Proceedings of the 2nd International Conference on Business and Policy Studies
DOI: 10.54254/2754-1169/15/20230859

The Future of Electric Vehicle Batteries

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Abstract: As the performance of BEVs has received increasing attention in recent years as electric vehicles have become hot, the focus of our research is on a series of problems brought about by the over-engineering of EV batteries that are detrimental to the development of EVs including the charging range of EVs and the problem of excessive weight and solutions to make EVs dominate the automotive industry, we use "swap stations" and "mobile with dual charging ports in a platform with adaptive fast charging of multiple battery systems" are two strategies to solve the above problems. As a result, we found a solution to the battery over-engineering problem. In this way, electric vehicles will be able to stand out in the automotive industry and thus increase sales.

Keywords: EVs, BEVs, Over-engineering, Swap station, Multi-Pack, Automotive industry, Charging time, Battery weight

1. Introduction

Nowadays, the traditional traffic situation has led to many severe consequences and even endangered people's daily life; the most familiar one is global warming. According to statistics, the global annual temperature has risen by 0.18 degrees Celsius per decade over the past four decades [1]. The leading cause of global warming is many greenhouse gas emissions due to human activities. Among these human activities, transportation is the primary source of greenhouse gas emissions, accounting for 23% of energy-related greenhouse gas emissions. In comparison, the road of ICE vehicles accounts for 75% of these emissions [2]. According to the survey, the CO2 emission from burning one gallon of gasoline is 8.887 grams of CO2 / gallon, and the average passenger car emits about 404 grams of CO2 per mile. Hence, a typical passenger car emits about 4.6 tons of CO2 annually, increasing greenhouse gas emissions [3].

Moreover, traditional fuel vehicles also lead to the emission of some toxic gases, such as CO. According to research, vehicles are the most significant air quality hazard in the United States, accounting for about one-third of air pollution in the United States, putting air quality and people's health at risk [3]. However, with the signing of the Paris Agreement in 2015, reaching the peak of global greenhouse gas as soon as possible has become the goal of all countries. In the process,

DOI: 10.54254/2754-1169/15/20230859

electrification has gradually become an attractive and practical solution. Research shows that in 95% of the world, driving an EV is more environmentally friendly than driving a gasoline vehicle [4]. EVs in the United States currently emits an average of 200 grams of CO2 per mile, and by 2050 this will be reduced to 50 grams [4]. In the best-case scenario, EVs could reduce global transport greenhouse gas emissions by 80%-90% by 2050 [2]. A few days ago, California announced that it will stop selling gasoline vehicles in 2035, and the state requires 35% of new passenger cars to be zero-emission in 2026. This requirement will be increased in 2030 to 68% and reduce greenhouse gas emissions by 50% by 2040 [5]. Therefore, various countries have begun to promote the EV industry vigorously. In the U.S., about $15 billion will be spent on building a national network of 500,000 charging stations to provide more convenience for EV users. Of this, $10 million will be used to develop innovative technologies to supply a large number of DC charging units, $20 million will be used to accelerate the adoption of commercially available plug-in electric vehicles (PEVs) to drive the market, and $4 million will be used to establish partnerships [3]. In Europe, 20 billion euros of the EU's 750 billion euros will be used to promote EV sales, and 1 million EV charging stations will be installed by 2025. Therefore, under the government's vigorous promotion, global EV sales in 2020 will increase by 43% compared with 2019, and the market share of the EV industry will also rise to 4.6% [6]. Therefore, we can feel that more and more EVs have appeared in front of us in recent years, inseparable from the government's help. However, despite the many benefits of electric vehicles and the vigorous development of various countries, according to statistics, only about 1% of the 250 million vehicles in the United States are EVs, which means that EVs are not mainstream today [6].

There are still many problems that prevent the development of EVs in the industry today, or it can be said that there are still some defects in EVs and batteries that cause a lack of user adoption, which fall back to the hazards mentioned above of traditional gasoline vehicles. The problems described below include the speed of charging electric car batteries, the batteries' weight, and the trams' range.

First, electric vehicles take too long to charge. For a typical EV, a charger using a 7kW charge point takes 8 hours to charge the battery [7] fully. Although some fast charging technologies are popular today, such as most DC fast chargers that can output 50kW per hour, it still takes 1 hour to charge an EV to 80% [6]. This means that EV users cannot use their EV during charging, even in some emergencies.

