehicles are jointly determined by vehicle material quality, vehicle material carbon emission factor, energy consumption in the production and manufacturing process, vehicle power consumption, upstream carbon emission factor of electric power, and travel characteristics. According to the calculation, from the weight of carbon emissions in each stage in the total carbon emissions of the BEV life cycle, the upstream power of the vehicle is the largest, followed by the traditional component raw material acquisition stage, battery raw material acquisition stage, and the vehicle manufacturing stage is the smallest. In addition, the mass of a battery electric vehicle is negatively correlated with the battery energy density. The higher the battery density, the lower the vehicle mass [7]. Therefore, this paper focuses on the analysis of the correlation between the five impact factors of vehicle mileage, power grid cleaning, energy consumption level, battery energy density and renewable material utilization rate and carbon emissions.

2.4. Representative vehicle model

In order to distinguish the correlation between the carbon emissions of vehicles equipped with different types of power batteries and various influence factors, and at the same time, it is necessary to take into account the principle of comparability of vehicle parameters of different objects, this paper selects different versions of a company's A-class battery electric car as the research object, and records the driving range of 410 km, the vehicle model equipped with lithium iron phosphate battery as BEV①, the driving range of 510 km and the model equipped with ternary lithium battery as BEV②, and the driving range of 602 km and the model equipped with ternary lithium battery as BEV③. Table 1 shows some parameters of representative vehicle models, mainly referring to the Catalogue of Recommended Models for the Promotion and Application of New Energy Vehicles in the 9th batch in 2020 and the 5th batch in 2021 [8-9]. Assuming that the vehicle life cycle mileage is 150,000 km, the carbon emissions per unit mileage of BEV①, BEV② and BEV③ are 115.6g·km^{-1}, 127.5g·km^{-1} and 133.3g·km^{-1}.

Table 1. Main Parameters of Representative Vehicle

Abbreviation	BEV①	BEV②	BEV③
Length/mm	4 768	4 768	4 810
Width/mm	1 880	1 880	1 880
Height/mm	1 530	1 530	1 515
Unladen mass/kg	1 625	1 610	1 750
Driving range/km	410	510	602
Battery type	Lithium iron phosphate	Ternary lithium	Ternary lithium
Battery capacity/kW·h	50.69	58.81	69.94

Battery mass/kg	402	360	433
Battery mass energy density/W·h·kg^{-1}	125	163	170
Power consumption/kW·h·100 km^{-1}	12.9	13.1	13.1
Carbon emissions/g·km^{-1}	115.6	127.5	133.3

3. Correlation analysis of key influencing factors

3.1. Vehicle mileage

Vehicle mileage reflects the use intensity of a vehicle throughout its life cycle. With the increase of vehicle use intensity, the carbon emissions of battery electric vehicle cycle are greatly diluted, so the total carbon emissions will be significantly reduced. In this paper, the total carbon emissions of the three BEV models are calculated with 50,000 km as the division interval. It can be seen from Figure 1 that when the driving mileage in the life cycle increases from 50,000 km to 200,000 km, the total carbon emissions of all models show a rapid downward trend. For every additional 10,000 km, the carbon emissions per unit mileage of BEV① decrease by 5.5 g·km^{-1}, and that of BEV② and BEV③ decrease by 7~8 g·km^{-1}. It can be seen that with the increase of vehicle driving mileage, The carbon emission of BEV equipped with ternary lithium battery decreased more than that of BEV equipped with lithium iron phosphate battery; When the driving mileage in the life cycle is from 200,000 km to 500,000 km, the total carbon emissions of vehicle models still keep a downward trend, but the decline is slowing down, which also shows that for commercial vehicles, due to the long driving mileage, the total carbon emissions per mile are significantly lower than private vehicles, and the carbon reduction effect is very obvious, so the taxi field should vigorously promote electrification.

