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Capabilities Analysis of Electricity Energy Conservation and Carbon Emissions Reduction in Multi-Level Battery Electric Passenger Vehicle in China

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Abstract: The battery electric passenger vehicle (BEPV) has the potential to conserve electric energy and reduce carbon emissions, making it an effective tool for achieving low-carbon development in the road transport industry by replacing the internal combustion engine vehicle (ICEV). Several factors, such as comprehensive electricity power generation efficiency, proportion of thermal power, vehicle technical performance, regional mileage credibility and low temperature, affect the BEPV's electricity energy consumption and carbon emissions. In this study, an electricity conservation index model and a carbon emission reduction index model for multilevel BEPVs are established to evaluate their capabilities of electricity energy conservation and carbon emissions reduction, considering the electricity supply chain, including the generation and transmission of electricity. The research shows that the electricity energy conservation ability of BEPVs is not outstanding, but their carbon emissions reduction ability is strong. When the composition of energy for electricity generation is transformed from 2025 to 2035, with a 10% increase in comprehensive electricity generation efficiency, all levels of BEPVs show fruitful electricity energy conservation ability. When the proportion of thermal power decreases to 10%, the carbon emissions reduction is exponentially reduced to 1/25 to 1/30 of ICEV's total carbon emissions. However, the regional mileage credibility weakens the BEPVs' ability to save energy and reduce emissions in most Chinese provinces except for the southwest and the south regional provinces, where the regional mileage credibility parameter can increase the energy conservation and carbon emission reduction performance of A00+A0 level BEPV. Low temperatures make BEPV models lose their electricity energy conservation advantage, but most models still have the characteristic of carbon emissions reduction. On this basis, the electricity energy consumption and carbon emissions of all BEPV models are higher than those of ICEVs when the low temperature endurance mileage accuracy is added.

Keywords: electricity consumption; carbon emissions; electricity supply chain; regional mileage credibility; low temperature endurance mileage accuracy; sustainable transportation

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1. Introduction

The use of ICEV powered by non-renewable energy sources has led to a dependence on foreign crude oil, which accounts for 70% of China's total crude oil. The development of new energy vehicles powered by electricity, hydrogen and other renewable energy sources can alleviate the increasingly tense energy crisis [1]. The carbon emissions generated by ICEV contribute to serious environmental issues [2], with ICEVs' carbon emissions accounting for 7.5% of China's total carbon emissions [3]. The carbon emissions from

ICEVs' consumption in the use stage account for more than 90% of their total carbon emissions. By contrast, new energy vehicles are characterised by low energy consumption and low carbon emissions throughout their life cycle [4]. Electric vehicles have become a popular alternative in today's transportation system as they have zero emissions, save energy and reduce pollution [5]. The deployment of electric vehicles is critical importance for promoting the development of energy conservation and emission reduction in the automobile industry.

New energy vehicles are one of the strategic emerging industries in China, which can effectively reduce carbon dioxide and various harmful pollutant emissions and solve the increasingly prominent environmental pollution problems. In accordance with the energy-saving and new energy vehicle technology roadmap 2.0, China's automobile industry's carbon emissions to 2035 will be reduced by more than 20% compared with peak emissions. On the basis of the evaluation results of energy saving and emission reduction in new energy vehicles on the national regulatory platform, China's new energy automobile industry should strengthen the top-level design, promote and apply skills and emission reduction technologies in various dimensions, such as upstream energy links and automobile production links, and improve the overall energy saving and emission reduction in the automobile industry. The specific measures include accelerating the cleanness of vehicle energy structure, enhancing the layout of green products and promoting the lightweight and miniaturisation of vehicles.

The new energy vehicles' power types in China mainly include the battery electric vehicle, plug-in hybrid vehicle and hydrogen fuel cell vehicle, with battery electric vehicle still dominating the new energy vehicle market [3]. In 2020, the total sales volume of BEPV accounted for 73.1% of the new energy vehicle market, with the top 10 best-selling models selling 544,900 units, accounting for 39.86%. On this basis, BEPV is chosen as the main research object to specifically analyse the electricity energy conservation and carbon emission reduction capabilities of multilevel BEPVs under different scenarios. From another point of view, the comparison between ICEV and BEPV might be expanded, mentioning the scenario of car sharing possibilities [6]. Therefore, the factors that affect BEPVs' capabilities are explored from the perspective of the energy composition for electricity generation in the upstream and vehicle technical performance in the downstream usage stage.

The major contribution of this study is to analyse the electricity energy conservation and carbon emissions reduction in multilevel BEPVs. The rest of this paper is structured as follows. Section 2 reviews the related literature. Section 3 establishes an electricity conservation index model (ECIM) of BEPV and a carbon emissions reduction index model (CERIM) of BEPV. Section 4 presents the data of our analysis. Section 5 discusses our analytical results, and Section 6 provides the conclusions and some directions for further study.

2. Literature Review

Regarding the research methods of energy consumption and greenhouse gas emissions of new energy vehicles, many scholars have explored the greenhouse gas emissions of pure electric vehicles, plug-in hybrid vehicles and traditional fuel vehicles [7,8]. Research on the influencing factors of energy consumption and greenhouse gas emissions of new energy vehicles reveals that the energy structure of power generation plays a decisive role in carbon emission reduction during the life cycle of electric vehicles [9]. This research aims to optimize the greenhouse gas emissions of new energy vehicles based on the power generation energy structure of different countries and analyse how to improve the market penetration rate and environmental impact of new energy electric vehicles by improving the power generation energy structure [10]. Climate change can cause remarkable fluctuations in the battery capacity of electric vehicles, which can directly affect their maximum mileage and carbon emissions [11]. In China, the marginal cost of long-term carbon emission reduction and concluded that the transition from traditional fuel vehicles to new energy

vehicles can achieve carbon emission reduction at a negative cost (net benefit) in China are calculated [12].

Many well-to-wheel (WTW) methods have been employed in the previous literature to investigate the real sustainability effects of electric vehicles and compare them with those of ICEVs [13,14]. Researchers have also utilised the WTW method to evaluate the carbon emission reduction effect brought by deploying battery electric vehicles [15]. On the basis of the WTW method, an indicator is proposed to quantify the actual environmental impact of electric vehicles and capture the carbon dioxide emissions of electricity from production to consumption [16]. The emission reduction effect of SO_2 and NOx when using electric vehicles rather than traditional fuel vehicles is revealed by using the WTW model [17]. The WTW method is used to evaluate the carbon emission reduction effect after the promotion of battery electric vehicles in China [18]. It is also used to analyse the influence of a country's electricity imported from countries with low power carbon intensity and countries with high power carbon intensity on the emission reduction in battery electric vehicles [19]. Compared with ICEVs, factors such as vehicle specific fuel consumption [20] composition of energy for electricity generation [21] and temperature significantly affect the greenhouse gas emissions of battery electric vehicles. The comprehensive impact of these factors will determine whether the transportation industry can successfully decarbonise.

The overall energy conservation and emission reduction performance of battery electric vehicle largely depends on the combination of electric energy consumed in the use stage [22,23]. The proportion of clean energy in the composition of energy for electricity generation has a profound impact on the life-cycle greenhouse gas emissions of battery electric vehicle [24]. The emission reduction capacity of battery electric vehicle are analysed under four charging scenarios and five grid configurations [25]. The result shows that the carbon emissions are highly dependent on the percentage of fossil fuel power generation in the composition of energy for electricity generation. Although the share of renewable energy in Italy and Germany are similar, they do not produce the same carbon emission reduction effect by deploying battery electric vehicle [26].

The number and technology of electric vehicles that need to be promoted should be clarified in order to meet future 2030–2050 greenhouse emission targets [27]. Specific fuel consumption is considered to be the key factor in achieving carbon emission reduction for battery electric vehicles based on market data in 2018 and scenario forecasts in 2030 [28]. The relationship between endurance mileage, air conditioning system energy consumption and total electricity consumption is explored to understand the law of battery electric vehicle's energy conservation and emission reduction [29]. Dynamic wireless power transmission (DWPT) technology promotes the popularization of battery electric vehicles and helps reduce air pollution [30]. The impact of energy management strategies of charging technology on energy conservation and emission reduction in battery electric vehicle is studied. Whether the transportation industry can successfully decarbonise through the deployment of battery electric vehicle depends on the comprehensive influence of power grid combination, vehicle specific fuel consumption, vehicle technical performance and other factors [31].

The above literature suggests that BEPVs do not emit carbon during driving and are considered to have remarkable potential for energy conservation and emission reduction. However, the electricity generation and transmission in the electricity supply chain are important sources of carbon emissions. From the perspective of the fuel whole life cycle, the electricity consumption per 100 km and carbon emissions per 10,000 km of all levels of BEPVs are analysed. Then, the electricity energy conservation and carbon emissions reduction capabilities of BEPVs are compared with the same level ICEVs. The forecast for BEPVs' electricity energy conservation and carbon emissions reduction in 2025, 2030 and 2035 is based on the improvement of Chinese composition of energy for electricity generation and BEV's technology. BEPVs face problems, such as a remarkable reduction in the endurance mileage and the mileage accuracy, due to the negative impact of vehicle technical performance barriers. The influence rule of mileage credibility on BEPVs' elec-

tricity energy consumption and carbon emissions in seven regional provinces of China is investigated. The low temperature endurance mileage accuracy parameters of mainstream BEPV models in the market are the input variables used to quantitatively analyse BEPVs' electricity energy consumption and carbon emissions.

3. Model

3.1. Basic Model

Figure 1 show the methodological framework for the BEPVs WTW analysis. The main research objective is to study the energy consumption and greenhouse gas emissions throughout the whole fuel cycle of BEPVs. The fuel cycle includes two stages: well to pump (WTP) and pump to wheels (PTW), which together make up WTW. For ICEVs, WTP includes crude oil extraction, refining and transportation processes. For BEPV, the WTP stage includes the production and transmission of electricity (thermal power, hydropower, wind power, photovoltaic power generation and nuclear power, etc.).

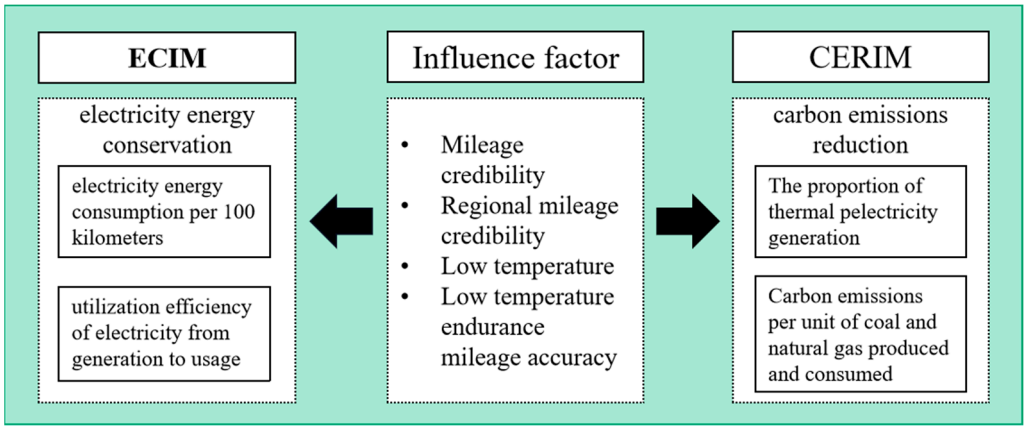


Figure 1. Methodological framework for the BEPVs WTW analysis.

