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Evaluation of Performance and Technological Characteristics of Battery Electric Logistics Vehicles: China as a Case Study

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Abstract: The powertrain characteristics of battery electric logistics vehicles (BELVs) are extremely suited for the urban driving context and have a higher environmental protection potential for sustainable development, which can provide solutions for urban logistics decarbonization. The BELV is an important part of the Chinese national new-energy vehicle program, and the market penetration of BELVs has greatly improved. However, BELVs still have many technical shortcomings, which seriously affect their widespread acceptance. Therefore, it is necessary to reveal the technological characteristics and development direction of BELVs based on a large amount of marketing and technological data. This research reviewed the Chinese incentive policies and industrialization progress of BELVs. An evaluation system comprising 8 technological indicators for evaluating BELV technological progress was proposed. The distribution characteristics of the curb mass, vehicle volume, all-electric range, top speed, driving power, energy efficiency, traction battery and motor technology were analyzed for 2017 and 2019 markets' models. The vehicle total cost, vehicle performance and reliability of BELVs are not advantageous yet. However, all the performance parameters are improving year by year, constantly meeting logistics demands. The subsidies are needed for longer for the market to mature. Finally, several suggestions for the technical development direction of BELVs were proposed. All these results can be used to improve the vehicle performance, reliability and market penetration of BELVs.

Keywords: battery electric logistics vehicles; vehicle performance; technological characteristics; evaluation; all-electric range; energy efficiency; traction battery; subsidy

1. Introduction

City logistics face the major challenge of the rapid growth of express delivery businesses and the additional air pollution caused by diesel technology applied for it. The volume of the Chinese express delivery market is notable. The business volume exceeds the total volume of developed economies in the United States, Japan and Europe, accounting for more than 50% of the global market share of express packages [1]. The volume of express delivery business has ranked first in the world for five consecutive years, which is the power source and stabilizer for the development of the global express package market. The problem of air pollution caused by vehicle emissions is becoming increasingly prominent. In 2018, the number of diesel trucks in China was 18.18 million, accounting for only 7.9% of the total number of vehicles, but the emission of nitrogen oxides (NO_x) from these trucks accounted for 72.6% (3.789 million tons) of the total emissions. The emission of atmospheric particulate matter (PM) from these trucks accounted for more than 90% of the total PM emissions from

all vehicles [2]. Therefore, solving the air pollution problem of freight vehicles is the top priority of Chinese environmental protection work.

The strategic transformation of the energy structure of China is imminent. China has long relied heavily on crude oil imports. In 2013, China surpassed the United States as the largest importer of gasoline and other liquid fuels. According to the China Energy Development Report of 2018, in 2017, Chinese crude oil imports totaled 420 million tons, and oil dependence on foreign countries increased by 2.4% to 67.4% year upon year, and even increased to 70.9% in 2018 [3]. There is an urgent need to reduce the Chinese energy dependence on foreign countries and realize the strategic transformation of its energy structure. Against the background of environmental and energy pressures and promotion of new technology development, many countries around the world, including China, have proposed exit schedules of fuel vehicles and provided relevant industrial policies to support the development of new energy vehicles (NEVs) [4]. NEVs include NE passenger cars (category M1 in Europe), NE buses and NE special purpose motor vehicles, among which special vehicles include logistics vehicles, postal vehicles and sanitation vehicles.

In 2018, the Chinese market accounted for 56% of the total sales of NEVs worldwide. The number and market penetration of NEVs in China is shown in Figure 1. By the end of 2019, the number of NEVs was 3.81 million. The growth rates from 2015 to 2019 were 430%, 133%, 90%, 63% and 46%, respectively [3]. Although Chinese NEVs have experienced four years of rapid growth, in general, the proportion of NEVs in the whole Chinese car industry is 1.09%, which is extremely low and has broad market prospects.

Figure 1. Industrial progress of new energy vehicles (NEVs) in China.

The number of new energy logistics vehicles (NELVs) in China is also increasing year by year. By the end of June 2019, the number of NELVs was 0.36 million. The penetration rate is 1.34%, which is higher than the overall penetration rate of NEVs. Despite declining NEV subsidies and the sluggish growth of new energy buses (NEBs), NELVs have bucked the trend, and their output has risen sharply. The main driving factors include favorable policies, improvement of the NEV technology level, public awareness of environmental protection and market awareness.

Concerns about the environmental impacts of urban mobility have led to the development of alternative solutions, such as BELVs, which are highly applicable to certain sectors, namely urban logistics, since the powertrain characteristics of BELVs are extremely suited for the urban driving context [5]. BELV operation may contribute to decarbonization of urban logistics [6].

Despite these advantages, BELVs face notable challenges. The batteries have a lower energy density than internal combustion engine trucks (ICETs), which is why the range of these vehicles is limited. The recharging of batteries is time consuming, and the charging point infrastructure must be suitably in place before any market penetration, and the corresponding investment is important. The most difficult issue, however, is social acceptance of these vehicles, which is the last large hurdle

for BELVs before penetrating the market to a large extent [7]. Their high capital cost is a barrier for consumers, and the range anxiety is perhaps the most important obstacle. Because the BELV range is smaller than that of ICETs and charging takes time, consumers worry that they will not be able to complete their journey [8]. An inadequate charging infrastructure exacerbates this problem [9–11]. However, as for most governments, Chinese roadmaps play an important role in promoting battery electric vehicles (BEVs) because of their high potential for technological improvement [12]. BELVs are an important part of the Chinese NEV program. At present, BELVs account for the majority of the Chinese NELV market, and BELVs account for 99% of the total NELVs [13]. In addition, new business models have been developed to compensate for some of their shortcomings, and policies have been implemented to support their development [14,15].