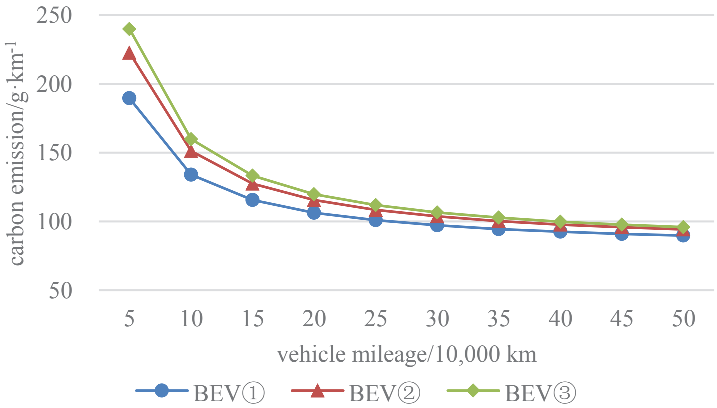

Figure 1. Vehicle mileage correlation

3.2. Power grid cleaning

Due to the rich coal resources, thermal power generation is the main power generation mode in China, accounting for about 70% of the total power generation in China [10]. The carbon emission factor of 0.6101 kg·(kW·h)$^{-1}$ used in this paper is from the Accounting Methods and Reporting Guidelines for Greenhouse Gas Emissions of Enterprises issued by the Ministry of Ecology and Environment in March 2021 [11]. The upstream of electric power, that is, the upstream of fuel, is the main component of carbon emissions during the whole life cycle of battery electric vehicles. According to the current level of power production, the carbon emissions in the upstream of fuel account for about 60% of the total. Therefore, the degree of grid cleanliness is crucial to improve the emission reduction performance of battery electric vehicles in their life cycle. It is estimated that the carbon emission factor of electric power production will decrease by 0.1 kg·(kW·h)$^{-1}$ for every 10% decrease in the proportion of thermal power generation. Figure 2 shows the relationship between grid cleaning and carbon emissions. It can be seen that there is a linear correlation between the two. For every 0.1 kg·(kW·h)$^{-1}$ reduction in carbon emission factor of power production, the total carbon emissions of vehicle models will decrease by about 13 g·km^{-1}. By changing the power structure of China, the proportion of clean energy power generation (such as wind power, nuclear power and hydropower) will gradually increase [12], the carbon emissions in the upstream of fuel will be significantly reduced, and the proportion in the entire life cycle will also be reduced synchronously, and the carbon emissions in the full life cycle of battery electric vehicles will be gradually reduced.

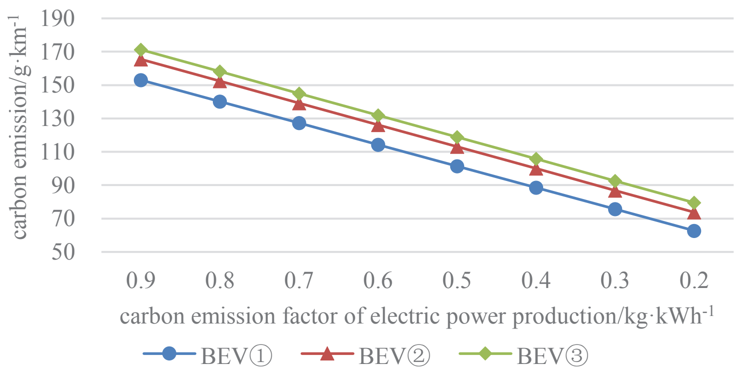

Figure 2. Correlation of Power Grid Cleanliness

3.3. Energy consumption level

The energy consumption of battery electric vehicles is related to the curb weight, motor power, wind resistance coefficient and driving range. The level of energy consumption directly determines the carbon emissions upstream of the fuel. In recent years, with the gradual expansion of the industrial scale, the technical maturity of battery electric vehicles has been improved, and the energy consumption level has been declining. From 2016 to 2019, the power consumption of China's battery electric cars under comprehensive working conditions decreased from 15.3 $kW·h·100km^{-1}$ to 12.8 $kW·h·100km^{-1}$, and the power consumption of battery electric SUV under comprehensive working conditions decreased from 17.8 $kW·h·100km^{-1}$ to 14.9 $kW·h·100km^{-1}$ [13]. Compared with traditional vehicles, the carbon reduction effect of battery electric vehicles is better. It is estimated that a battery electric car with a power consumption of 16~18 $kW·h·100km^{-1}$ has the same carbon emissions in its life cycle as a gasoline car with a fuel consumption of 4~5 $L·100\ km^{-1}$. It can be seen from Figure 3 that for every 1 $kW·h·100km^{-1}$ decrease in energy consumption level of BEV, carbon emissions will decrease by about 6 $g·km^{-1}$. In the future, the energy consumption level of electric vehicles will still be further reduced. It is estimated that by 2025, the power consumption of a typical class A battery electric car with advanced technology under comprehensive working conditions will be less than 11 $kW·h·100km^{-1}$ [13].