The electricity energy conservation effect of BEPVs compared with ICEVs is calculated by comprehensively considering the electricity energy consumption per 100 km of BEPVs during the operation stage and electricity production loss caused by electricity production and transmission in the upstream electricity energy link. Although BEPVs do not produce carbon emissions during the vehicle operation stage, the upstream energy link is also an important part of its life cycle carbon emissions. The upstream electricity energy carbon emissions of BEPVs are calculated to analyse the BEPVs' carbon emissions reduction effect compared with ICEVs of the same level.

3.1.1. Electricity Conservation Index Model (ECIM) of BEPV

The ECIM of BEPVs is established by using the WTW method to evaluate the electricity energy consumption of BEPVs with different levels, denoted by $\eta_{y,i}$. When the $\eta_{y,i}$ value is 100%, the electricity energy consumption of BEPV is equal to that of ICEV which has the same level as BEPV. The larger the $\eta_{y,i}$ value, the better the energy saving effect. The ECIM calculation formula is as follows.

$$\eta_{y,i} = \frac{\beta_{cfv,y-\mathrm{WTW}}}{\beta_{bev,y,i-\mathrm{WTW}}} \times 100\% \quad (1)$$

BEPV directly consumes electricity during driving, in addition, there will be some losses at the electricity generation and transmission in electricity supply chain. The concept of BEPVs' electricity energy consumption per 100 km from the perspective of fuel whole life cycle is introduced to account for the total energy consumption of BEPVs, including direct and indirect energy consumption. This concept considers the energy losses during fuel extraction, generation and transmission, and is expressed as $\beta_{bev,y,i-\mathrm{WTW}}$

(unit: kW·h/100 km). Similarly, the electricity consumption per 100 km of level y ICEV when the whole fuel life cycle is considered is represented as $\beta_{cfv,y-\mathrm{WTW}}$ (unit: kW·h/100 km).

3.1.2. From Perspective of the Fuel Whole Life Cycle, BEPVs' Electricity Energy Consumption per 100 km

From perspective of the fuel whole life cycle, BEPVs' electricity energy consumption per 100 km is modeled. $\beta_{bev,y,i,0}$ refers to the official electricity energy consumption per 100 km of type i level y BEPV (unit: kW·h/100 km). $\gamma_{bev,\mathrm{WT}}$ indicates the utilization efficiency of electricity from generation to usage. $bc_{y,i,0}$ represents the official battery energy capacity of type i level y BEPV (unit: kW·h). $m_{y,i,0}$ is the standard mileage of type i level y BEPV (unit: km). γ_{total} is the comprehensive electricity generation efficiency. $\gamma_{\mathrm{transfer}}$ is the electricity transmission efficiency. t_k is the total electricity generation efficiency of type k energy. z_k is the proportion of electricity generated by type k energy.

$$\beta_{bev,y,i-\mathrm{WTW}} = \frac{\beta_{bev,y,i,0}}{\gamma_{bev,\mathrm{WT}}} \tag{2}$$

$$\beta_{bev,y,i,0} = \frac{bc_{y,i,0}}{m_{y,i,0}} \times 100 \tag{3}$$

$$\gamma_{bev,\mathrm{WT}} = \gamma_{\mathrm{total}} \times \gamma_{\mathrm{transfer}} \tag{4}$$

$$\gamma_{\mathrm{total}} = \sum_{k} t_k z_k \tag{5}$$

3.1.3. From Perspective of the Fuel Whole Life Cycle, ICEVs Energy Consumption per 100 km

From perspective of the fuel whole life cycle, ICEVs energy consumption per 100 km is calculated. $\beta_{cfv,y,0}$ denotes the electricity consumption per 100 km of level y ICEV (unit: kW·h/100 km). $\beta_{cfv,y}$ denotes the official gasoline consumption per 100 km of level y ICEV (unit: L/100 km). ρ_f represents the gasoline density, which is 0.75 kg/L. q_f and q_e represent the thermal power generation efficiency of gasoline and electricity, respectively, which are 4.6×10^7 J/kg and 3.6×10^7 J/kg. $\gamma_{cfv,\mathrm{WT}}$ indicates the fuel utilization efficiency from the oil well to the car fuel tank, γ_{gp} from crude oil exploitation to gasoline refining; the value is 21.5%. γ_{gt} is the efficiency of gasoline transportation, which is 97%.

$$\beta_{cfv,y-\mathrm{WTW}} = \frac{\beta_{cfv,y,0}}{\gamma_{cfv,\mathrm{WT}}} \tag{6}$$

$$\beta_{cfv,y,0} = \beta_{cfv,y} \times \rho_f \times \frac{q_f}{q_e} \tag{7}$$

$$\gamma_{cfv,\mathrm{WT}} = \gamma_{gp} \times \gamma_{gt} \tag{8}$$

3.1.4. Carbon Emissions Reduction Index Model (CERIM) of BEPV

The CERIM is measured BEPVs' carbon emissions reduction potential. The CERIM for all type i level y BEPV is expressed in $c_{y,i}$, and the calculation formulation is as follows. $c_{bev,y,i}$ is the concept of type i level y BEPVs carbon emissions per 10,000 km. $c_{cv,y}$ represents the carbon emissions per 10,000 km of level y ICEV.

$$c_{y,i} = \frac{c_{cv,y}}{c_{bev,y,i}} \times 100\% \tag{9}$$

3.1.5. Carbon Emissions Model per 10,000 km of BEPV

From the perspective of the fuel whole life cycle, BEPVs do not directly emit carbon during the driving process, but the generation and transmission of electricity to power them release carbon. Therefore, the carbon emissions of BEPVs are explored. In this regard, hydrogen electric generation, wind electric generation and other renewable electric generation modes are ignored because they do not produce carbon emissions. Thermal power electric generation is identified as the principal source of carbon emissions from BEPVs during driving. The calculation formula for BEPVs' carbon emissions per 10,000 km is as follows.

$$c_{bev,y,i} = \frac{bc_{y,i,0} \times 10,000 \times z_{\text{th}}}{m_{y,i,0} \times \gamma_{tranfer}} \times \sum_{k=1}^{2} \frac{q_k \times f_k \times (c_{k1} + c_{k2})}{\gamma_{k,e} \times \gamma_{k,t}} \tag{10}$$

where z_{th} represents the proportion of thermal power, 70.4%, 69.8% and 69.4% in 2018, 2019 and 2020, respectively. q_k indicates the proportion of coal and natural gas electric generation in thermal power, which is 94.5% and 5.5% in 2018, respectively, 94.1% and 5.9% in 2019, respectively, and 93.8% and 6.2% in 2020, respectively. f_k refers to the amount of coal and natural gas required to produce per kilowatt-hour electricity, coal is 0.326 kg/(kW·h) and natural gas is 0.312 kg/(kW·h). c_{k_1} and c_{k_2} indicate carbon emissions per unit fuel combustion and production, respectively: coal is 3.06 and 0.012, natural gas is 1.87 and 0.002. $\gamma_{k,e}$ and $\gamma_{k,t}$ are the efficiency of exploitation and transportation, which is 97% and 99% for coal, and 94.5% and 89% for natural gas, respectively.

3.1.6. Carbon Emissions Model per 10,000 km of ICEV

The calculation formulation of carbon emissions per 10,000 km of level y ICEV is as follows.

$$C_{cv,y} = 100 \times \beta_{cv,y} \times \left(c_{f1} + c_{f2}\right) / \gamma_{gt} \tag{11}$$

c_{f1} and c_{f2} are the carbon emissions of combusting and producing 1 L gasoline, which are 2.49 kg/L and 0.15 kg/L, respectively.

3.2. Influence Factor

3.2.1. Mileage Credibility of BEPV

The mileage credibility refers to the consistency between the official endurance mileage and the actual endurance mileage. The closer the mileage credibility is to 1, the higher the credibility of the BEPVs' actual endurance mileage. The significance of introducing mileage credibility is to comprehensively measure the endurance mileage performance of different vehicle types in different regions. The actual electricity energy consumption and carbon emissions reduction capabilities of BEPVs in a real driving environment are determined on the basis of mileage credibility.

$$\varphi_{y,i} = \frac{m_{y,i}}{m_{y,i,0}} \tag{12}$$

$$\beta_{bev,y,i,1} = \frac{bc_{y,i,0}}{m_{y,i}} \times 100 \tag{13}$$

$$\beta_{bev,y,i-\text{WTW},1} = \frac{\beta_{bev,y,i,1}}{\gamma_{bev,\text{WT}}} = \frac{bc_{y,i,0} \times 100}{m_{y,i,0} \times \varphi_{y,i} \times \gamma_{bev,\text{WT}}} \tag{14}$$

$$\eta_1 = \frac{\beta_{cfv,y-\text{WTW}}}{\beta_{bev,y,i-\text{WTW},1}} \times 100\% \tag{15}$$

$$c_{bev,y,i,1} = \frac{bc_{y,i,0} \times 10,000 \times z_{th}}{m_{y,i,0} \times \varphi_{y,i} \times \gamma_{tranfer}} \times \sum_{k=1}^{2} \frac{q_k \times f_k \times (c_{k1} + c_{k2})}{\gamma_{k,e} \times \gamma_{k,t}} \tag{16}$$

$$c_{y,i,1} = \frac{c_{cv,y}}{c_{bev,y,i,1}} \times 100\% \tag{17}$$

$\varphi_{y,i}$ indicates the mileage credibility parameter of level y type i BEPV. $m_{y,i}$ is the actual endurance mileage of level y type i BEPV. $\beta_{bev,y,i,1}$ is the actual electricity energy consumption per 100 km of level y type i BEPV considering mileage credibility. $\beta_{bev,y,i-\mathrm{WTW},1}$ is level y type i BEPV's electricity energy consumption per 100 km from the perspective of the fuel whole life cycle considering mileage credibility.$c_{bev,y,i,1}$ is the carbon emissions of level y type i BEPV considering mileage credibility. η_1 is the ECIM value considering mileage credibility. $c_{y,i,1}$ is the CERIM value of level y type i BEPV considering mileage credibility.

3.2.2. Regional Mileage Credibility

Regional mileage credibility is introduced to measure the actual electricity consumption and carbon emissions of all levels BEPVs in China's seven regional provinces.

$$\varphi_{y,i,z} = \frac{m_{y,i,z}}{m_{y,i,0}} \tag{18}$$

$$\beta_{bev,y,i,2} = \frac{bc_{y,i,0}}{m_{y,i,z}} \times 100 \tag{19}$$

$$\beta_{bev,y,i-\mathrm{WTW},2} = \frac{\beta_{bev,y,i,2}}{\gamma_{bev,\mathrm{WT}}} = \frac{bc_{y,i,0} \times 100}{m_{y,i,0} \times \varphi_{y,i,z} \times \gamma_{bev,\mathrm{WT}}} \tag{20}$$

$$\eta_2 = \frac{\beta_{cfv,y-\mathrm{WTW}}}{\beta_{bev,y,i-\mathrm{WTW},2}} \times 100\% \tag{21}$$

$$c_{bev,y,i,2} = \frac{bc_{y,i,0} \times 10,000 \times z_{th}}{m_{y,i,0} \times \varphi_{y,i,z} \times \gamma_{tranfer}} \times \sum_{k=1}^{2} \frac{q_k \times f_k \times (c_{k1} + c_{k2})}{\gamma_{k,e} \times \gamma_{k,t}} \tag{22}$$

$$c_{y,i,2} = \frac{c_{cv,y}}{c_{bev,y,i,2}} \times 100\% \tag{23}$$

$\varphi_{y,i,z}$ refers to the mileage credibility parameter of level y type i BEPV in China z region. $m_{y,i,z}$ is the actual endurance mileage of level y type i BEPV in China z region. $\beta_{bev,y,i,2}$ is actual electricity energy consumption per 100 km of level y type i BPEV considering regional mileage credibility. $\beta_{bev,y,i-\mathrm{WTW},2}$ is level y type i BPEVs electricity energy consumption per 100 km from the perspective of fuel whole life cycle considering regional mileage credibility. $c_{bev,y,i,2}$ is carbon emissions of of level y type i BEPV considering regional mileage credibility. η_2 is the ECIM value of level y type i BEPV considering regional mileage credibility. $c_{y,i,2}$ is CERIM value of level y type i BEPV considering regional mileage credibility.