However, the barriers for further development still exist. Previous research on NEVs have focused on life-cycle emissions, market penetration, energy efficiency, infrastructure, charging technology, etc. The main focus in the studies of the market penetration's influencing factors is on the perspective of customer behavior [16–19] and economic cost [20–26]. Lishan et al. conducted a consumer satisfaction survey about the people who have EVs in China, and found that the policy of “No traffic restrictions for EVs”, charging infrastructure availability and technical support were the most important factors influencing the EVs users' preference [19]. Zhang et al. found that technical and policy improvements were more effective than improving the battery capacity at increasing the adoption potential of BEVs [16]. Yong et al. proposed a fuzzy-set qualitative comparative method to analyze the factors influencing the EV deployment, and stated that an effective policy mix needs to be promoted [17]. Hardman et al. stated that incentives were an effective policy measure in increasing plug-in electric vehicle (PEV) sales [18]. Other studies have reported that the cost competitiveness of BEVs is critical to their market success, so the impact of subsidies on BEV penetration was analyzed from an economic perspective. Based on simulations and literature reviews, these studies focused on the interaction between fiscal policy and customer acceptance and the resulting impact on market penetration [20–26]. In addition to policy, infrastructure development and charging technology were also identified as key factors in the rapid promotion of BEVs [9–11,27]. For example, Longjian et al. proposed a multi-agent-based pricing strategy for electric vehicle charging, considering customer satisfaction degree [27].

The above analysis of market penetration is EV-oriented and does not differentiate between electric cars, BELVs and battery electric buses (BEBs). BELV is considered as a possible alternative to the fuel-based logistics mode. Recent research focused on economic feasibility [28–31], benefit estimation [29,32–35], business mode [15], charging mode [9–11], policy support [36], competitive power [37], investment risk [38], dynamics [39] and barriers [40–42]. Juan et al. identified some research challenges related to the promotion of NELVs, including: (1) environmental-related issues, and (b) strategic, planning and operational issues [35]. More studies have analyzed the use of BELVs in urban delivery and assessed the social, environmental and economic impacts [29,34,43]. Teoh comparatively analyzed the fuel and energy used by BELVs during transportation under several scenarios with different charging strategies and charging technologies and calculated the life-cycle cost of the operation and the impact on CO₂ emissions. His study found that the use of charging strategies significantly reduced life-cycle costs and did not have any strong negative impact on CO₂ emissions [10]. To encourage the use of BELVs, Lebeau investigated users' choice intentions towards BELVs, using a joint-based choice analysis to understand the interaction between choice influencing factors and evaluate the trade-offs between BEV attributes in urban freight companies. Some effective policies to stimulate BEV adoption by users based on their preference structure were proposed [40]. Yong et al. explored Chinese logistics dispatchers' preference in electric tricycle-related policies [44].

Nonetheless, there have been few studies on BELV technology [8,45–49]. Mahmoudzadeh et al. analyzed the technological readiness of the different components of BEVs, including batteries, electric motors, power electronics, weight and aerodynamics characteristics, range extenders, super capacitors and charging options [8]. Sun summarized key technologies regarding batteries, charging technology, electric motors, control features and charging infrastructure of BEVs [45]. Research has focused on

the technology of BEBs based on a large amount of technological data for all the models on the market [46–48]. Du et al. analyzed the distribution characteristics of the curb mass, top speed, driving power, all-electric range and energy consumption based on a large number of actual BEB models and their operational data [47]. Du et al. further focused on the comprehensive evaluation method of addressing the inner influencing principle of technological specification mentioned in a new subsidy scheme on the technological development direction of BEBs [48].

It could be seen that there has not been any research that has tracked the development of the BELVs based on the vehicle performance and technological data of all the market's models, which is the main objective of this research.

The Chinese BELV industry is characterized by multiple models (minivans, light trucks and light buses), different business models and various charging modes [13]. By the end of 2019, the BELV's market share had reached 99% of the NELV sales, indicating that there was a large amount of technological data available for analysis that could help to better understand BELV technology and its market development. However, a comprehensive study on the Chinese progress in BELV technology and industrialization has not yet been conducted. There are still many technical shortcomings in BELVs, which seriously affect the widespread acceptance of them. Therefore, it is necessary to reveal the status quo and development direction of the technical performance of BELVs based on extensive market and technical data and evaluate the impact of state financial subsidies on the development of BELVs.

To fill these knowledge gaps, this study aimed to comprehensively study the technical development of BELVs in China by using extensive marketing and technological data. After analyzing the market penetration's influencing factors of BELVs, a system to evaluate BELVs technological progress is proposed. The vehicle performance and battery motor technologies of BELVs are evaluated for BELV models. Finally, the key challenges and suggestions for the BELV industry development are identified.

This paper is structured as follows. Section 2 reviews the incentive policies for BELVs in China. Section 3 evaluates the overall state of BELV industrialization and analyses market penetration's influencing factors. Section 4 examines the progress of BELV technology based on the market's models. Section 5 analyzes the challenges and suggestions to BELV technologies and industrialization. Conclusions are provided in Section 6.

2. Review of BELV Incentive Policies

China has been promoting the application of NEVs in three phases since 2009. The first phase (2009–2012) of the promotion of NEV applications in China was focused on support and acquisition subsidies for NEB in 13 cities [50].

In the second phase (2013–2015), the area of application was expanded to 88 cities, and BELVs began to be promoted and applied [51]. The incentive policies of BELVs mainly focus on the national financial subsidies. In addition to the purchase subsidy, three subsidy policies were proposed: exemption from vehicle purchase tax from 2014 [52], exemption from travel tax from 2015 [53] and access to supportive electricity price from 2014 [53].

The third phase (from 2016 onwards) will extend the application to the whole country [54]. In September 2019, the Central and State Council of China issued an outline of building a powerful transportation industry, which requires that all urban logistics vehicles achieve electrification, new energy and cleanliness by 2035 [55].

The BELVs must meet certain technical standards to qualify for the purchase subsidy, exemption from the purchase tax and travel tax [50–53,56–58]. The technical standards are mainly based on three indicators: battery energy density, energy consumption and all-electric range (AER). The national subsidy standard and technical standards for BELVs from 2009 to 2022 are summarized in Table 1.