The second problem is the excess weight of EV batteries. Excessive battery weight results in a heavier car and has some negative consequences. First, heavy batteries pose some safety concerns. Second, heavier EVs cause more tire wear. According to statistics, electric vehicles wear tires 20% faster than internal combustion engines [7]. Finally, heavier EVs mean more road wear, so EV users pay extra road tax, which increases the overall cost [8].

The third problem with the development of EVs is the short endurance capacity. The endurance capacity of most current EVs is too weak to satisfy consumers' requirements. Furthermore, EV batteries are much more susceptible to temperature, speed, and inner working appliances, meaning that the actual endurance mileage of EVs is much lower than that provided by producers [9].

Due to the current technology, EV enterprises cannot solve multiple battery problems simultaneously. They need to meet the demand on one hand while sacrificing the demand on the other. Therefore, firms will have to make a trade-off between battery problems. For example, Tesla Model S, which aims for strong endurance capacity, has an endurance of 652km but weighs 2,162kg, 300 to 500kg heavier than a conventional EV [9]. Thus, we require new frameworks to address the charging mode of electric vehicles because the technical issues relating to battery technology cannot be resolved.

To expand EV's niche market share in the transportation sector, solving the above problems to increase demand for EVs is critical in ensuring optimal integration. Furthermore, it measures the benefits to policymakers and the auto industry regarding green consumption. Therefore, the purpose of this paper is to find a reliable solution to the over-engineering of BEVs in order to make EVs become mainstream in the future.

2. Literature Review

2.1. Consumer Preferences on EV Battery

In the market, consumer behavior is a critical factor in adoption, participation, and consumption. The theory of planned behavior (TBP)is considered an appropriate underpinning theory to predict consumers' preferences for EVs and conclude consumers' dissatisfaction with current EVs. The improvement of problems causing consumer dissatisfaction would solve the problem of low adoption of EVs and expand the EV market.

Table 1: Possible Factors about Consumer Perferences on EV Battery.

Factors	Specific variable	Studies find it has a significant positive effect	Studies find it has a significant negative effect
Psychological theories Factors	Environmental concerns	- Aguilar-Luzón et al	
Attitudinal Factors	Maintenance and Battery Replacement Cost		- Taljegard et al [10] -Egbue and Long [11] - Zeng et al. [12] - Dasharathraj et al. [13]
Behavioral Factors	Vehicle Performance	- Egbue and Long [11] - Zeng et al. [12] - Taljegard et al. [10]	

2.2. Factors from Psychological Theories

Psychological theories use diverse factors to explain behavior, including perceptions, attitudes, norms, and more. Huijts, Molin, and Steg provided a framework that integrates most major psychological theories and factors associated with sustainable technology acceptance/adoption [14,15]. Selection studies also attempted to incorporate some of these structures into more comprehensive models with higher explanatory power.

2.3. The Theory of Planned Behaviour (TPB)

The Theory of Planned Behaviour (TPB) was transformed from the Theory of Reasoned Action (TRA) in 1980 to predict an individual's intention to engage in a specific behavior at a particular place and time. TPB is considered an involutional process with a volitional dimension. Specifically, in TPB, the development of personal intent can be explained more effectively and comprehensively than in TRA. Its scope covers both volitional and involutional processes [16].

TBP has become one of the most sustained theories in social psychology because of its pre-emptive solid. As a result, it has been applied in an extensive range of study perspectives for predicting an

DOI: 10.54254/2754-1169/15/20230859

individual's behaviors (such as environmental and pro-environmental) [17]. Moreover, TPB analyses the factors influencing consumers' self-interest as the most critical motivation for pro-environmental behavior [18]. Therefore, this section adopts TPB to explore the beliefs that drive consumers to adopt EVs and aims to give recommendations for a future solution.

Many previous studies have shown a positive correlation between consumers' attitudes and their intention to adopt EVs [19]. For instance, Yan and Wang found a positive relationship between perceived behavioral control and purchase intention regarding EV consumption [20].