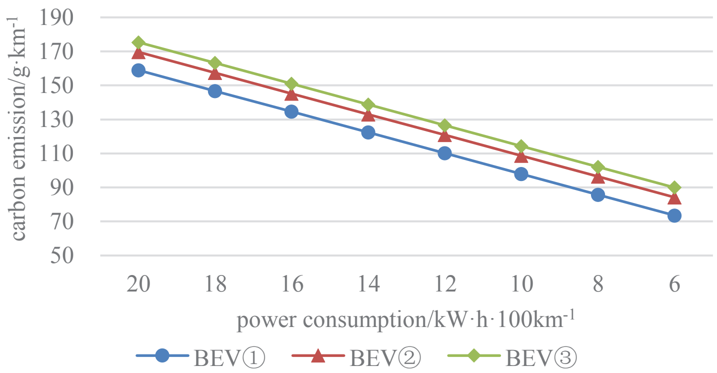

Figure 3. Correlation of energy consumption level

3.4. Battery energy density

At present, in the battery electric passenger vehicle market, for lithium iron phosphate battery, the sales of models with energy density of 120~140 $Wh·kg^{-1}$ account for the largest proportion. For ternary lithium batteries, the sales volume of models with energy density of 160~180 $W·h·kg^{-1}$ accounted for the largest proportion, and some models reached 190~200 $W·h·kg^{-1}$. With the increase of battery energy density, the battery quality will decline, and the carbon emissions generated by the battery will decrease. At the same time, the decline of the vehicle's curb weight will also lead to a decrease in power consumption [14], and the carbon emissions of the entire vehicle model will gradually decrease. It can be seen from Figure 4 that when the energy density increases from 80 $W·h·kg^{-1}$ to 120 $W·h·kg^{-1}$, the carbon emissions of BEV① decrease by 10%, and those of BEV② and BEV③ decrease by about 15%; When the energy density increases from 120 $W·h·kg^{-1}$ to 160 $W·h·kg^{-1}$, the carbon emission of BEV① decreases by 5.5%, and that of BEV② and BEV③ decreases by 8%~9%; In general, with the increase of battery energy density, the carbon reduction effect of BEV equipped with ternary lithium battery is better than that of BEV equipped with lithium iron phosphate battery. Therefore, starting from the green design of power battery, improving its energy density will play a certain role in emission reduction of battery electric vehicle life cycle [15].