Table 1. The national purchase subsidy standards and technical standards for battery electric logistics vehicles (BELVs) from 2009 to 2019.

Year	Subsidy Standard	Energy Density, Wh/kg	Energy Consumption, Wh/(km·kg)	All-Electric Range (km)
2009–2012	60,000 RMB per new energy light commercial vehicle	/	/	≥50
2013–2016	2000 RMB/kWh (2013), 1900 RMB/kWh (2014), 1800 RMB/kWh (2015, 2016)	/	/	≥80
2017	1500 RMB/kWh for the part below (and including) 30 kWh 1200 RMB/kWh for the part between 30 and 50 (including) kWh 1000 RMB/kWh for the part above (and including) 50 kWh	≥90	≤0.5	≥80
2018	850 RMB/kWh for the part below (and including) 30 kWh 750 RMB/kWh for the part between 30 and 50 (including) kWh 650 RMB/kWh for the part above (and including) 50 kWh	≥115	≤0.4	≥80
2019	350 RMB/kWh	≥125	≤0.3	≥80
2020–2022	315 RMB/kWh (2020), 252 RMB/kWh (2021), 176 RMB/kWh (2022)	≥125	≤0.29	≥80

As shown in Table 1, the technical standards of battery energy density and energy consumption have been increased year by year. In recent years, the requirement for AER is 80 km or more. The national subsidy amount was 60,000 RMB per new energy light commercial vehicle before 2012. Since 2013, the state subsidies have been declining year by year. Subsidies for BELVs based on the battery's capacity were first proposed in 2013. From 2017 to 2018, the subsidy was issued as sectional excess and accumulation. On 23 April 2020, four ministries issued the notice on improving financial subsidy policies for the promotion and application of new energy vehicles, which specifies that the subsidy period will be extended to 2022, and determines that the subsidy rates for 2020–2022 will be reduced by 10%, 20% and 30% from the previous year, respectively [57].

3. Analysis of Market Penetration's Influencing Factors for BELVs

3.1. Industrialization Progress

Both the number and market penetration of NELVs in China are increasing year by year, which is evident in Figures 2 and 3, respectively. The growth rates from 2015 to 2018 were 643%, 140%, 155% and 25.6%, respectively [13]. Both NEVs and NELVs experienced a steep growth in 2015. The growth rate of NEVs has decreased year by year since 2016, but the growth rate of NELV vehicles has continued to increase since 2016. Based on the data released by the Traffic Administration of the Ministry of Public Security, the number of NELVs was 0.36 million by the end of June 2019 [3]. The penetration rate of NELVs is also increasing year by year. By the end of June 2019, the penetration rate was 1.34%, which is higher than the overall penetration rate of NEVs.

Figure 2. Industrial progress of new energy logistics vehicles (NELVs).

Figure 3. Penetration rates of NELVs and NEVs.

3.2. Market Penetration's Influencing Factors

Despite declining BELV subsidies, the NELV industry has bucked the trend, and its output has increased sharply. The main driving factors include favorable policies, improvement of the NEV technology level, public awareness of environmental protection and market awareness.

- Policy promotion

The incentive policies have promoted the growth of NELVs. From 2013, relevant policies on the promotion of NELVs were introduced for the first time [51], and NELVs began to be applied. From 2016 onwards, the promotion began to extend the application to the whole country. As seen from Table 1 and Figure 3, the growth of market penetration rates is closely related to the subsidies. In addition to the subsidy policies mentioned in Section 2, the guarantee for the right-of-way is also adopted to guide the transition from ICETs to NEVs. The pilot areas of NEV promotion put forward measures such as simplifying the licensing procedures, opening the right-of-way and preferential parking fees to guarantee the right-of-way. Since 2018, China has promoted the demonstration project of urban green delivery in 22 cities, which also strongly promoted the development of NELVs, and another 24 cities are involved in the second batch of demonstration projects announced at the end of 2019.

- Improvement of the NEV technology level

Domestic pure electric vehicle technology is gradually approaching the international advanced level. For example, the driving range reliability, safety and power level have been continuously improved. With the continuous optimization of comprehensive benefits, the capacity of large-scale commercial promotion has gradually been established.

- Public awareness of environmental protection

With the increasing awareness of environmental protection, the public has increasingly realized the importance of environmental protection and actively participates in social supervision of environmental protection.

- Market awareness

Commercial vehicle fleets constitute a favorable entry for BEVs into the transport system [41]. In terms of market recognition, the right-of-way, cost and social responsibility promote companies to choose NELVs. Compared with ICETs, NELVs have clear advantages in terms of the right-of-way, data collection ability, notable oil and electricity price differences, easy management, etc., which provides value to NELV users in operation optimization. NELVs can obtain more rights-of-way because of their little impact on local air pollution, so they can reduce the costs for urban distribution companies. BELVs have their own complete data collection system and can collect real-time online data, which plays an important role in optimizing the operation efficiency of companies and reducing costs. China has defined the public data acquisition technical specifications for NEVs and charging infrastructure. This technical specification requires 61 real-time upload data, including 10 driving motor data, 3 vehicle position data, 3 engine data, 11 vehicle data, 12 fuel cell data, 12 extreme value data and 10 alarm data [59]. NEVs in the public service field are required to upload data in real time, and NEVs in the private sector report on demand [59]. Since 2018, Shenzhen, China, has carried out hierarchical management and given priority of the right-of-way to NELVs that have voluntarily installed radio frequency identification devices, accessed global position system data and accepted electronic filling [60]. The price difference between fuel oil and electricity is distinct. Oil prices are relatively stable, with little room for fluctuations. However, the difference in electricity prices between different regions and periods is very large, which leads to much space for cost optimization. BELVs can substantially reduce the workload of vehicle management departments, and power consumption management is easier than oil management. In summary, NELVs have become an important means for promoting the transformation and development of freight logistics. Domestic logistics companies have issued logistics electrification plans. Among them, Chinese Post, Jingdong, Shunfeng, Yuantong, Suning and other companies play a leading role in the application of NELVs. Chinese Post expects to achieve 100% of new NELVs in cities by the end of 2020. Jingdong logistics will replace all logistics vehicles in Tianjin and Hebei with BELVs, and Shunfeng planned to promote tens of thousands of NELVs, more than half of which will be operated in cities such as Beijing, Guangzhou and Shenzhen serving trunk, branch and terminal distribution. Cainiao proposed to realize city-wide distribution of NELVs in 100 cities by the end of 2020.