2.4. Environmental Concerns

Environmental concerns have been related to individual or general environmental beliefs and worldviews. Therefore, consumers' decision to use pro-environment green products is shaped by their environmental beliefs/protection. Previous studies on consumer consumption of environmentally friendly EVs have indicated that EVs are ecological innovations, reducing environmental problems in the transportation sector. Since EV adoption is thought to be driven by environmental concerns, these environmental-related variables motivate the adopter to choose EV [17]. Found to previous research, environmentally concerned individuals are more willing to purchase fuel-efficient vehicles. Environmentally sensitive consumers who perceive themselves as environmentally responsive will be more likely to adopt and purchase EVs [21]. Therefore, economists suggest EV users would sense "intrinsic emotional reward in pro-environmental behavior" [22], which is similar to carrying out self-sacrificing activities, in other words, feeling altruistic (e.g., a donation to charity). They perceived that they play a role in curtailing carbon emissions and preserving the environment. In addition, environmental concern has been thriving in recent years due to several environmental issues and the government's appeal to protect the environment.

3. Attitudinal Factors

3.1. Cost of Battery

A significant barrier to the high take-off of EVs is the uncertainty about the cost of the battery. In Long and Egbue's study, they indicated that even though the key influences of EV adoption are environmental benefits and sustainability factors, they are still ranked low in factors such as battery replacement costs [11]. This has been verified by Dasharathraj et al [13]. Who found that battery price is one of the main concerns leading to the behavioral control of EVs. Furthermore, Zeng et al also indicated that when consumers plan to adopt new EVs, battery replacement costs directly impact consumer adoption attitudes and behavioral control and remain a significant EV adoption issue [12].

3.2. Behavioral Factors

Vehicle Performance

The safety, range, and performance of EVs are essential characteristics that consumers will consider when adopting EVs. Several empirical studies have discovered that vehicle performance is also more significant in addition to environmental and social factors [23]. Long and Egbue found that EVs' performance, such as reliability, safety, and range, has been reported as a barrier to adoption in studies of potential consumers' intentions to adopt EVs. Carley et al examined the factors inducing the behavior of 2302 early EV purchasers in the 21 largest urban areas in the USA [11, 24]. Their findings specified that the early adopters were sensitive to environmental factors, but safety, purchase cost, and driving range were the primary factors. Zeng et al found that performance attributes are an essential factor influencing consumers' willingness to adopt EVs [12].

Therefore, in the above market research, we can see that users have various anxieties and worries

DOI: 10.54254/2754-1169/15/20230859

about electric vehicles, which makes electric vehicles unable to become famous. And one of the biggest problems holding back the development of electric vehicles is the over-engineering of batteries. Here are three main problems.

First, the charging time of electric vehicles. Take, for example, the three most popular EVs today (150kW charging units), the first being Tesla's Model Y. According to statistics, Model Y has become the most popular electric vehicle in the US electric vehicle market, with sales of 172,700 units in 2021. Model Y can charge 80% in just 20 minutes [25]. Ford's Mustang Mach-E came in second with 27,140 units, while the Mustand Mach-E needed 30 minutes to charge to 80 percent. In third place is the Chevrolet Bolt, with 24,828 sold, but it takes 35 minutes to charge to 80 percent [25]. So while these three EVs are the most popular today and feature fast-charging technology, they still do not take as long to charge as gasoline cars. Therefore, the long charging time has become a significant obstacle to the development of the EV industry.

Nowadays, users have more and more requirements for electric vehicles—for example, the battery life of electric vehicles, kinetic energy, and safety. In order to meet the various needs of customers, manufacturers have launched more excellent electric vehicles. However, as electric vehicles' performance improves, batteries' size and weight also increase. Electric cars are heavier than gasoline cars because of the batteries. Electric vehicle batteries mainly comprise lithium, and one cubic foot reaches 33 pounds. In order to protect the battery from damage by other objects, manufacturers will also install a rugged metal casing on the outside of the battery, thereby increasing the weight of the battery.

Moreover, to provide higher battery power and make the battery last longer for some large electric vehicles, the size of the battery is also increasing, resulting in increased battery weight. Tesla's Model S, for example, has the most extended battery life in the entire series, but its battery weighs a staggering 1,200 pounds [17]. Therefore, the excessive weight of electric vehicle batteries has become a significant problem hindering the development of the electric vehicle industry.