3.2.3. Low Temperature

Affected by the low temperature weather in winter, the BEPVs' endurance mileage is sharply shortened, and the accuracy of endurance mileage estimation is reduced, making the BEPVs' electricity consumption and carbon emissions uncertain. In this section, the low temperature endurance mileage influence parameter is introduced to explore the influence rule of low temperature environment on electricity energy conservation and carbon emissions reduction in level y type i BEPV.

$$m_{y,i,t} = m_{y,i,0} \times \tau_{y,i,t} \tag{24}$$

$$\beta_{bev,y,i,3} = \frac{bc_{y,i,0}}{m_{y,i,t}} \times 100 \tag{25}$$

$$\beta_{bev,y,i-\mathrm{WTW},3} = \frac{\beta_{bev,y,i,3}}{\gamma_{bev,\mathrm{WT}}} = \frac{bc_{y,i,0} \times 100}{m_{y,i,0} \times \tau_{y,i,t} \times \gamma_{bev,\mathrm{WT}}} \tag{26}$$

$$\eta_3 = \frac{\beta_{cfv,y-\mathrm{WTW}}}{\beta_{bev,y,i-\mathrm{WTW},3}} \times 100\% \tag{27}$$

$$c_{bev,y,i,3} = \frac{bc_{y,i,0} \times 10,000 \times z_{th}}{m_{y,i,0} \times \tau_{y,i,t} \times \gamma_{tranfer}} \times \sum_{k=1}^{2} \frac{q_k \times f_k \times (c_{k1} + c_{k2})}{\gamma_{k,e} \times \gamma_{k,t}} \tag{28}$$

$$c_{y,i,3} = \frac{c_{cv,y}}{c_{bev,y,i,3}} \times 100\% \tag{29}$$

$m_{y,i,t}$ refers to the endurance mileage displayed on the instrument of level y type i BEPVs at t °C. $\tau_{y,i,t}$ is low temperature endurance mileage influence coefficient of level y type i BEPV at t °C. $\beta_{bev,y,i,3}$ is actual electric energy consumption per 100 km of level y type i BPEV at t °C. $\beta_{bev,y,i-\mathrm{WTW},3}$ is level y type i BPEVs' electricity energy consumption per 100 km at t °C from the perspective of fuel whole life cycle. $c_{bev,y,i,3}$ is carbon emissions of level y type i BEPV in low temperature. η_3 is the ECIM of BEPV value in low temperature. $c_{y,i,3}$ is the CERIM value of level y type i BEPV in low temperature.

3.2.4. Low Temperature Endurance Mileage Accuracy

The low temperature environment will produce negative effects such as the deviation between the endurance mileage displayed on the instrument and the actual endurance mileage. Therefore, the low temperature endurance mileage accuracy parameter is introduced to reflect the deviation degree between the endurance mileage displayed on the instrument and the actual endurance mileage. The closer the evaluation result is to 1, the higher the estimation accuracy of endurance mileage.

$$m_{y,i,t,1} = m_{y,i,0} \times \tau_{y,i,t} \times \varpi_{y,i,t} \tag{30}$$

$$\beta_{bev,y,i,4} = \frac{bc_{y,i,0}}{m_{y,i,t,1}} \times 100 \tag{31}$$

$$\beta_{bev,y,i-\mathrm{WTW},4} = \frac{\beta_{bev,y,i,4}}{\gamma_{bev,\mathrm{WT}}} = \frac{bc_{y,i,0} \times 100}{m_{y,i,0} \times \tau_{y,i,t} \times \varpi_{y,i,t} \times \gamma_{bev,\mathrm{WT}}} \tag{32}$$

$$\eta_4 = \frac{\beta_{cfv,y-\mathrm{WTW}}}{\beta_{bev,y,i-\mathrm{WTW},4}} \times 100\% \tag{33}$$

$$c_{bev,y,i,4} = \frac{bc_{y,i,0} \times 10,000 \times z_{th}}{m_{y,i,0} \times \tau_{y,i,t} \times \varpi_{y,i,t} \times \gamma_{tranfer}} \times \sum_{k=1}^{2} \frac{q_k \times f_k \times (c_{k1} + c_{k2})}{\gamma_{k,e} \times \gamma_{k,t}} \tag{34}$$

$$c_{y,i,4} = \frac{c_{cv,y}}{c_{bev,y,i,4}} \times 100\% \tag{35}$$

$m_{y,i,t,1}$ refers to the endurance mileage displayed on the instrument of level y type i BEPV at t °C when the low temperature endurance mileage accuracy is considered. $\varpi_{y,i,t}$ is the low temperature endurance mileage accuracy parameter of level y type i BEPV at t °C. $\beta_{bev,y,i,4}$ is actual electricity energy consumption per 100 km of level y type i BPEV. $\beta_{bev,y,i-\mathrm{WTW},4}$ is level y type i BPEVs electricity energy consumption per 100 km at t °C from the perspective of the fuel whole life cycle when the low temperature endurance mileage accuracy is considered. $c_{bev,y,i,4}$ is carbon emissions of level y type i BEPV when the low temperature endurance mileage accuracy is considered. η_4 is the level y type i BEPVs ECIM of value when the low temperature endurance mileage accuracy is considered. $c_{y,i,4}$ is the CERIM value of level y type i BEPV when the low temperature endurance mileage accuracy is considered.

4. Data

The actual electricity energy consumption per 100 km of BEPV is declining year by year. The average electricity energy consumption per 100 km of A00+A0 entry-level BEPV, A level universal BEPV and B level high-end BEPV from 2018 to 2020, and the average electricity energy consumption per 100 km of all level BEPVs in 2025, 2030 and 2035 specified in the Technical Roadmap of Energy Saving and New Energy Vehicles 2.0 are shown in Table 1 [32]. The electricity energy conservation and carbon emissions reduction effect of BEPV is not only related to vehicle performance, but also related to generation and transmission efficiency of electricity. In the composition of energy for electricity generation, the numerical values of comprehensive electricity generation and transmission efficiency from 2018 to 2020 are shown in Table 2 [32].

Table 1. The average electricity energy consumption per 100 km of BEPV.

Level	2018	2019	2020	2025E	2030E	2035E
A00+A0 entry-level	13.1	12.8	12.4	9	8.5	8
A universal level	15.3	14.4	14.1	11	10.5	10
B high-end level	20.5	19.6	16.9	13	12.5	12

Table 2. Electricity data.

	Category	Hydro Power	Thermal Power	Nuclear Power	Wind Power	Solar Power	Comprehensive Generation Efficiency	Power Transmission Efficiency
2018	Proportion of power generation	17.6%	70.4%	4.2%	5.2%	2.5%	46.37%	94.1%
	power generation efficiency	87.5%	38.1%	41.5%	36.5%	18.8%		
2019	Proportion of power generation	16.8%	69.8%	4.5%	5.7%	3.2%	46.37%	94.2%
	power generation efficiency	88.8%	38.3%	42.6%	38.3%	19.4%		
2020	Proportion of power generation	16.15%	69.26%	4.74%	6.10%	3.76%	46.1%	94.3%
	power generation efficiency	89.2%	38.4%	42.6%	38.5%	19.5%		

Table 3 [32] shows the average gasoline consumption per 100 km of ICEV in 2018, 2019 and 2020. In view of the energy conservation technology promotion of ICEV, the average gasoline consumption per 100 km of ICEV will reach 5.6 L/100 km in 2025, 4.8 L/100 km in 2030 and 4 L/100 km in 2035. The endurance mileage credibility data of BEPV with good performance are shown in Table 4 [32]. Meanwhile, the numerical values of BEPVs' endurance mileage credibility in Chinese seven regions are shown in Table 5 [32].

Table 3. The average gasoline consumption of ICE. (unit: L/100 km).

	2018	2019	2020
A00+A0	6.9	6.6	6.2
A	8.7	8.4	7.9
B	10.1	9.7	9.1

Table 4. Endurance mileage credibility and relevant data of BPEV in 2020.

Level	A00+A0			A			B		
Model	Chery Eq1	JMC E100	BAIC EC180	BAIC EU260	BYD Qin	BYD E5	DENZA EV	BAIC EU7	BYD Han
Mileage credibility	1.02	1.00	0.99	1.03	0.89	0.88	0.90	0.76	0.75
Standard mileage	151.00	152.00	200.00	260.00	400.00	405.00	352.00	451.00	550.00
Actual mileage	154.02	152.00	198.00	267.80	356.00	356.40	316.80	342.76	412.50
Standard battery capacity	18.20	18.80	30.40	41.40	52.00	51.20	62.00	60.23	76.90
Electric consumption per 100 km	11.82	12.37	15.35	15.46	14.61	14.37	19.57	17.57	18.64

Table 5. Regional mileage credibility and related data of BEPV in 7 regions of China.