3.3. Distribution of the NELV Market

NELVs include battery electric logistics vehicles (BELVs), range-extended electric logistics vehicles (REELVs), plug-in hybrid electric logistics vehicles (PHELVs), fuel cell electric logistics vehicles (FCELVs) and energy storage trolleybuses (ESTBs). Among them, because of range limitations, the first four are suitable for urban logistics, while the last one is suitable for intercity logistics. In China, the number of BELVs accounts for the vast majority. In 2017, the total number of BELVs was 145,930, and the total number of the other vehicles was 840 [13]. The major reason is the price gap between the manufacture retail price (MRSP) and the post-subsidy price resulting from subsidy policies. Figure 4

shows a price comparison of four light trucks in 2017. After subsidy, the price of BELVs is significantly lower than that of the other three kinds of vehicles. Therefore, all manufacturers basically choose to promote BELVs, and BELVs thus account for 99%.

Figure 4. Price comparison of four light trucks in 2017.

According to the recommended catalogue of NEVs issued by the Ministry of Industry and Information Technology, NELVs include battery electric van-type transport vehicles, battery electric rail-type trucks, battery electric refrigerated vehicles, battery electric bin grid transport vehicles, battery electric traction vehicles and battery electric semi-trailer traction vehicles. The NELV model composition is very complex. Generally, for the convenience of statistics, trucks are usually divided into micro trucks, light trucks, medium trucks and heavy trucks, according to their weight. There are five types of NELVs according to weight in China: new energy minivans (NE minivans), new energy light buses (NE light buses), new energy minitrucks (NE minitrucks), new energy light trucks (NE light trucks) and new energy medium and heavy trucks (NE medium and heavy trucks). Figure 5 shows the market proportions of these five types of NELVs based on market penetration data. In 2017, NE minivans, light trucks and light buses accounted for 40%, 37.4% and 15.6% respectively, of the total market, at a combined share of 93%.

Figure 5. Annual numbers of the various types of NELVs.

NELVs have been widely used in the field of urban distribution. Limited by the current technical level of NELVs, NELVs are mainly light closed trucks and light van trucks, with AERs ranging from 200 to 300 km. Therefore, NELVs are mainly used in the field of urban distribution, especially in the last express delivery section. Upgrading the retail industry provides development opportunities for the development of NELVs. NELVs have gradually penetrated many industries, such as retail, medical, home furnishing, fresh produce and other industries.

4. Evaluation of Performance and Technologies for BELVs

4.1. Evaluation Method

BELVs are classified into detailed categories based on the above-mentioned definitions. The minivan, light bus and light truck account for more than 90% of the market share, and battery electric vehicles account for 99% of the market share. Therefore, the following technological characteristics focus on typical models of these three BELVs, including the battery electric minivan (BE minivan), battery electric light bus (BE light bus) and battery electric light truck (BE light truck).

This evaluation system consists of two components, namely, vehicle performance evaluation and battery motor technologies evaluation. Vehicle performance is the evaluation parameter for BELVs users, which includes 4 parameters: the curb mass (CM), vehicle volume, AER and top speed. Battery and motor technologies are the technical support provided by the manufacturer to achieve the above vehicle performance indexes, including driving power, energy efficiency, traction battery technology and traction motor technology. These 4 parameters are integrated with 4 battery and motor technologies to examine the technological progress associated with BELVs development.

The following evaluation analysis selected 2017 and 2019 data. The 2019 data is the most recent and reflects the latest vehicle performance and battery motor technology from BELVs in China. China's NELVs penetration rate started at over 1% in 2017 and has been growing steadily year by year [13]. The data for the 2017 BELVs market is therefore used to analyze vehicle performance and technology at the beginning of its life. The vehicle performance and technologies for 2017 and 2019 were analyzed separately and a comparative analysis was performed. While the 2017 and 2019 are only three years apart, the number of BELVs models has grown more [61]. This paper evaluated the performance of the vehicle by analyzing the vehicle performance parameters, battery motor technology and identified problems. We tried to explore the future development trend of battery motor technologies of BELV and make suggestions for improvement in accordance with the national technical requirements of BELVs.

The data of 2017 BELVs come from the 2018 development report of Chinese NELVs [13]. This report tracked the market's main selling models, including 3 BE minivans, 5 BE light trucks and 5 BE light buses models. The data of 2019 BELVs are sourced from a webpage [61], which provides a library of BELVs for the Chinese market, including 11 BE minivans, 20 BE light trucks and 28 BE light buses models.

4.2. Vehicle Performance

4.2.1. CM Distribution Characteristics

The CM of BELVs is largely influenced by the battery energy consumption rate. In 2017, the CM of BE minivans, BE light trucks and BE light buses was approximately 500–1000 kg, 1500 kg and 500–1300 kg, respectively [13]. In 2019, the average CM of BE minivans, BE light trucks and BE light buses were approximately 935 kg, 1381 kg and 1308 kg, respectively. The present CM distribution of various BELVs are shown in Figure 6, which could be seen that CM has grown in recent years.

Figure 6. Curb mass (CM) distribution of the various BELVs (2019).

Weight restrictions common in urban areas limit the access of certain BELVs that would have been authorized if they had been diesel powered. According to regulation GA802-2014 promulgated by the Public Security Ministry, the total mass of blue brand light trucks must be below 4500 kg, while the CM of internal combustion engine (ICE) light trucks is usually 3000 kg. According to the subsidy policy for NEVs released by the state in 2018, the indicator of the energy consumption per unit of mass (E_{kg}) must reach 0.35 Wh/(kg·km) to enjoy full subsidies. To meet the E_{kg} requirements, the actual dead mass of the NE light truck must be below 2910 kg, so the CM of NE light trucks is 1500 kg, only half of that of ICE light trucks. The inevitable reality is that BELVs are much heavier than ICE trucks and buses of an equivalent size. This occurs because of the large mass of the large-capacity batteries due to their limited energy density, as low as 0.35 Wh/(kg·km).