Short endurance mileage is also the main problem for the development of EVs. In recent years, with the development of the battery industry, new batteries like lithium batteries, which could provide much stronger endurance capacity, replaced the lead-acid battery that was used in the early ages [26]. Most current electric cars have an endurance range of 300 to 500 kilometers, with more luxurious models reaching more than 600 kilos. However, these data are measured in the appropriate environment with the lowest energy consumption, which is inconsistent with the consumer's normal driving conditions. Furthermore, research has shown that the battery endurance of EVs is susceptible to the influence of external temperature and driving speed. At low temperatures, the internal resistance of batteries increases, and the voltage platform decreases. At high temperatures, batteries are prone to thermal runaway. At high speeds, fast motor running speed reduces efficiency [27]. Therefore, the actual endurance mileage of electric cars is much lower than their maximum threshold [26].

We chose a reliable and potential solution - the swap station to solve the battery problem.

4. Hypothesis

From the above assumption, the following hypotheses are proposed.

Hypothesis 1: Positive attitude is associated with adopting a more sustainable EV.

Hypothesis 2: Environmental concerns positively correlate with subjective norms toward adopting sustainable EVs.

Hypothesis 3: Maintenance and battery replacement costs can negatively impact consumer attitudes toward sustainable EV adoption.

Hypothesis 4: There is a positive correlation between vehicle performance and the attitude of the consumer intention to adopt a sustainable EV.

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5. The Solutions to Battery Over-engineering

To solve the problems of the EV industry, we have another example solution of a company called Better Place which first proposed swapping stations in 2007 [28]. The battery swapping technology allows EV users to take out the exhausted battery from the EV and replace it with a fully charged battery at a designated swapping station to achieve the purpose of fast charging. Moreover, due to the influence of the sharing economy and circular economy, the batteries in the swapping station can be reused many times, thus providing convenience for more users.

One of the swap station's main advantages is it could solve the EV charging limit by shortening the EV recharging waiting time [29]. Nowadays, the most popularized charging method for EVs is by charging piles. However, DC fast charging, one of the advanced fast-charging technologies, still needs 0.5 to 2 hours to fully charge an EV [30, 36]. Such charging speed could not satisfy consumers' specific demands in certain circumstances, like long-distance journeys. In order to fulfill EV users' demand for fast charging and long-time endurance, charging firms need to provide a fully charged battery when consumers' one runs out instantaneously. Swap stations significantly solve this problem. This mode could shorten the recharging time to 3 minutes or even less. In this mode, the charging time of EVs is one-tenth of the fast-charging tech, which is close to the refueling time of a gas-powered car. Therefore, swap stations significantly shorten the Evs' recharging time, improve the efficiency of EVs, and effectively solve the charging efficiency problem of charging pile mode, which solved the charging limit.

In addition, swapping stations can solve the problem of overweight batteries, thereby indirectly reducing additional costs for electric vehicle users and becoming safer [30]. At the replacement station, all batteries are standardized so that the battery replacement process can be carried out accurately and safely. Moreover, the latest composite materials can be used in the power exchange station to reduce weight, such as the new Porsche Taycan, which uses metals such as magnesium to reduce the weight of the battery. Therefore, those batteries that are too heavy need to be reduced in weight to meet the standard of the swap station and achieve unity. With the lighter weight of the battery, the lighter weight of the electric vehicle can reduce the resistance of the road to the tires, thus mainly avoiding tire wear. In addition, a lighter EV means less damage to the road, reducing road tax for EV users and lower post-purchase costs. Finally, a lighter EV body could allow the vehicle to do less damage to the victim in a crash, thereby increasing the victim's survival rate.

Third, the swapping stations also address whether the vehicle is fully charged and whether the specified range has been completed [30]. After removing the depleted battery can be slowly charged to 100% in the swap station. Therefore, the user can replace the fully charged battery at any time without worrying about the ranging problem of the battery. However, for charging devices, this situation is not easy to solve. As the EV industry protects batteries, when the charge reaches 80%, the battery will reduce the charging rate [31]. In this case, most of the time, the owner cannot fully charge the EV, causing the owner to have anxieties and worries about the range.