Region	Level	A00+A0			A			B		
North China	Type	Chery Eq1	JMC E100	BAIC EV200	BAIC EU260	Emgrand EV	BYD E5	DENZA EV		
	Mileage credibility	1.00	0.99	0.95	0.99	0.91	0.87	0.91		
	Standard mileage	151.00	152.00	200.00	260.00	400.00	405.00	352.00		
	Actual mileage	151.00	150.48	190.00	257.40	364.00	352.35	320.32		
	Standard battery capacity	18.20	18.80	30.40	41.40	52.00	51.20	62.00		
	Electric consumption per 100 km	12.05	12.49	16.00	16.08	14.29	14.53	19.36		
East China	Type	Chery Eq1	JMC E100	BAIC EV200	BYD E5	BYD Qin	BAIC EU 5	DENZA EV	BAIC EU7	BYD Han
	Mileage credibility	1.02	0.99	0.98	0.91	0.89	0.86	0.87	0.78	0.78
	Standard mileage	151.00	152.00	200.00	405.00	450.00	260.00	352.00	451.00	550.00
	Actual mileage	154.02	150.48	196.00	368.55	400.50	223.60	306.24	351.78	429.00
	Standard battery capacity	18.20	18.80	30.40	51.20	53.56	41.40	62.00	60.23	76.90
	Electric consumption per 100 km	11.82	12.49	15.51	13.89	13.37	18.52	20.25	17.12	17.93
South China	Type	BAIC EV200	BAIC EC180	Chery Eq1	BYD E2	BYD E5	Geometry A	DENZA EV	BYD Han	BAIC EU7
	Mileage credibility	1.08	1.07	1.06	0.93	0.92	0.9	0.87	0.87	0.82
	Standard mileage	200.00	156.00	151.00	401.00	405.00	430.00	352.00	550.00	451.00
	Actual mileage	216.00	166.92	160.06	372.93	372.60	387.00	306.24	478.50	369.82
	Standard battery capacity	30.40	20.30	18.20	43.20	51.20	53.00	62.00	76.90	60.23
	Electric consumption per 100 km	14.07	12.16	11.37	11.58	13.74	13.70	20.25	16.07	16.29
Central China	Type	Chery Eq1	JMC E100	BAIC EC180	Junfeng E17	BYD Qin	Geometry A	Model 3	BYD Han	
	Mileage credibility	1.01	1.01	0.96	1.06	0.90	0.89	0.74	0.73	
	Standard mileage	151.00	152.00	156.00	310.00	450.00	430.00	556.00	550.00	
	Actual mileage	152.51	153.52	149.76	328.60	405.00	382.70	411.44	401.50	
	Standard battery capacity	18.20	18.80	20.30	49.93	53.56	53.00	60.00	76.90	
	Electric consumption per 100 km	11.93	12.25	13.56	15.19	13.22	13.85	14.58	19.15	
North-west China	Type	BAIC EC180	Chery Eq1	JMC E200	BAIC EU260	BAICEU5	Emgrand EV			
	Mileage credibility	1.01	1.01	0.96	0.91	0.84	0.83			
	Standard mileage	156.00	151.00	152.00	260.00	260.00	400.00			
	Actual mileage	157.56	152.51	145.92	236.60	218.40	332.00			
	Standard battery capacity	20.30	18.20	17.30	41.40	41.40	52.00			
	Electric consumption per 100 km	12.88	11.93	11.86	17.50	18.96	15.66			
South-west China	Type	Chery Eq1	JMC E100	JMC E200	BAIC EU260	BYD Qin	Geometry A	DENZA EV		
	Mileage credibility	1.06	1.05	0.93	1.03	0.91	0.88	0.91		
	Standard mileage	151.00	152.00	152.00	260.00	450.00	430.00	352.00		
	Actual mileage	160.06	159.60	141.36	267.80	409.50	378.40	320.32		
	Standard battery capacity	18.20	18.80	17.30	41.40	53.56	53.00	62.00		
	Electric consumption per 100 km	11.37	11.78	12.24	15.46	13.08	14.01	19.36		
North-east China	Type				Roewe Ei5	Maruti E70				
	Mileage credibility				0.76	0.74				
	Standard mileage				501.00	401.00				
	Actual mileage				380.76	296.74				
	Standard battery capacity				61.10	50.30				
	Electric consumption per 100 km				16.05	16.95				

The standard endurance mileage of BEPV is taken as the reference object to explore the influence rule of low temperature environment on the BEPVs capability of energy

conservation and carbon emissions reduction. The actual endurance mileage of BEPV in low temperature environment decreased significantly compared with the standard endurance mileage, with the average decline rate of 41.21%, the lowest rate of 25.82% and the highest rate of 62.17%. The low temperature endurance mileage decline rate data and relevant data of A00+A0 level BEPV are shown in Table 6 [33], and the corresponding data of A level and B level BEPV are shown in Table 7 [33].

Table 6. Low temperature endurance mileage and relevant data of A00+A0 level BEPV.

	Changan Benben EV260	JAC IEV6E	Yujie E-Line	BAIC EC180	Saic GM Wuling Baojun E100	JMC E200S	Chery Eq1	Zhongtai E200
The percentage of the standard mileage	71.49	68.51	67.43	58.29	58.24	57.03	46.69	6.92
Standard battery capacity	31.00	34.90	22.00	20.30	28.00	17.30	32.2	31.90
Standard mileage	251	310	153	156	305	144	251	301
the endurance mileage after descent	179.44	212.38	103.17	90.93	177.63	82.12	117.19	20.83
Electric consumption per 100 km after descent	17.28	16.43	21.32	22.32	15.76	21.07	27.48	153.15

Table 7. Low temperature endurance mileage and relevant data of A level and B level BEPV.

	BYD Qin Pro EV	BYD Qin EV	DENZA EV	Geometry A	BYD Song EV	Dongfeng Fengshen E70	Xpeng G3	Gac Trumpchi GE3	NIO ES8
The percentage of the standard mileage	74.18%	72.46%	72.25%	69.65%	68.36%	65.3%	63.39%	63.23%	63.14%
Standard battery capacity	51.3	53.56	62	53	16.9	43.2	55	48.39	75
Standard mileage	401	450	352	430	80	330	460	410	450
the endurance mileage after descent	297.46	326.07	254.32	299.50	54.69	215.49	291.59	259.24	284.13
Electric consumption per 100 km after descent	17.25	16.43	24.38	17.70	30.90	20.05	18.86	18.67	26.40
	Soueast Motor DX3 EV400	BAIC EU7	Roewe Ei5	Wima EX5 Chi Xing 2.0	Chery Tiger 3Xe	Gac AION S	BAIC EU5	Yudo π1	
The percentage of the standard mileage	62.71	58.17	56.84	56.25	55.01	54.06	51.7	37.83	
Standard battery capacity	50.12	60.7	61.1	59.53	53.6	58.8	50.8	49.8	
Standard mileage	351	475	501	460	401	460	416	430	
the endurance mileage after descent	220.11	276.31	284.77	258.75	220.59	248.68	215.07	162.67	
Electric consumption per 100 km after descent	22.77	21.97	21.46	23.01	24.30	23.65	23.62	30.61	

In view of the fact that the endurance mileage of A00+A0 level BEPV has been seriously affected when only the low temperature factor is listed as major considerations, six types of A level and two types of B level BEPV with outstanding performance characteristics are selected to discover the impact of low temperature endurance mileage accuracy on the BEPVs' electricity energy conservation and carbon emissions reduction. The average low temperature endurance mileage accuracy values of the BEPV is 0.45, which leads to significant decreases in its actual endurance mileage data. The low temperature endurance mileage accuracy data of BEPV and other relevant data are shown in Table 8 [33].

Table 8. Low temperature endurance mileage accuracy and related data of A level and B level BEPV.

	Wima EX5 Chi Xing 2.0	BYD Qin Pro EV	Geometry A	Xpeng G3	BAIC EU7	Chery Tiger 3Xe	NIO ES8	Gac AION S
Accuracy	0.99	0.98	0.69	0.62	0.42	0.19	0.18	0.15
The percentage of the standard mileage	56.25	72.46	69.65	63.39	58.17	55.01	63.14	99.85
Standard battery capacity	59.53	51.3	53	55	60.7	53.6	75	58.8
Standard mileage	460	401	430	460	475	401	450	460
the endurance mileage after descent	256.16	284.75	206.65	180.79	116.05	41.91	51.14	68.90
Electric consumption per 100 km after descent	23.24	18.02	25.65	30.42	52.31	127.89	146.65	85.35

5. Case Analysis

5.1. Analysis of All Levels BEPVs' ECIM and CERIM Values

Figure 2 shows the BEPVs' average electricity energy conservation per 100 km of all levels of BEPVs. The average ECIM values of B level high-end BEPV in 2018 and 2019 are lower than one, indicating that their electricity energy consumption is higher than that of ICEV. With the continuous improvement of energy-saving technology performance, the electricity energy consumption of B level high-end BEPV is significantly lower than that of ICEV in 2020. However, the average ECIM values of A00+A0 entry-level and A level universal BEPVs fluctuated to a certain extent from 2018 to 2020, with values greater than or equal to one, showing an obvious electricity energy saving effect. Figure 3 shows that the average carbon emissions per 10,000 km of all levels of BEPVs from 2018 to 2020 are smaller than those of ICEVs from the perspective of the fuel whole life cycle, indicating the excellent carbon emissions reduction ability of BEPVs (Appendix A).

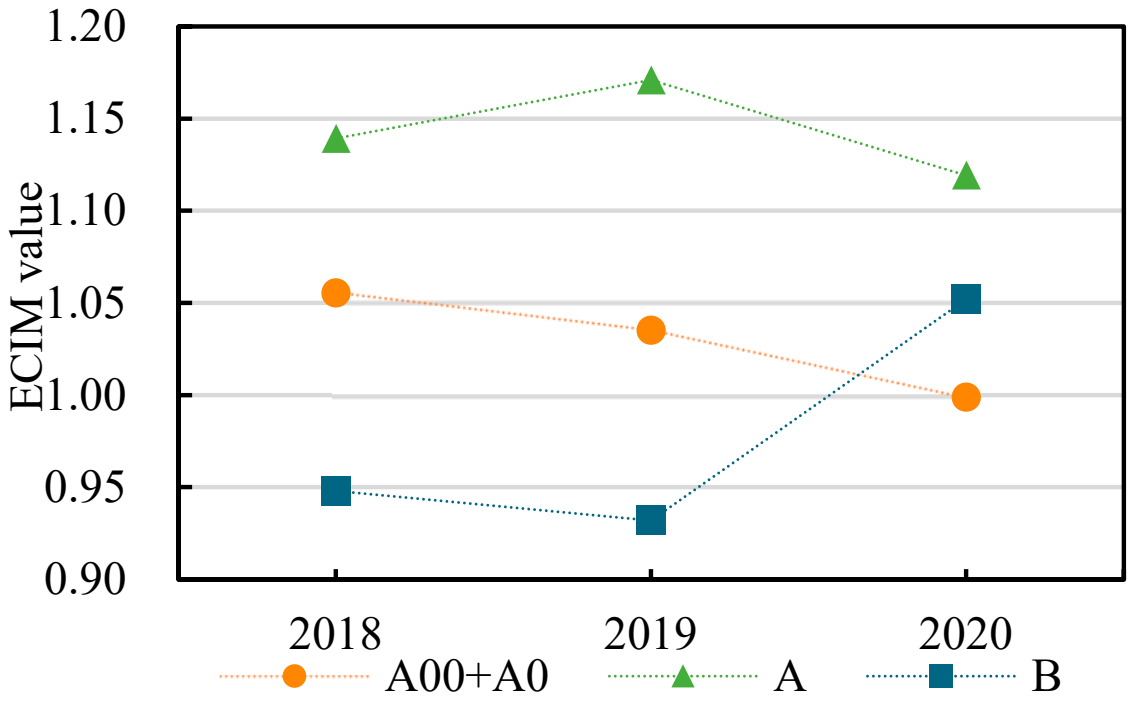


Figure 2. BEPVs' ECIM values.

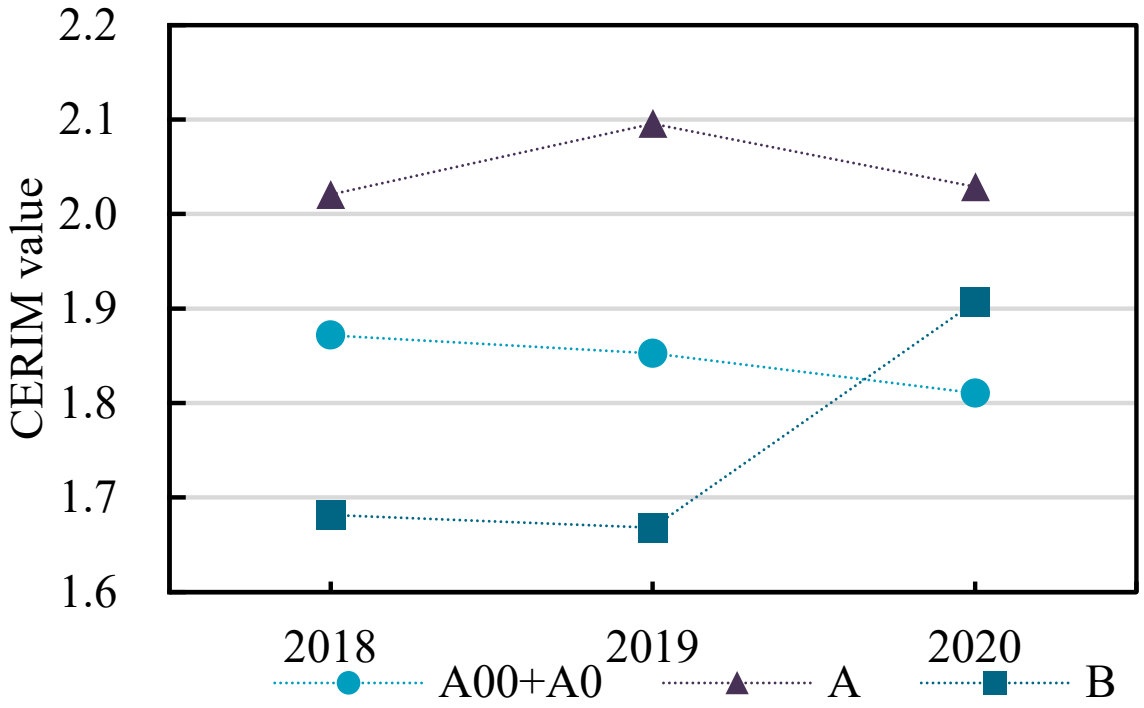


Figure 3. BEPVs' CERIM value.