4.2.2. Vehicle Volume Distribution Characteristics

The vehicle volume can reflect the CM. The volumes of various BELVs are shown in Figure 7. At present, the volumes of BE minivans, BE light trucks and BE light buses are approximately 5 m³, 17 m³ and 8.5 m³, respectively. Both BE minivans and BE light trucks have increased in volume but BE light buses have decreased in volume.

Figure 7. Volume distribution of the various BELVs, (a) 2017 and (b) 2019.

4.2.3. AER Distribution Characteristics

According to survey data, 86% of urban logistics customers' average daily mileage is basically below 200 km, but approximately 70% of customers indicated that due to business reasons, the driving mileage over approximately 1–2 days in a 10-day period can exceed 200 km [13]. The AER is a very important parameter for BELVs users [8,47].

The official AER for BELVs operating in China is shown in Figure 8. In 2019, the average AER for BE minivans, BE light trucks and BE light buses were approximately 255 km, 241 km and 233 km, respectively. As seen from the data of 2017 and 2019, all BELVs have increased in AER in recent years. The AER of BELVs currently on the market are 80 km or more that meet the requirements of the national technical standards listed in Table 1.

Figure 8. All-electric range (AER) distribution of the various BELVs, (a) 2017 and (b) 2019.

In addition, due to battery attenuation every year, the actual AER decreases rapidly year by year, which makes it difficult to truly meet the logistics demand [13]. AER anxiety is particularly prominent in intercity logistics. Most of intercity logistics transportation relies on heavy trucks driving on highways, and the daily miles travelled often exceeds 600 km. However, there are currently no BE heavy trucks on the Chinese market with AER of 600 km or more.

4.2.4. Top Speed Distribution Characteristics

Top speed is considered the main parameter of dynamic performance for BELVs [47]. The top speed distribution of the various BELVs is shown in Figure 9. The present average top speed of BE minivan, the BE light truck and BE light bus is 95 km/h, 89 km/h and 100 km/h, respectively. The National Technical Committee for road transport standardization issued technical requirements for the selection of electric freight vehicles (Exposure Draft), in which the top speed in 30 min shall be increased to no less than 80 km/h [62]. For vehicles with a total mass below 4500 kg, the acceleration time from 0 to 50 km/h shall be no more than 10 s, while the acceleration time from 50 to 80 km/h shall be no more than 15 s. For vehicles with a total mass of at least 4500 kg, the acceleration time from 0 to 50 km/h shall be no more than 15 s, and the acceleration time from 50 to 80 km/h shall be no more than 20 s.

Figure 9. Top speed distribution of the various BELVs.

4.3. Battery and Motor Technologies

4.3.1. Driving Power Distribution Characteristics

Driving power is also considered the main parameter of dynamic performance for BELVs [47]. A plot of the driving power is shown in Figure 10. In 2017, the BE minivan had an average driving power of approximately 45 kW, while the BE light truck and BE light bus are both rated at 55 kW. In 2019, the BE minivan, the BE light truck and BE light bus had an average driving power of approximately 32 kW, 58 kW and 48 kW, respectively.

Figure 10. Driving power distribution of the various BELVs, (a) 2017 and (b) 2019.

4.3.2. Energy Efficiency Distribution Characteristics

With regard to the vehicle performance of BELVs, the energy consumption rate is an important parameter [8]. This parameter is expressed as E_{kg} in the following Equation (1):

$$E_{kg} = \frac{E}{M} \quad (1)$$

where E_{kg} is the energy consumption per unit of mass, Wh/(km·kg), M is the additional mass transported, kg, and E is the electricity consumption rate, Wh/km. Both values are measured according to the Chinese national standard (GB/T) 18386-2017.

According to GB/T 36980-2018, the energy consumption rate of an N1 BEV with a maximum design total mass not exceeding 3500 kg is limited. However, there is no energy consumption limit for BEVs with a maximum design total mass exceeding 3500 kg.

The National Technical Committee for road transport standardization issued technical requirements for the selection of electric freight vehicles (Exposure Draft), in which the energy consumption per unit of mass is required to not be higher than 0.45 Wh/(km·kg) [62].

E_{kg} is a compound evaluation indicator used to determine the subsidy amount. The E_{kg} value of BELVs needs to be reduced. There is national technical standard to limit the E_{kg} value of BELVs, and the national subsidy policy reflects the limit. The subsidy of BELVs is based on the battery's capacity, which provides the driving power, and the subsidy is issued by sectional excess accumulation. In the notice of 2018 [58], it is stipulated that if the E_{kg} value is higher than 0.4 Wh/(km·kg), no subsidies will be granted, if the E_{kg} value ranges from 0.35 to 0.4 Wh/(km·kg), a subsidy of 0.2 times will be issued, and if the E_{kg} value is 0.35 Wh/(km·kg) or lower, the full subsidy amount will be granted. In the new policy of 2020 [57], it is stipulated that if the E_{kg} value is higher than 0.29 Wh/(km·kg), it will not be subsidized.

Reducing the value of E_{kg} is the trend, and it is more challenging. In the future, improvements in lightweight technologies, thermal pump air conditioning and regenerative braking have a high potential for decreasing BELV energy consumption [47].