Fourth, the swapping stations help protect the battery [32, 35]. Although fast charging can shorten the charging time, the excessive current and voltage will reduce the battery's reducing ability, reduce the number of battery charge-discharge cycles, and accelerate the battery capacity decay, thereby shortening the battery's service life. On the other hand, swapping stations hold more batteries, allowing the battery to charge slowly. In addition, the swapping station can carry out standardized testing and maintenance of batteries, reducing battery capacity degradation and extending battery life. Therefore, users can replace a fully qualified battery at the swapping station without worrying about the quality, resulting in a good driving experience.

Fifth, swapping stations also provide consumers with greater flexibility [32]. Due to continuous innovation in battery technology, leasing batteries can save 30%-50% of the cost of EVs. In addition,

DOI: 10.54254/2754-1169/15/20230859

separating the battery from the EV vehicle means that EV owners can use batteries with the latest technology in the case of a Battery Management System (BMS). This means that even a long-term EV can perform as well as it did when it rolled out of the factory.

Finally, swapping stations are more environmentally friendly than charging points [33]. Swapping companies can choose to use some clean energy to power the batteries. For example, Ample's swapping stations can capture wind and solar energy to charge batteries when in use and provide it to vehicles when the driver needs it, reducing the need for large power resources at the swapping stations.

However, despite the many benefits of swapping stations, it still has some limitations.

The first is battery standardization. To achieve battery replacement, cross-brand compatibility is necessary [34]. Different electric vehicle brands must produce the same model of battery packs to be interchangeable. However, this seems impossible, as each manufacturer will continue to innovate to make their products more unique, and a unified battery will limit the manufacturer's innovation and flexibility [34]. Moreover, each country has different requirements for voltage and charging, so it is challenging to switch stations [35].

Another problem is the high fixed cost of infrastructure. Firstly, the infrastructure of an exchange station is more complex than a charging station's. First, swap stations are more demanding on the grid as all backup batteries need to be charged at the swap station [34]. Second, the swap station must have sufficient battery packs to easily handle the high battery demands during peak traffic hours [34]. In this case, replacing the power station is too expensive.

With these constraints, swapping stations seems unlikely to become a reality. In this case, GM has filed a patent called "Adaptive Fast-Charging of Multi-Pack Battery System In A Mobile Platform Having Dual Charge Ports", which may be another solution for the overdesign [30]. The devices outlined in the GM patent relate to direct current fast-charging (DCFC) architectures and adaptive charging methods for electric vehicles and other mobile devices with dual charging ports. The patented design helps electric cars adapt to a broader range of applications in the form of two batteries, one high voltage and one low voltage. First, the dual charging port's design helps adapt to a broader range of charging voltages and provides better charging performance at high voltages by changing the form of series and parallel to achieve the highest charging efficiency. For example, when the charging voltage is one high and one low voltage, the high-voltage charging battery can transmit power to the low-voltage battery again by in-series batteries, which undoubtedly improves the charging efficiency. When both charge voltages are low, the parallel connection provides a faster-charging speed. The dual-battery charging design adapts to various voltage conditions and delivers high efficiency. Second, the design allows the battery to be used in a broader range of applications. For example, under extreme temperatures, low-voltage batteries can adjust the charging condition of high-voltage batteries to achieve high charging efficiency.

6. Conclusion

Therefore, we analyze why the electric vehicle market is hindered by studying the three main problems of battery overdesign including charging limitation, overweight, and electricity consumption. The overdesign seems to be in line with market intuitions about the development of EVs, such as overdesigns designed to make EVs last longer for even over 800km [36]. But after our research, we found that EVs actually need less than the overdesign of these parts. We try to provide two solutions to solve the battery overdesign. One is to design battery swapping stations intended to reduce the possible requirements which may lead to overdesign for EV batteries. The other is a Multi-Pack Battery System designed to support more situations that EVs may face with a smaller number of simpler cells [30]. We hope that through our research and solutions, electric vehicles can become a megatrend faster in the future to solve a series of problems caused by today's gasoline vehicles.

Therefore, we believe that shortly, we can see more EVs on any street in the city.

Acknowledgement

Yixuan Cao, Yuzheng Zhang, Jiehui Chen, Runze Zhao and Yutong Guo contributed equally to this work and should be considered co-first authors.

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