5.2. Forecast All Levels BEPVs' Average Electricity Energy Conservation and Carbon Emissions Reduction Capability in 2025, 2030 and 2035

Figure 4 shows that in accordance with the analysis of the capability of all levels of BEPVs in 2025, the comprehensive electricity energy generation efficiency is increased by 10% on the original basis from the perspective of the fuel whole life cycle, and all levels of BEPVs have energy conservation characteristics compared with ICEVs. In 2030, considering the enhancement of ICEVs' energy conservation technology, the comprehensive electricity generation efficiency will need to be increased by 20–25% on the original basis to make the ECIM values of A level and B level BEPVs greater than one. When renewable energy sources with high comprehensive electricity generation efficiency dominate the composition of energy for electricity generation, the electricity energy consumption of BEPVs will be reduced to one-third to one-half of that of ICEVs. Therefore, vigorously developing renewable energy generation to reduce the energy consumption of non-renewable fossil fuels is one of the reliable ways to highlight the BEPVs' electricity energy conservation.

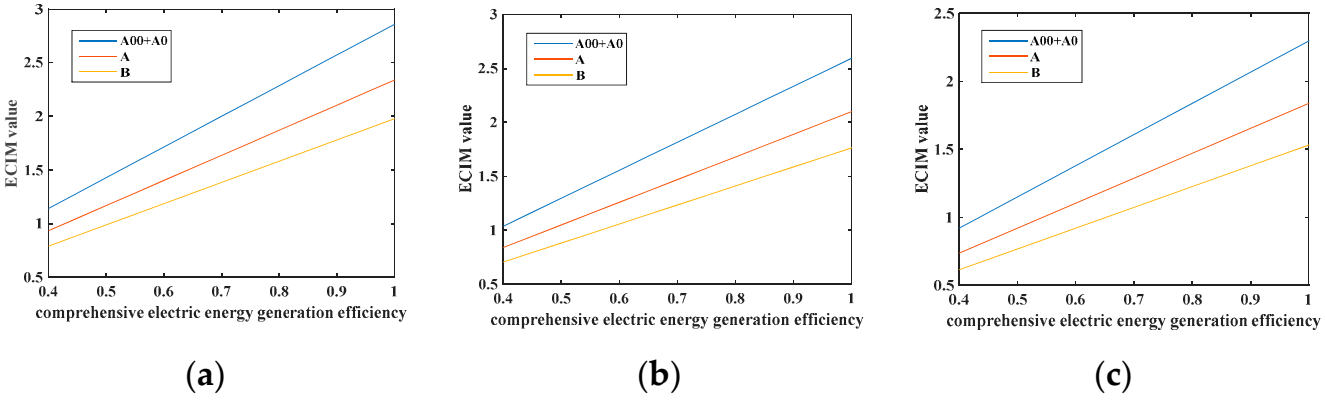


Figure 4. The influence rule of comprehensive electricity energy generation efficiency on BEPVs' ECIM value in 2025 (**a**), 2030 (**b**) and 2035 (**c**).

In Figure 5, on the basis of the current proportion of thermal power generation, the carbon emissions reduction capability of BEVPs in 2025, 2030 and 2035 is superior to those of ICEVs with weak advantages. When the proportion of thermal power drops to less than 40% in composition of energy for electricity generation, all levels of BEPVs emissions reduction capacity highlight will emerge. When the proportion of thermal power droops to less than 15%, all levels of BEPVs CERIM values begin to show exponential growth. The carbon emission reduction capacity of all levels of BEPVs has an order of magnitude breakthrough. Substituting BEPV for ICEV will bring approximately 30 times the emission reduction benefits. Therefore, BEPVs can be deployed in Yunnan, Guizhou, Sichuan and other southwest provinces where clean electricity energy proportion accounts for more than 80% to achieve a strong emission reduction effect, promoting green development of the road transportation industry.

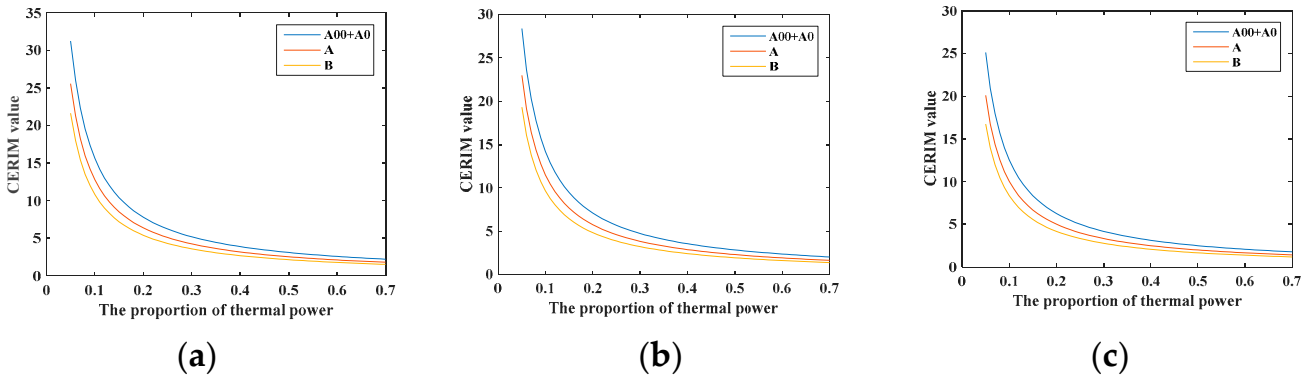


Figure 5. The influence rule of thermal power proportion on BEPVs' CERIM values in 2025 (**a**), 2030 (**b**) and 2035 (**c**).

5.3. The Impact of Mileage Credibility on BEPVs' Electricity Energy Conservation and Carbon Emission Reduction Capability

In this section, three types with high sales volume at each level are selected to conduct mileage credibility research on the electricity energy conservation and carbon emissions reduction capability of BEPVs. In Figure 6, the higher the BEPVs' level, the more remarkable the negative impact of mileage credibility on their energy conservation performance. For A00+A0 level BEPVs, mileage credibility has a small impact on them. For A level BEPVs, perhaps the mileage credibility may reduce their ECIM values, but their electricity energy consumption is still lower than those of ICEVs. Although mileage credibility sharply reduces the ECIM values of B level BEPVs, the electricity energy consumption of all B level BEPVs types is less than or similar to that of ICEVs. In particular, for some A00+A0 level and A level BEPVs types, mileage credibility will make their energy conservation performance become more excellent. In Figure 6, when mileage credibility is taken as a key measurement factor, although the CERIM value decreases, the carbon emissions per 10,000 km of all levels of BEPVs types are still fall far below those of ICEVs due to their obvious emission reduction property.

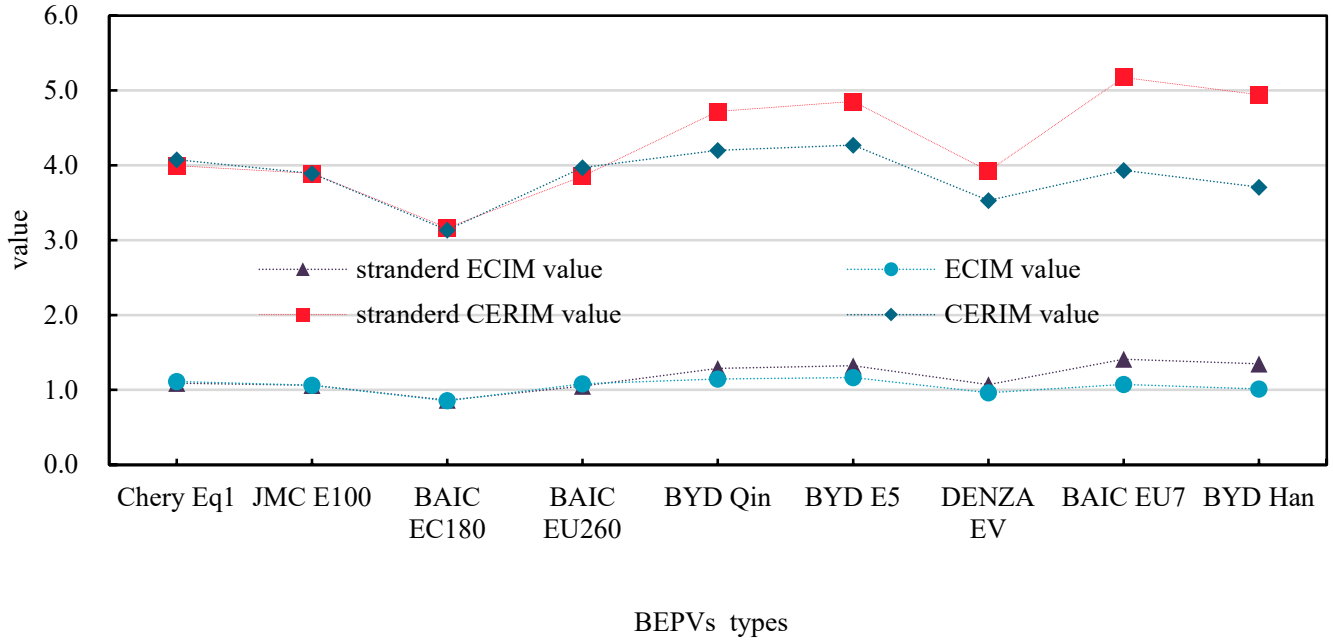


Figure 6. BEPVs' ECIM values and CERIM values.

5.4. The Impact of Regional Mileage Credibility on BEPVs' Electricity Energy Conservation and Carbon Emissions Reduction Capability

In Figures 7–13, the impact of regional mileage credibility on the electricity energy conservation and carbon emission reduction capability of BEPVs in seven regions of China is investigated. In Figure 7, the electricity energy conservation capability of A00+A0 level and A level BEPVs in northern Chinese region provinces is less affected by the regional mileage credibility, whereas for some B-level BEPVs, such as Denza EV, their electricity energy consumption per 100 km is higher than that of ICEVs, and their capability is strongly affected by regional mileage credibility from the perspective of fuel whole life cycle. However, the carbon emissions reduction capability of all levels of BEPVs is not remarkably impacted by regional mileage credibility.