4.3.3. Traction Battery Technology

Lithium iron phosphate (LFP), nickel cobalt manganese (NCM) and lithium manganese oxide (LMO) batteries are the primary energy storage systems (ESSs). The market shares of the various ESSs are shown in Figure 11. LFP batteries have a better safety performance and charging cycle performance than NCM batteries [48]. In 2016, LFP batteries accounted for 84% of the market share. The ESS of NCM batteries gradually occupy the BELV market due to its higher energy-density performance, higher power density and better low-temperature performance, with its market share increasing from 6% to 39% over 4 years [13]. The energy density of the NCM battery has been increasing year by year, and from 2015 to 2018, it was 160, 180, 210 and 230 Wh/kg, respectively [13]. With the gradual improvement of NCM technology, strict technical regulations and lightweight trends of logistics vehicles, NCM batteries will dominate the market in the medium terms [13].

Figure 11. Market share of the various energy storage systems (ESSs) for BELVs.

As shown in Figure 12, the minimum battery capacity of BE minivan, BE light truck and BE light bus was approximately 40 kWh, 70 kWh and 68 kWh, respectively.

Figure 12. Battery capacity distribution for BELVs (2017).

On the one hand, the energy density of the battery is constantly increasing to reduce the battery self-weight. On the other hand, due to the battery production technology and scale effect, the battery cost is also decreasing. The battery price decreased to 1300 RMB/kWh in 2018, down more than 50% compared with that in 2015 [63]. At the same time, the national subsidy standard is determined by the battery's capacity, and state subsidies are also decreasing year by year, as indicated in Table 1.

4.3.4. Traction Motor Technology

In Chinese market, there are four types of BELV traction motors: (1) permanent magnet synchronous motors, (2) direct current (DC) brushless motors, (3) alternating current (AC) induction motors, and (4) permanent magnet reluctance motors. With the rapid development of motor controller technology in China, it has gradually reached the level of that of foreign-funded companies. Table 2 lists the technical index changes of the motor controller from 2010 to 2018 [13,64].

Table 2. The technical index changes of the traction motor controller from 2010 to 2018.

Index	PRIUS—2010	CAMRY—2013	BOSCH—2015	Domestic Prototype—2018
Power Density (kW/L)	11.1	19	12.8	25
Power-to-Weight Ratio (kW/kg)	16.7	17.2	10.5	16
Power Semiconductor Device Type	IGBT	IGBT	IGBT	IGBT
DC Voltage Range (V)	200–600	200–600	300–480	300–480
Maximum Current (A)	500	550	660	800

IGBT means Insulated Gate Bipolar Transistor.

All 2019 BELVs models use the permanent magnet synchronous motors. Based on the changes of the technical indicators of the traction motor controller, the traction motor controller is developing towards the direction of high integration, high power density, high reliability and high safety.

5. Challenges and Suggestions

5.1. Vehicle Performance and Reliability Issues Associated with BELVs

The vehicle performance and reliability of currently used BELVs in the field of urban distribution are disadvantageous. Technical deficiencies lead to numerous problems, such as safety issues caused by misleading vehicle technical indicators, and the utilization rate of these vehicles is lower than that of fuel vehicles. The details are as follows.

(1) Vehicle performance comparison between BELVs and ICETs

As presented in Section 4, compared with the same types of ICETs, the vehicle performance and reliability of currently used BELVs in the field of urban distribution are not beneficial, in terms of the CM, AER and energy efficiency. But all three parameters are improving year by year, constantly meeting logistics demands.

The payload of BELVs is significantly smaller than that of ICETs. For example, the CM of an NE light truck is 1500 kg, only half of that of an ICE light truck.

Seen from the data of 2017 and 2019, all BELVs have increased in AER in recent years. At present, the range anxiety of BELV customers is not prominent. The relevant national standards have imposed requirements on the energy consumption per unit of mass (E_{kg}), and the relevant national subsidy policies also include corresponding subsidy standards according to the E_{kg} value. Reducing the E_{kg} value is the trend, which has proven to be more challenging. In the future, improvements in lightweight technologies, thermal pump air conditioning and regenerative braking have a high potential for decreasing BELV energy consumption [36].

(2) Loss of trust in vehicle technical indicators leading to safety issues

The actual data of the CM, AER and E_{kg} of BELVs produced by some automakers are not trustworthy. For example, there is a large gap between the actual and official AER data of some BELV models, which makes it impossible for BELV users to use this parameter to evaluate vehicle performance. In addition, some vehicle brands omit spare wheels to achieve the CM and load utilization factor. To meet the E_{kg} requirements, some manufacturers simplify the protection and temperature control devices of the battery [7], causing the hidden danger of spontaneous combustion. According to relevant reports, there have been dozens of spontaneous combustion accidents of NELVs in China since 2018 [65]. Figure 13 shows the fire causes of NELVs in China.

Figure 13. Distribution of the fire causes of NELVs in China.

(3) Vehicle utilization issues

BELV utilization is lower than that of ICETs. Due to the limitations of the current battery technology of BELVs, the one-charge AER does not satisfy the operation requirements for the whole day, so it is generally required to charge in the operation process. The inconveniences of a long single-charge time and a long queuing time seriously affect the operation efficiency. The slow charging time of most BELVs is generally 8–12 h, and the fast-charging time is 2 h. BELVs are generally fully charged overnight. However, due to the AER limit, many users have to recharge batteries at least once in the daytime. Generally, the charging time is approximately half an hour, and including the waiting time, charging usually requires more than one hour. To reduce the fuel cost, add-on and plug-in vehicles generally need to be refueled twice a day, while ICETs usually need to be refueled only once every 4–5 days.

On the other hand, at present, the AER of BELVs under low-temperature conditions will generally decrease by approximately 20%, and the charging time will increase by about 50% [7]. This leads to a decrease in vehicle utilization in winter compared with that in summer. With the increase in vehicle age and decrease in the battery's capacity, the vehicle utilization rate further decreases.

5.2. Total Costs and Benefits of Subsidies for BELVs

The logistics industry is a highly cost-sensitive heavy-asset industry, and transportation vehicles are one of the most important means of production in the logistics industry. Therefore, the vehicle total cost of operation (TCO) is one of the key factors for logistics service providers to decide whether to use NELVs. With the decline of subsidies, the cost of NELVs will continue to rise. How to reduce the TCO will be the main problem facing engine plants, operation companies and users.