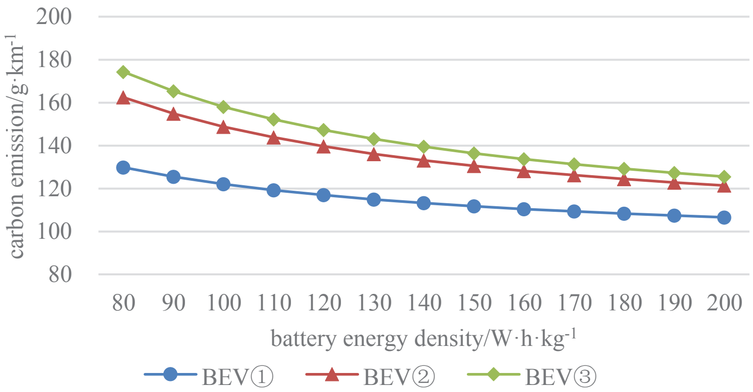

Figure 4. Correlation of battery energy density

3.5. Utilization rate of renewable materials

Automobile production needs to consume a large amount of steel, nonferrous metals, plastics, rubber, glass and textile resources. The reasonable reuse of scrapped automobile resources can effectively promote energy conservation and consumption reduction in the automobile industry [16]. At present, the utilization rate of renewable materials for domestic automotive products is not high, and the application scope is limited. There is no authoritative organization to calculate the specific value of this proportion. This paper mainly considers the steel, aluminum, copper and plastic traditional materials used on chassis and body, and takes the current level and assumed future proportion increase as variables to calculate the change trend of vehicle carbon emissions. It can be seen from Figure 5 that every 5% increase in the utilization rate of renewable materials will reduce the carbon emissions by about 1 $g \cdot km^{-1}$. With the increase in the utilization rate of renewable materials, the carbon emissions of electric vehicles will decrease, but the reduction is limited. In June 2021, the four ministries and commissions jointly issued the Implementation Plan for the Pilot Program for the Extension of Producer Responsibility of Automotive Products [17], which proposed that by 2023, the green supply chain system for automobiles should be fully established, with the recyclability rate of automobiles reaching 95%, and the utilization rate of renewable raw materials for key components no less than 5%. In the future, with the progress of recycling technology, automotive renewable materials will be widely used in automobiles, thereby reducing production costs.

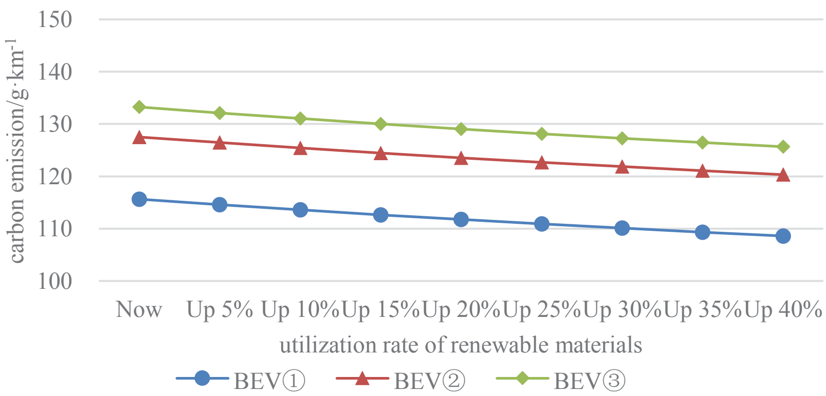

Figure 5. Correlation of utilization rate of renewable materials

4. Summary

Based on the life cycle research theory, this paper selects different versions of typical models of battery electric passenger vehicles, and focuses on the correlation between vehicle mileage, grid cleaning, energy consumption level, battery energy density, renewable material utilization and carbon emissions. According to the quantitative research conclusion, the changes of these five influencing factors are positively or negatively correlated with the carbon emissions of vehicle models. The main conclusions are as follows.

(1) The change of vehicle mileage has the greatest impact on carbon emissions of vehicle models, and taxi electrification is of great significance to carbon emission reduction;

(2) Power grid cleaning is an important way to control carbon emissions and total carbon emissions of single vehicles. In the medium and long term, there is great room for carbon emission intensity of power production to decline;

(3) The energy consumption level of electric vehicles will directly affect the carbon emissions upstream of the fuel. In the next five years, there is still 10% room for energy consumption to decline, and then the energy consumption will enter a slow decline period;

(4) On the premise of meeting the requirements of battery safety, power, driving range, service life and cost,

the carbon reduction effect of electric vehicles equipped with higher energy density power batteries is better;

(5) In the short term, the improvement of the utilization rate of renewable materials has a weak effect on reducing carbon emissions in the life cycle of electric vehicles.

In a word, compared with traditional fuel vehicles, battery electric vehicles have obvious carbon reduction advantages. Under the dual carbon goal, the development of battery electric vehicles will become a favourable measure for energy conservation, emission reduction and carbon reduction in the field of transportation.

Acknowledgments

This paper was supported by the project fund of the major science and technology project "Implementation Roadmap of the Automotive Industry for Carbon Neutralization (ZX21230001)" by China Automotive Technology and Research Center Co., Ltd.