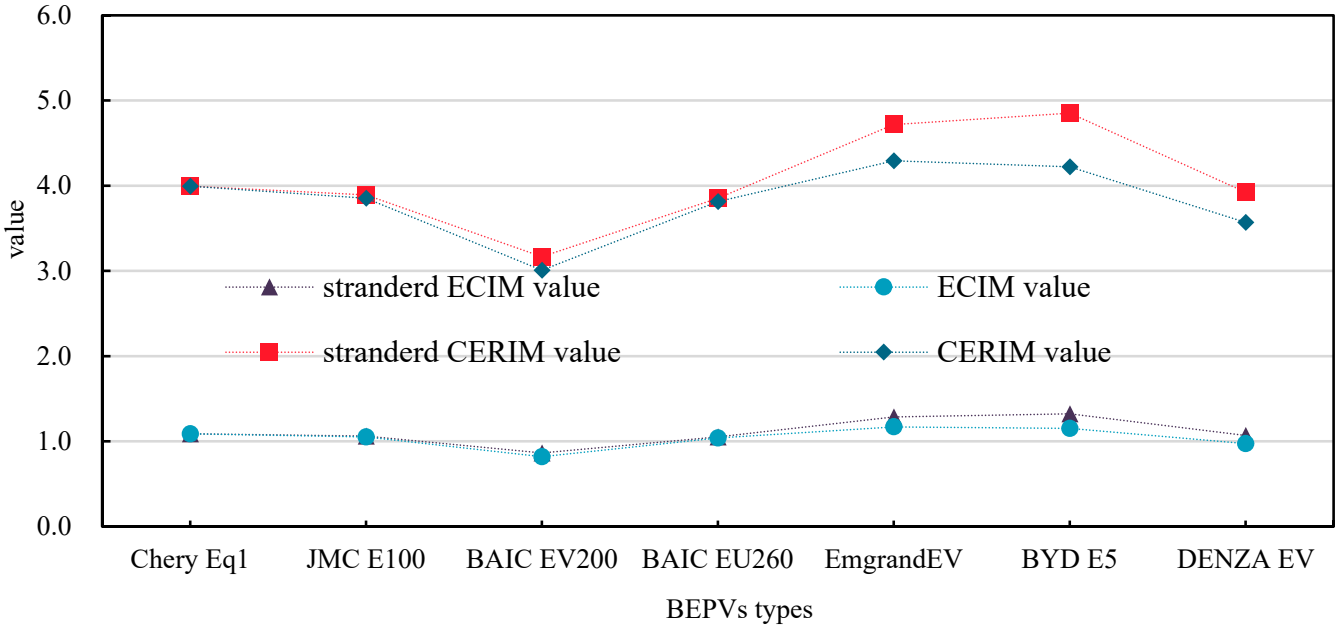


Figure 7. BEPVs' ECIM values and CERIM values in northern Chinese region provinces.

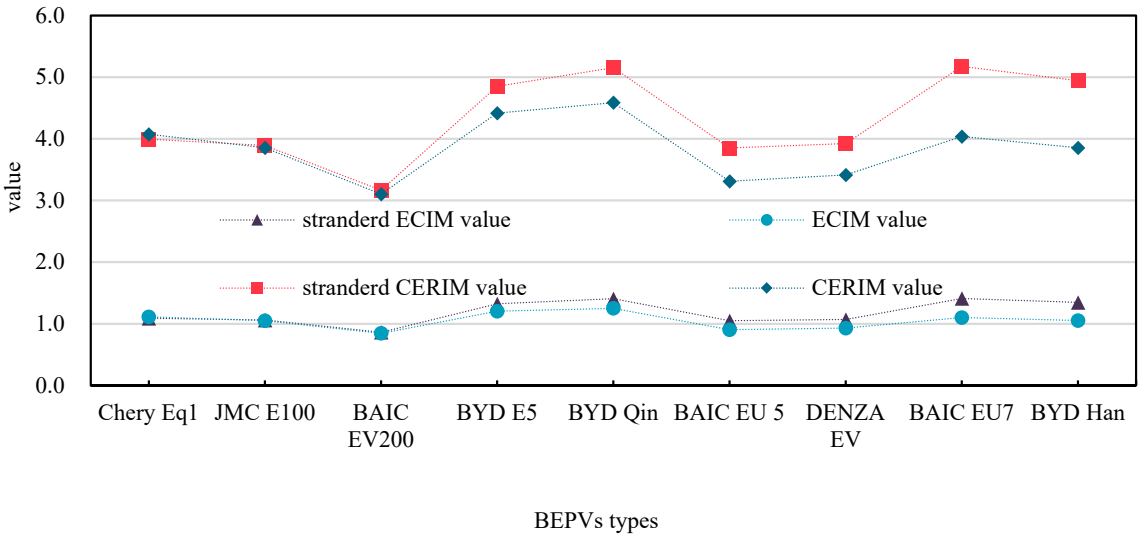


Figure 8. BEPVs' ECIM values and CERIM values in eastern Chinese region provinces.

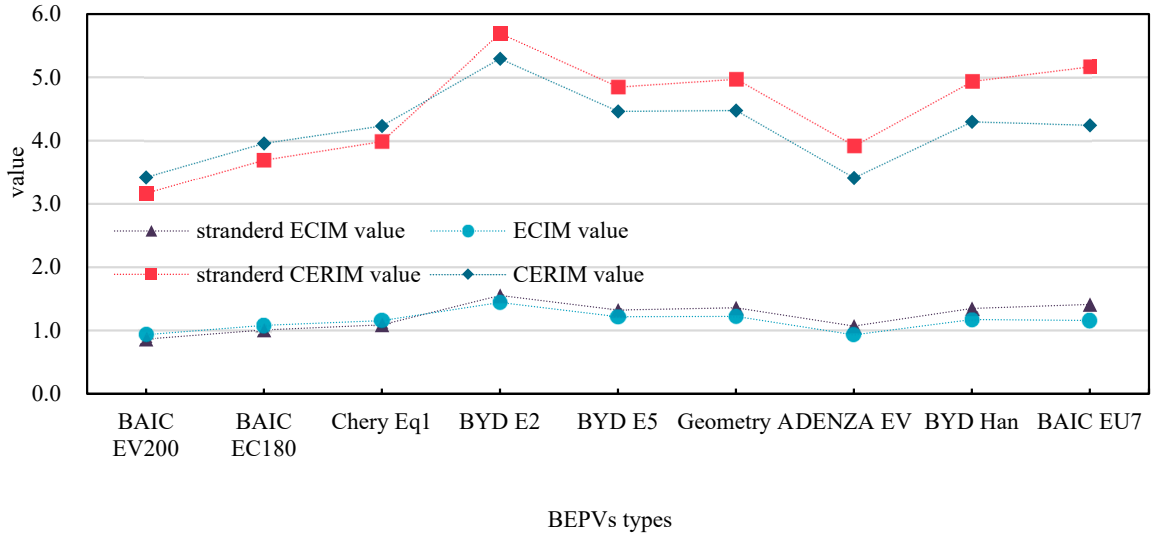


Figure 9. BEPVs' ECIM values and CERIM values in southern Chinese region provinces.

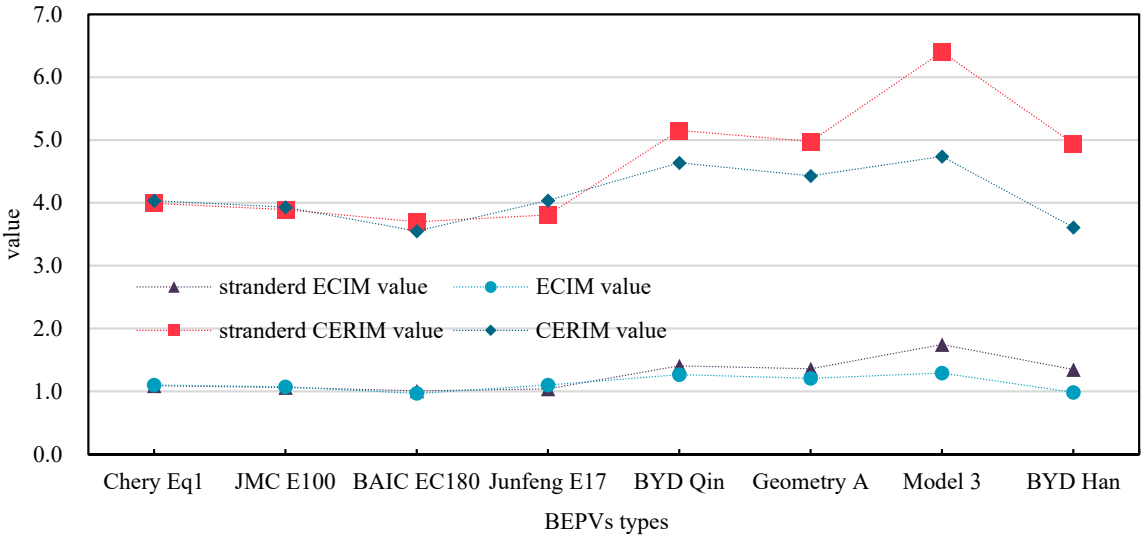


Figure 10. BEPVs' ECIM values and CERIM values in central Chinese region provinces.

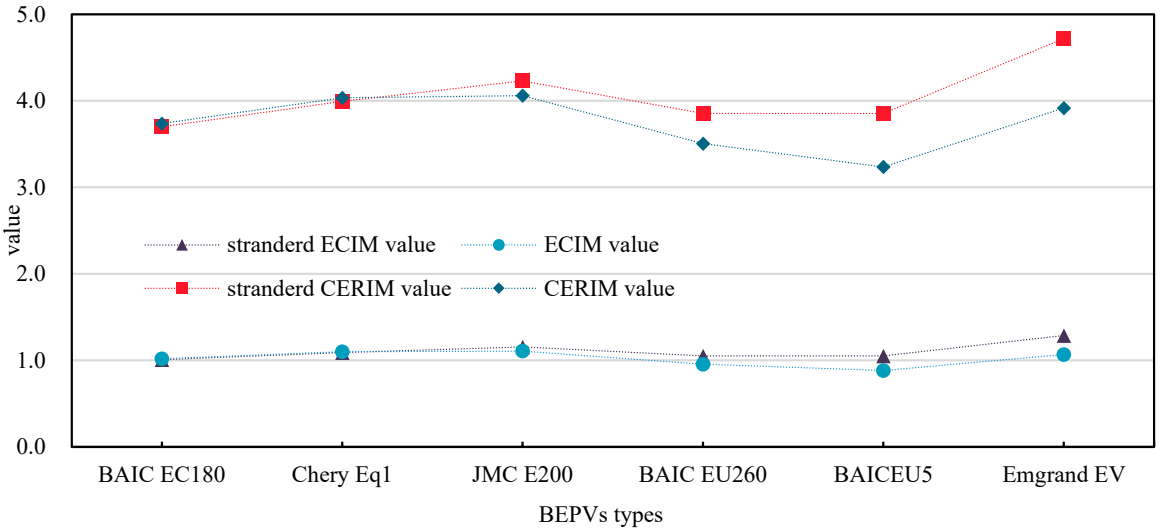


Figure 11. BEPVs' ECIM values and CERIM values in southwest Chinese region provinces.