(1) Total cost comparison between BELVs and ICETs

Compared with ICETs, BELVs are not superior to ICETs in terms of vehicle performance and reliability or in terms of the TCO [13]. At present, mainstream insurance companies have insured BEVs according to the price before the subsidy, and the premium for BEVs of the same model is higher than that of fuel vehicles. Subsidies decrease while battery production costs decrease as well. The tipping point for BEVs to become cheaper to produce than petrol equivalents is expected to be reached by 2024, whereas three years ago, this was expected by 2026, indicating how quickly these things tend to evolve [18]. The TCO is still a great challenge in promoting BELVs over the next 5 years.

(2) Evaluation of the benefit of subsidies for the different BELV models

Relevant studies have analyzed the influence of subsidies on the development of BEBs in China, and the conclusion is as follows: the subsidy efficiency for the different sizes of BEBs is not reasonable owing to the poor performance of heavy-duty BEBs. However, the total fossil energy replacement for light-duty BEBs is comparably higher due to the higher available subsidy [47,48]. Therefore, is the subsidy of NELVs reasonable? Is the subsidy policy inclined to a certain model? The following is an analysis of the impact of subsidy policies on the various BELV models.

- Subsidy offset rate

The price (or cost) difference between a BELV and an ICET as well as the subsidy offset rate (SOR) can be considered as evaluation indicators. The SOR can be calculated using the following Equation (2):

$$\text{subsidy offset rate} = \frac{S_{BELV}}{MRSP_{BELV} - MRSP_{ICET}} \times 100\% \quad (2)$$

where S_{BELV} is the total national and local government subsidy amount, and $MRSP_{BELV}$ and $MRSP_{ICET}$ are the manufacture retail prices (MRSPs) of typical BELVs and ICETs, respectively.

The MRSPs of typical BELVs and ICETs, the subsidy offset rate and the difference between the ICET price and the post-subsidy price of BELVs were analyzed, as shown in Figure 14.

As shown in Figure 14, the MRSP of typical BELVs in 2017 is 2–3 times that of ICETs. Subsidies decrease while battery production costs decrease as well. The subsidies for BELVs are decreasing year by year, and the difference between the ICET price and the post-subsidy price of BELVs is increasing year by year. The subsidy offset rate values in 2017 were approximately 110%, and the post-subsidy price differences were negative. The post-subsidy prices of all typical BELVs are lower than those of ICETs. Taking the BE minivan as an example, a fiscal subsidy amount of 80,000 RMB can be obtained from the central government and provinces. The post-subsidy price of the BE minivan is only 30,000 RMB, but the MRSP of an ICE minivan is 40,000 RMB. Because the MRSP of the BE minivan is much lower than that of the BE light bus and light truck, many operators and logistics companies have bought a large number of BE minivans. In 2018 and 2019, the subsidy offset rates were approximately 70% and 20% respectively, and all subsidies may be cancelled by the end of 2020. It can also be seen that there is no significant difference in the subsidy offset rates of BE minivans, light trucks and light buses, and the subsidy offset rate for a BE light truck is slightly lower, which implies that subsidy policies do not favor a certain vehicle model.

Figure 14. The price difference for the various BELVs.

Although the price of the battery system is declining rapidly and the price of BELVs is also declining rapidly, in the absence of subsidies, the price of BELVs is still 2–3 times that of ICETs. This is a great challenge in promoting BELVs. Therefore, it is indicated that subsidy schemes should be prolonged after 2020 to make sure the EV-market becomes self-sustainable.

- Subsidy efficiency

Furthermore, the evaluation indicator of the subsidy efficiency (S_{eff}) is proposed here to clarify the effect of subsidies on fuel displacement. It is defined as the subsidy of fuel replacement. S_{eff} can be calculated by the following Equations (3)–(5):

$$S_{eff} = \frac{S_{BELV}}{C_{ICET}} \quad (3)$$

$$C_{ICET} = \frac{F_e \times R \times d \times c_f}{100} \quad (4)$$

$$C_{BELV} = \frac{E_e \times R \times d \times c_e}{100} \quad (5)$$

where S_{BELV} is the total national and local government subsidy amount, C_{ICET} and C_{BELV} are the annual energy consumption costs of an ICET and a BELV respectively, F_e is the fuel consumption of an ICET travelling 100 km, L/100 km, E_e is the battery consumption of a BELV travelling 100 km, kWh/100 km, R is the daily millage, km, d represents the annual operation days ($d = 300$), c_f is the unit price of fuel ($c_f = 6.8$ RMB/L) and c_e is the unit price of electricity ($c_e = 1$ RMB/kWh).

Figure 15 shows the energy consumption comparison between BELVs and ICETs. The figure reveals that the energy consumed by an ICET is approximately twice that of a BELV. In addition, there is little difference in the subsidy efficiency among the different models of logistic vehicles, and the

subsidy efficiency for light trucks is slightly lower. This result is consistent with the subsidy offset, which again shows that subsidy policies do not favor a certain logistic vehicle model.

Figure 15. Energy consumption comparison between BELVs and internal combustion engine trucks (ICETs).

The national subsidy threshold for BELVs is increasing year by year. The above analysis also shows that the subsidy conditions are gradually becoming reasonable. The BELV industry is gradually leaving the era of subsidies and developing towards mass-adaption by consumers.

5.3. Suggestions

According to the key challenges analyzed in Sections 5.1 and 5.2, it is necessary to improve the level of vehicle parameters such as the CM, AER, energy efficiency and charging efficiency, and develop the technology of power exchange and charging. To improve the vehicle performance and use efficiency, suggestions for the technical development direction of BELVs are as follows.

(1) To reduce the CM and increase the AER for BELVs, high-energy, high-quality and low-cost battery technologies should be widely applied.

(2) Reducing the E_{kg} value is the trend, and it is more challenging. In the future, improvements in lightweight technologies, thermal pump air conditioning and regenerative braking have a high potential for decreasing BELV energy consumption [47].