References

1. Wu Z, Wang M, Zheng J, et al. Life cycle greenhouse gas emission reduction potential of battery electric vehicle[J]. *Journal of Cleaner Production*. 2018, 190(07): 462-470.
2. C Tagliaferri, S Evangelisti, F Acconcia, et al. Life cycle assessment of future electric and hybrid vehicles: A cradle-to-grave systems engineering approach[J]. *Chemical engineering research and Design*. 2016, 112(07): 298-309.
3. Feng C, Wang K, Xu Z Q, et al. Research on greenhouse gas emissions of private electric vehicles based on hybrid life cycle method [J]. *China's Population, Resources and Environment*. 2017 (10): 178-187.
4. Li S H. Life cycle analysis and environmental benefit evaluation of electric vehicles [D]. Changchun: Jilin University, 2014.
5. Chen Y S, Ma J Q, Ding Z S, et al. Research on performance evaluation of energy conservation and emission reduction in the whole life cycle of battery electric vehicle power system [J]. *Machinery and Electronics*, 2018 (11): 20-23.
6. General Office of the Ministry of Ecology and Environment Letter on Soliciting Opinions from the National Environmental Protection Standard Accounting Methods and Reporting Guidelines for Greenhouse Gas Emissions of Enterprises Power Generation Facilities (Draft for Comments) [DB/OL] (2020-12-03)[2022-12-01]. https://www.mee.gov.cn/xxgk2018/xxgk/xxgk06/202012/t20201203_811443.html.
7. Gao H, Zhang J H, Zhao J B, et al. Analysis of carbon emission reduction potential based on innovative technology application of electric vehicles [J]. *Science and Technology Management Research*, 2020 (10): 230-236.
8. Ministry of Industry and Information Technology Catalogue of Recommended Models for the Promotion and Application of New Energy Vehicles [DB/OL]. (2020-08-24) [2022-12-01] http://www.miit-eidc.org.cn/col/col100/index.html.
9. Ministry of Industry and Information Technology Catalogue of Recommended Models for Promotion and Application of New Energy Vehicles [DB/OL]. (2021-06-11) [2022-12-01] http://www.miit-eidc.org.cn/col/col100/index.html.
10. China Electricity Council China Electricity Statistics Yearbook 2020 [M]. Beijing: China Machine Press, 2020.
11. General Office of the Ministry of Ecology and Environment Guidelines for Accounting Methods and Reporting of Greenhouse Gas Emissions by Enterprises [DB/OL]. (2021-03-28) [2022-12-01] https://www.mee.gov.cn/xxgk2018/xxgk/xxgk05/202103/t20210330_826728.html?keywords=%E4%BC%81%E4%B8%9A%E6%B8%A9%E5%AE%A4%E6%B0%94%E4%BD%93%E6%8E%92%E6%94%BE%E6%A0%B8%E7%AE%97%E6%96%B9%E6%B3%95.
12. Sun J M, Li L L. Research Status and Future Development Trend of Low Carbon Power Grid Construction [J]. *Power Grid and Clean Energy*, 2019 (03): 21-30.
13. Zhang J H, Zhao F Q, Hou F S, et al. Technical Roadmap for Energy Saving and New Energy Vehicles 2.0 [M]. Beijing: China Statistics Press, 2020.
14. Ha N N. Carbon emission assessment of electric vehicles throughout their life cycle and its impact on the environment [D]. Beijing: North China Electric Power University, 2020.
15. Ma J, Liu X D, Chen Y S, et al. Current Situation and Countermeasures of China's New Energy Vehicle Industry and Technology Development [J]. *Journal of China Highway Engineering*, 2018 (08): 1-19.
16. Chen Y H, Yang Y P, Hu S H, et al. Analysis on the current situation of end-of-life vehicle recycling in China and countermeasures [J]. *China Engineering Science*, 2018 (01): 113-119.
17. Ministry of Industry and Information Technology, Ministry of Science and Technology, Ministry of Finance, etc Implementation Plan for Pilot Program of Extended Producer Responsibility of Automobile Products [DB/OL]. (2021-06-09) [2022-12-01] https://www.miit.gov.cn/zwgk/zcwj/wjfb/zbgy/art/2021/art_41ae7b048792416ca167bde07368475f.html.