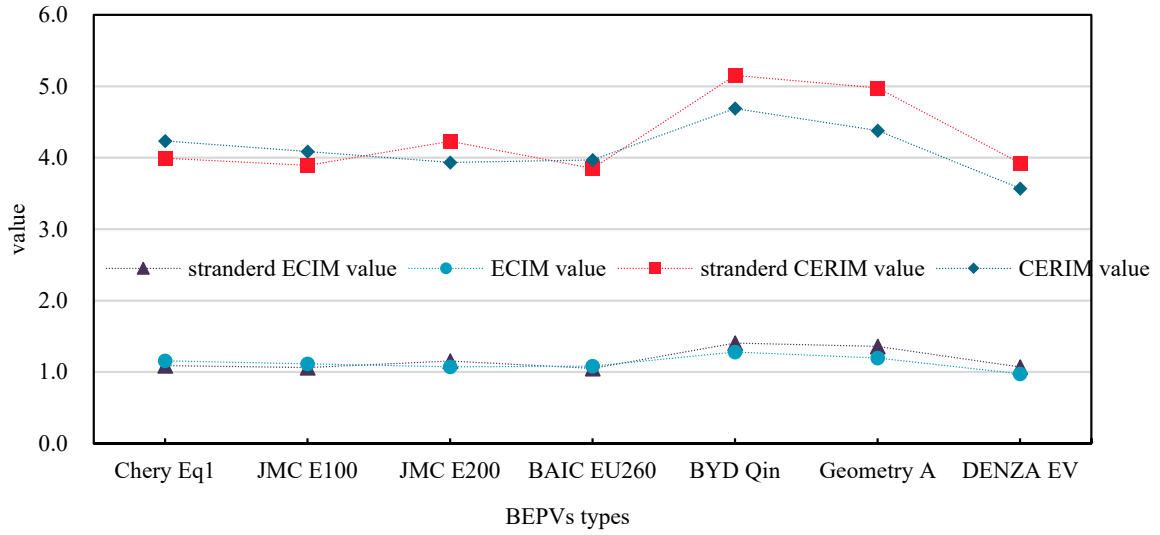


Figure 12. BEPVs' ECIM values and CERIM values in northwest Chinese region provinces.

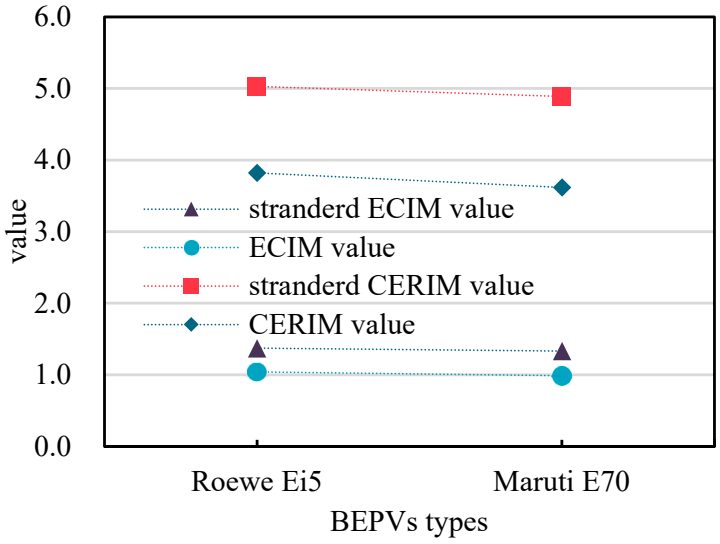


Figure 13. BEPVs' ECIM values and CERIM values in northeast Chinese region provinces.

In Figure 8, the electricity energy conservation and carbon emissions reduction capabilities of A00+A0 level BEPVs in eastern Chinese regions are weakly affected by regional mileage credibility, whereas the capabilities of A level BEPVs are greatly affected by regional mileage credibility, making BAIC EU5′s electricity energy consumption higher than that of ICEV with the same level. For B level BEPVs, the regional mileage credibility leads to their electricity energy consumption becoming close to or greater than that of ICEVs although they have strong energy-saving advantages.

In Figure 9, the influence of regional mileage credibility on all levels of BEPVs in southern Chinese region provinces follows similar patterns, where higher level BEPVs are more negatively impacted by regional mileage credibility. Specifically, the negatively influential degree is weaker than that of the above two regions provinces. Compared with other regions, the capabilities of A00+A0 level BEPVs are enhanced when the regional mileage credibility factor is taken into account, whereas A-level BEPVs are less affected. The carbon emissions reduction ability of B-level BEPVs is less affected by regional mileage credibility, but their electricity energy conservation ability is greatly reduced. For instance, the electricity energy consumption of Denza EV becomes higher than that of ICEV.

In Figure 10, the positive impact of regional mileage credibility on BEPVs' electricity energy conservation and carbon emission reduction in central Chinese regional provinces has been extended to some A-level BEPVs. The electricity energy conservation performance of Junfeng E17 is enhanced, making it more prominent than that of ICEV. Similarly, the electricity energy conservation and carbon emission reduction capabilities of B Level BEPVs are negatively affected by the regional mileage credibility, which reduces the efficiency of BYD HanEV's electricity energy conservation efficiency from the original approximately 40% higher than that of ICEVs to being equal, causing BEPVs' energy consumption to increase remarkably.

As shown in Figure 11, the regional mileage credibility can increase the electricity energy conservation and carbon emissions reduction capability of A00+A0 level and A level BEPVs with better performance in southwest China. For some types of A level BEPVs, the regional mileage credibility reduces the ECIM and CERIM values, but the decline is small which their capability is still more obvious than those of ICEV. The regional mileage credibility has a small negative impact on B-level BEPVs because they have not been widely promoted.

As shown in Figure 12, for A00+A0 level BEPV in northwest Chinese region provinces, their electricity energy conservation effectiveness is the same as that of ICEVs when the regional mileage credibility is considered. However, the electricity energy consumption for some A-level BEPVs is higher than those of ICEVs at the same level. In Figure 13, under standard conditions, the electricity energy conservation effectiveness of A level BEPV in northeast Chinese region provinces is about 1.3 times that of ICEVs under standard conditions. When the regional mileage credibility is taken as the main consideration factor, the electricity energy conservation capability of the latter two types is the same as those of ICEVs.

5.5. Sensitivity Analysis of Low Temperature on BEPVs' Electricity Energy Conservation and Carbon Emission Reduction

Figures 14 and 15 demonstrate that the all levels of BEPVs' electricity energy consumption have decreases to varying degrees in low temperature condition. Compared with A00+A0 level and B level BEPV, some A level BEPVs types still exhibit electricity energy conservation characteristics in low temperature environment. The actual electricity energy consumption per 100 km of BEPVs is higher than that of ICEVs due to reduced endurance mileage in low temperatures. Therefore, the energy conservation potential of BEPVs in low temperature environments remains unclear. From the perspective of energy conservation, provinces with average winter temperatures below −7 °C, such as northeast Chinese regional provinces, northwest Chinese regional provinces, Xizang and other provinces, are unsuitable for promoting A00+A0 level and B level BEPVs. The carbon emissions reduction

effectiveness of A00+A0, A and B level BEPV at −7 °C is seriously affected. The decrease in the endurance mileage of A00+A0, A and B level BEPVs in low temperature leads to an increase in their carbon emissions per 10,000 km, but they are still lower than those of ICEVs. At the same time, it has also been verified that the deployment of all levels and types of BEPVs should not be blindly encouraged, on account of the fact that it is difficult to have both electricity energy conservation and carbon emissions reduction properties for BEPVs at low temperatures in the provinces of North China, Northeast China and Northwest China.

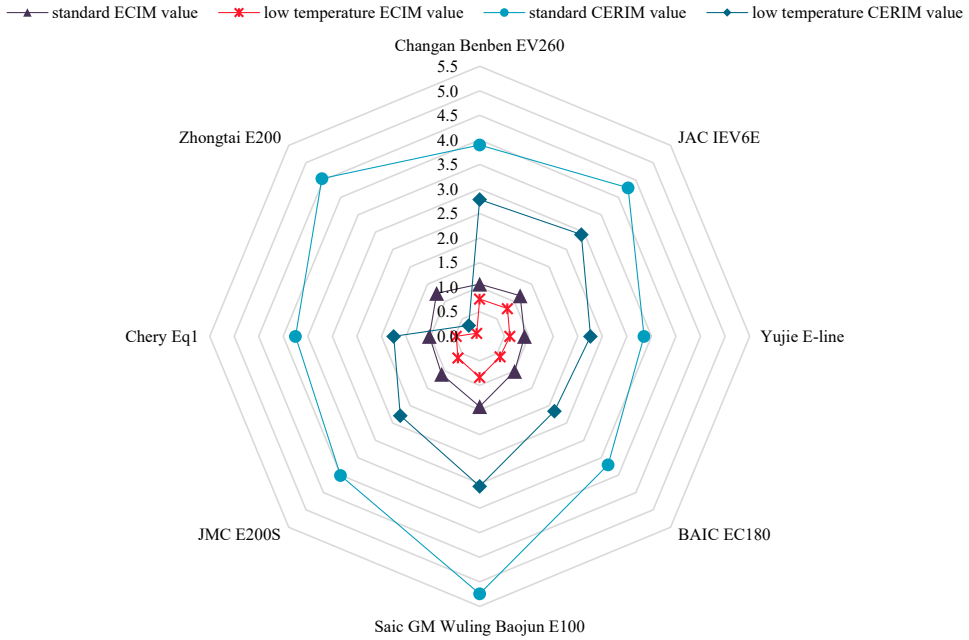


Figure 14. A00+A0 level BEPVs' ECIM values and CERIM values in low temperature.

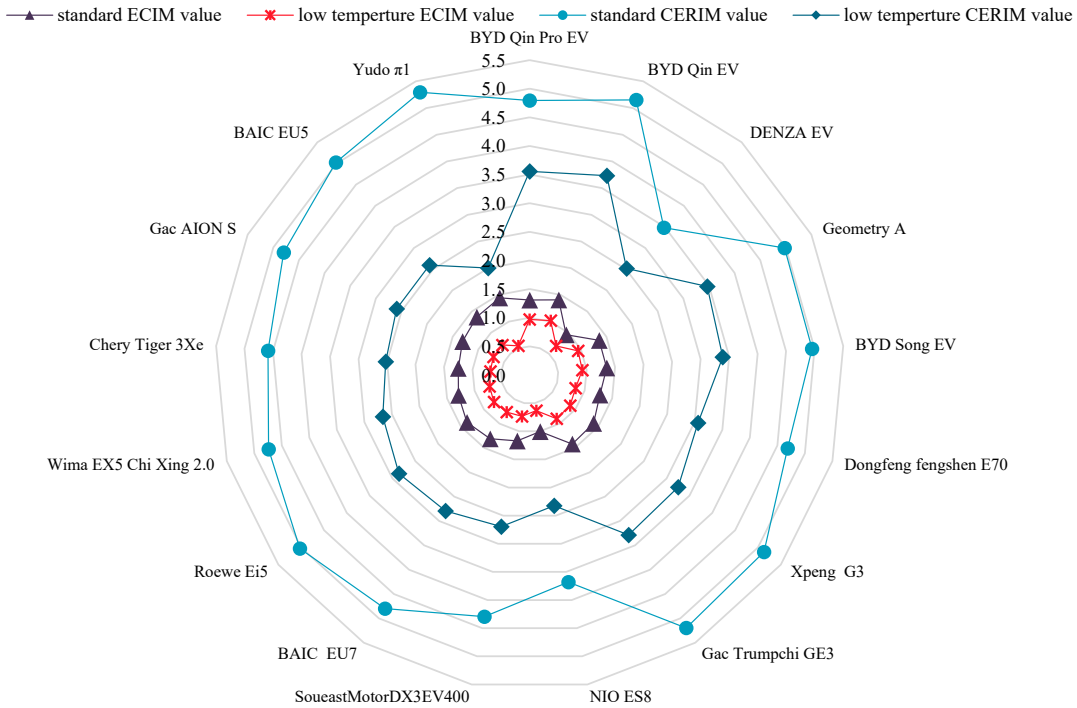


Figure 15. A level and B level BEPVs' ECIM values and CERIM values in low temperature.