(3) With the gradual improvement of NCM technology, strict technical regulations and lightweight trends of logistics vehicles, NCM batteries will dominant the market in the medium terms.

(4) With the rapid development of motor controller technology in China, it has gradually reached the level of that of foreign-funded companies. The changes in the technical indicators of the traction motor controller indicate that the traction motor controller is developing towards the direction of high integration, high-power density, high reliability and high safety.

(5) In response to battery decay, it is recommended that the government incentivize manufacturers to make better batteries and strengthen the management of battery recycling and reprocessing.

(6) In addition, Internet of Things (IoT) with inter-connected vehicles should be fully applied to BELVs to give full play to the role of BELVs in Intelligent Logistics. Through analysis of BELV positioning data, we can optimize the construction layout of charging supporting facilities, improve the utilization rate of vehicles and charging piles, and promote cost reduction, efficiency improvement and virtuous cycle development in the NE and logistics industries.

(7) In response to the safety problems caused by the loss of trust in vehicle technical indicators, it is recommended to establish strict technical standards and promote a unified NELVs monitoring service platform. China has mainly solved them by setting technical standards and establishing a strict safety regulatory system. This paper suggests that the whole life-cycle management of vehicles can be carried out by developing a standardization system to guarantee the quality of vehicle manufacturing and regulate the operation and use process of vehicles [7].

In 2016, Ministry of Industry and Information Technology of the People's Republic of China (MIIT) proposed the requirement of safety supervision of NEVs [66]. The monitoring and management platform of the NEVs focuses only on the operational status of NEVs at present [7]. It is recommended to establish and promote a unified NELVs monitoring service platform, access to operational vehicle information and supervision, in order to guarantee the safety of the entire industry chain and life-cycle of NEVs.

6. Conclusions

This study aimed to comprehensively study the development of BELVs in China and was primarily based on technical and industrial data of all BELVs available in the Chinese market. Several insights into the ongoing evolution of BELVs in recent years were obtained through a comprehensive analysis.

Firstly, despite the declining subsidies for NEVs and sluggish growth of the new energy bus (NEB) industry, the NELV industry has bucked the trend, and its output has risen sharply. The main market penetration's influencing factors include favorable policies, improvement of the NEV technology level, public awareness of environmental protection and market awareness.

Secondly, an evaluation system comprising 8 technological indicators for evaluating BELV performance and technological progress was proposed. The characteristics of the curb mass, vehicle volume, all-electric range, top speed, driving power, energy efficiency, traction battery and motor technology were analyzed for the 2017 and 2019 market's models. Compared with the same types of ICETs, the vehicle performance and reliability of currently used BELVs in the field of urban distribution are not beneficial, in terms of the CM, AER and energy efficiency. The shortcomings in the performance of BELVs also result in various problems, such as safety issues caused by misleading vehicle technical indicators, and the utilization rate of vehicles is lower than that of fuel vehicles. But all the parameters are improving year by year, constantly meeting logistics demands in recent years. In 2019, the average AER for BE minivans, BE light trucks and BE light buses were approximately 255 km, 241 km and 233 km, respectively. The average CM of BE minivans, BE light trucks and BE light buses were approximately 935 kg, 1381 kg and 1308 kg, respectively.

Thirdly, the benefit of subsidies for the different BELV models has been evaluated. Because the MRSP of BE minivans is much lower than that of BE light buses and light trucks, many operators and logistics companies have bought a large number of BE minivans. It was revealed that the subsidy policy does favor a certain vehicle model, and the subsidy conditions for BELVs are gradually becoming reasonable. The TCO is still a great challenge in promoting BELVs over the next 5 years. The subsidies are needed for longer for the market to mature. The BELV industry is gradually leaving the era of subsidies and developing towards mass-adaption by consumers.

Finally, several suggestions for the technical development direction of BELVs were proposed. It is necessary to improve the level of vehicle parameters such as the CM, AER, energy efficiency and charging efficiency and develop the technology of power exchange and charging. In response to battery decay, it was recommended that the government incentivizes manufacturers to make better batteries and strengthen the management of battery recycling and reprocessing. In response to the safety problems caused by the loss of trust in vehicle technical indicators, it was recommended to establish strict technical standards and promote a unified NELVs monitoring service platform.

In general, this research contributed to providing a better understanding of the technology development characteristics of BELVs by using marketing and technological data in China. In addition, market penetration's influencing factors for BELVs were analyzed, and the benefit of subsidies for

different BELV models was evaluated. All these results can be used to improve the vehicle performance, reliability and market penetration of BELVs and propose new incentive policies for BELVs. However, there are still unsolved problems in the analysis of their technological characteristics. In the process of analyzing the energy efficiency, because there are no complete data on the electricity consumption rate of the various models on the market, it is impossible to calculate the E_{kg} value. The development requirements of E_{kg} have only been revealed by comparing relevant national standards and national financial subsidies, which should be further studied in the future.

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Abbreviations

BELV	battery electric logistics vehicle
NEV	new energy vehicle
NELV	new energy logistics vehicle
NEB	new energy bus
ICET	internal combustion engine truck
EV	electric vehicle
BEV	battery electric vehicle
PEV	plug-in electric vehicle
BEB	battery electric bus
MRSP	manufacture retailed price
CM	curb mass
AER	all-electric range
ICE	internal combustion engine
LFP	LiFePO ₄
NCM	Li(NiCoMn)O ₂
LMO	LiMnO ₂
ESS	energy storage system
TCO	total cost of operation
SOR	subsidy offset rate
MIIT	Ministry of Industry and Information Technology of the People's Republic of China
MOST	Ministry of Science and Technology of the People's Republic of China
MOT	Ministry of Transport of the People's Republic of China
MOF	Ministry of Finance of the People's Republic of China
NDRC	National Development and Reform Commission
REELV	range-extended electric logistics vehicles
PHELV	plug-in hybrid electric logistics vehicles
FCELV	fuel cell electric logistics vehicles
ESTB	energy storage trolleybuses

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