5.6. Sensitivity Analysis of Low Temperature Endurance Mileage Accuracy on Electricity Energy Conservation and Carbon Emission Reduction Capability of BEPV

According to Figure 16a, only two A-level BEPV types show less sensitivity to the low temperature endurance mileage accuracy, whereas most BEPV types show increased electricity energy consumption per 100 km. The B level BEPVs' ECIM values are seriously affected by the low temperature endurance mileage accuracy, losing their energy conservation function, with electricity energy consumption three to five times that of ICEVs. In particular, for BYD Qin ProEV, Geely Geometry A and Xpeng G3, ECIM values have similarity only when considering the influence of low temperature factor on the endurance mileage. However, their ECIM values decrease, whereas their electricity energy consumption increases successively when the low temperature endurance mileage accuracy parameter is added. Therefore, the electricity energy conservation capability of BEPVs should be evaluated from various perspectives.

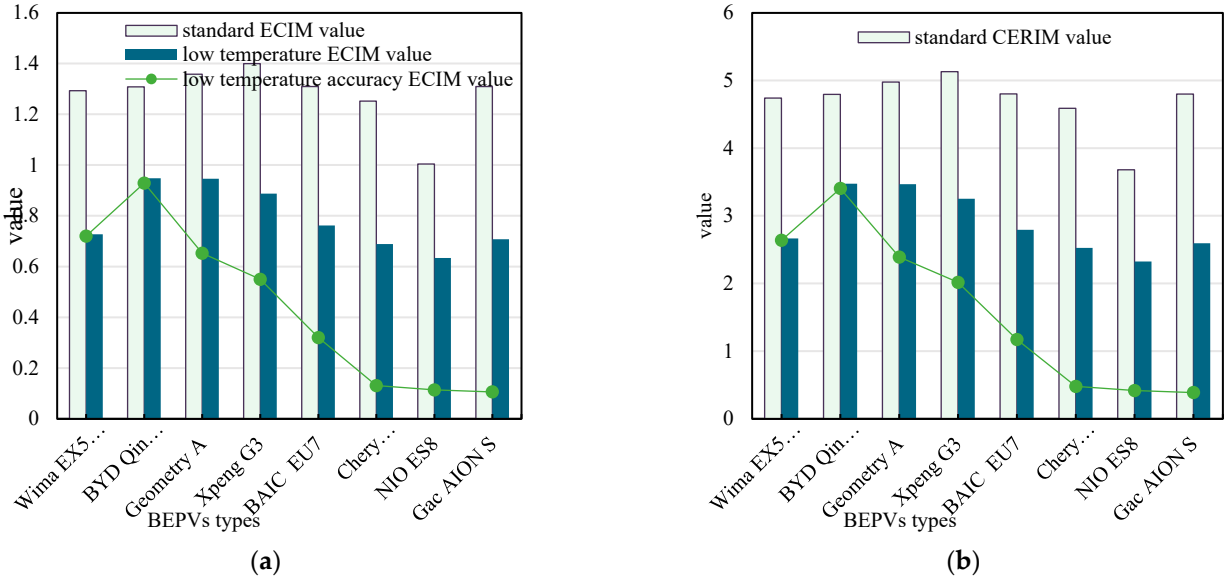


Figure 16. BEPVs' ECIM values (**a**) and CERIM values (**b**) considering low temperature endurance mileage accuracy.

As shown in Figure 16b, it can be intuitively concluded that the low temperature endurance mileage accuracy factor slightly reduces the carbon emission reduction ability per 10,000 km of some A level BEPVs types. Their carbon emissions are still lower than those of ICEVs, and their carbon emission reduction ability is relatively excellent. The emission reduction capability per 10,000 km of the three BEPV types under standard temperature scenarios is 2 to 2.5 times that of ICEVs. However, their carbon emission reduction advantage is weakened but still apparent when the endurance mileage is reduced because of low temperature. Their carbon emissions per 10,000 km are higher than those of ICEVs after adding the low temperature endurance mileage accuracy factor, and the advantage disappears. Therefore, only some A level BEPVs types are suitable for promotion in the northeast and northwest regions to achieve the goal of carbon emissions reduction in the road transportation industry nationwide from the perspective of carbon peaking and carbon neutralisation, and with the existing vehicle technology level.

6. Conclusions

In this study, an ECIM is established to assess the electricity energy conservation and carbon emission reduction characteristics of existing multilevel BEPVs in the Chinese market. This model considers the electricity energy consumption per 100 km of BEPVs from the perspective of the fuel whole life cycle, using the energy consumption of ICEVs with the same level as the reference object. A CERIM is established to measure the carbon

emissions reduction ability of best-selling BEPV types at all levels in China from 2018 to 2020. The results show that the carbon emission reduction capability of BEPVs is relatively excellent although their electricity energy conservation capability is largely unsuccessful. Specifically, the average ECIM values of A00+A0 entry-level and A level universal BEPVs values are still greater than or equal to one, indicating that they have an obvious electricity energy saving capacity. The carbon emission reduction abilities of all levels of BEPVs are excellent.

From the perspective of the fuel whole life cycle, the influence law of comprehensive electricity generation efficiency on the electricity energy consumption per 100 km of all levels of BEPVs is predicted to explore in 2025, 2030 and 2035. The interaction relationship between BEPVs' carbon emissions per 10,000 km and the proportion of thermal power is examined in 2025, 2030 and 2035. Increasing the proportion of renewable energy generation is one of the reliable means to improve the electricity energy conservation of BEPVs.

The mileage credibility, regional mileage credibility, low temperature and low temperature endurance mileage accuracy parameters are further explored to verify the electricity energy conservation and carbon emissions reduction potential of BEPV in the actual driving environment. The higher the level of BEPVs, the more remarkable the negative impact of mileage credibility on their energy conservation performance. It is noteworthy that for some provinces in south China and southwest China, regional mileage credibility can enhance the electricity energy conservation and carbon emissions reduction effect of some A00+A0 and A level BEPVs types. For B level BEPVs, the electricity energy consumption per 100 km will be higher than that of ICEVs when the regional mileage credibility is considered.

In low temperature environment, the electricity energy conservation abilities of all levels of BEPVs are weakened, but they still have the ability to reduce carbon emissions. When the factor of low temperature endurance mileage accuracy is further analysed, the carbons emissions per 10,000 km of most BEPVs are higher than those of ICEVs. Therefore, the promotion of BEPVs in provinces and regions with winter temperatures below $-7\,^{\circ}\mathrm{C}$ may lead to energy waste and increased carbon emissions.

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Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

ICEV	internal combustion engine vehicle
ECIM	electricity conservation index model
CERIM	carbon emissions reduction index model
WTW	well-to-wheel
WTP	well to pump
PTW	pump to wheels
km	Kilometer

Appendix A

Figure A1 shows the average electricity energy consumption per 100 km of A00+A0, A and B level BEPV from 2018 to 2020 from the perspective of the fuel whole life cycle. When the comprehensive electricity generation and transmission efficiency are identified as crucial factors, the electricity energy consumption per 100 km of all levels BEPVs has exceeded 25 kW·h/100 km. The 2018 B-level has the highest electricity consumption among all levels of BEPVs, with an average value of 47.02 kW·h/100 km. Along with the improvement of vehicle technology year by year, the electricity consumption per 100 km of all levels BEPVs have shown a downward trend, with the B level high-end BEPV exhibiting the largest drop in electricity consumption.

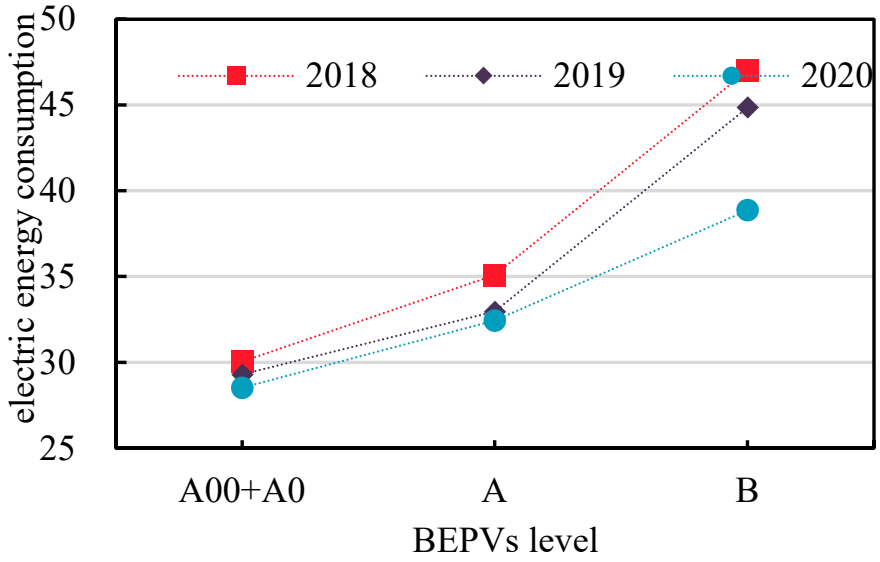


Figure A1. BEPVs' electricity energy consumption.

Figure A2 shows the average carbon emissions per 10,000 km of all levels of BEPVs from 2018 to 2020. In 2018, B-class high-end BEPV has the highest average carbon emissions per 10,000 km of about 1570 kg. In 2020, the A00+A0 level entry BEPVs have the minimum average carbon emissions per 10,000 km of 931 kg.

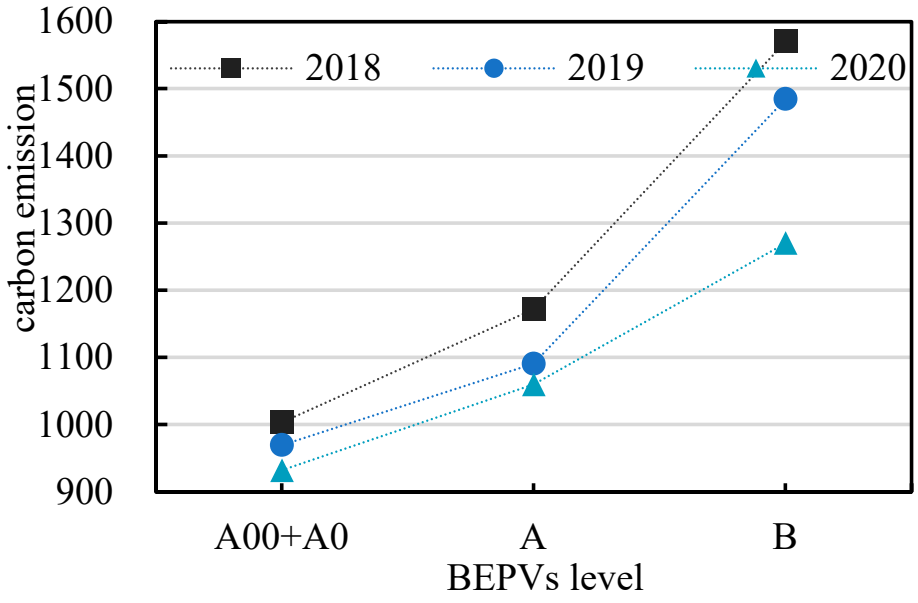


Figure A2. BEPVs' carbon emission.

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