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Review

Opportunities, Challenges and Strategies for Developing Electric Vehicle Energy Storage Systems under the Carbon Neutrality Goal

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Abstract: Developing electric vehicle (EV) energy storage technology is a strategic position from which the automotive industry can achieve low-carbon growth, thereby promoting the green transformation of the energy industry in China. This paper will reveal the opportunities, challenges, and strategies in relation to developing EV energy storage. First, this paper clarifies the strategic value and potential of developing EV energy storage under the carbon neutrality goal. Second, this paper demonstrates strategic opportunities and challenges during the development. Third, this paper proposes methods for creating a good market environment and business models. Finally, this paper suggests that relevant policies and regulations should be formulated and charts the course of technology development. The results show that EV energy storage technology has potential in terms of technology, the scale of development, and the user economy. The proposal of the carbon neutrality goal, the increasing market share of EVs, lower-cost and higher-efficiency batteries, etc., have all further accelerated the development of EV energy storage. The EV energy storage field should focus on developing battery technology, make advancements toward delivering longer cycle lives and improving the safety and availability of battery materials, and ramp up the R&D efforts with respect to developing vehicle-to-grid (V2G) management technologies. Simultaneously, it is necessary to create a business ecosystem centered on V2G operating platforms, constituting a process to which various players can contribute and achieve mutually beneficial results. It is also essential to formulate top-level strategic plans across industries and organizations, develop an electricity-trading mechanism as soon as possible, and promote the implementation of technical standards related to EV energy storage.

Keywords: carbon neutrality goal; electric vehicle; energy storage; V2G; business model

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1. Introduction

China's climate goal to reach peak carbon emissions before 2030 and achieve carbon neutrality before 2060 (referred to as the "dual-carbon goal" or "30/60 Target") has brought severe challenges to all walks of life in China [1,2]. The energy industry bears the brunt of these challenges since it is the largest carbon emitter in China. The key to fulfilling China's "dual-carbon goal" lies in the low-carbon energy transformation. Considering the safety of nuclear energy and the geographical limitations of hydropower, wind and solar power have become the primary forms of energy investigated in this regard. However, concerns regarding intermittency, uncertainty, transportation, storage, and wind and solar power consumption will hinder their large-scale promotion. Therefore, it is urgent to find a carrier that enables large-scale energy storage and consumption [3]. As one of the country's pillar industries, China's automotive industry accounted for more than 10% of the country's total carbon emissions in 2020. With a continuous increase in consumption, the carbon emissions generated by the automotive industry are also gradually on the rise. Developing new energy vehicles (NEVs) has become an important initiative through which the automotive industry plans to fulfill the "dual-carbon goal," which is also an established state strategy that will not be changed [4,5]. Driven by policy and market factors, the market penetration rate of NEVs has passed the critical point, showing a trend of large-scale development, especially with respect to electric vehicles [6]. Equipped with high-power batteries, electric vehicles can store and consume energy. From the perspective of electricity demand and energy storage capacity, EV and renewables-based energy storage systems have a very high degree of strategic matching, presenting extensive prospects, as shown in Figure 1. Considering the "dual-carbon goal", electric-vehicle-based energy storage is of strategic value to energy transitioning and the low-carbon growth of the automotive industry.

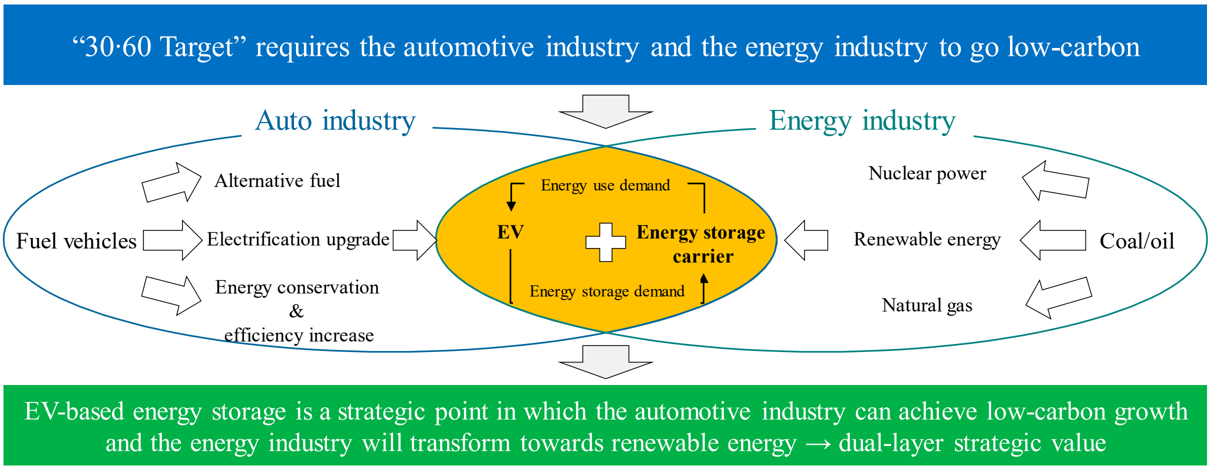

Figure 1. Strategic value of developing EV-based energy storage systems.

Electric-vehicle-based energy storage refers to the full exploitation of the advantages offered by electric vehicles regarding energy storage and consumption, which can replace fixed energy storage power stations to store unstable energy under the premise of meeting users' mobility needs. According to the China Energy Storage Alliance (CNESA), EV-based energy storage can be classified into four modes: orderly charging (V1G), vehicle-to-grid interaction (V2G), battery swapping, and the second-life use of decommissioned batteries [7,8] as shown in Figure 2. EV-based energy storage is commonly represented by V2G, whose technologies enable the two-way transmission of energy and information between electric vehicles and smart grids [9]. V2G offers advantages in many fields. Users can recharge their EVs during the off-peak periods when the electricity price is lower and feed electricity back to grids during peak hours when the electricity price is higher, thus generating economic benefits [10]. On the other hand, services such as peak regulation, frequency regulation, reactive power compensation, and spinning reserve can be provided to the power grid via V2G, thus replacing fixed energy storage to provide benefits [8]. With regard to power grids, V2G can reduce the spare capacity of thermal power generation or other conventional units, improve the stability of power grids, and cut investments in spare capacity and equipment renovation, thereby generating economic benefits for grid operators [11,12]. On the surface, V2G is just the interaction between vehicles and power grids, but it requires the participation of players from different fields. A complete V2G ecosystem generally includes three primary roles played by EV users, V2G operators, and power grid operators along with roles filled by secondary players like international standards organizations, governments, energy producers, battery-charging and swapping infrastructure operators, and automobile manufacturers [13]. The primary and secondary players become deeply involved in the operation and cooperate in developing adequate business models to deliver mutually beneficial results. In general, EV-based energy storage offers numerous advantages, whose commercialization will trigger profound changes in the automotive and energy industries.

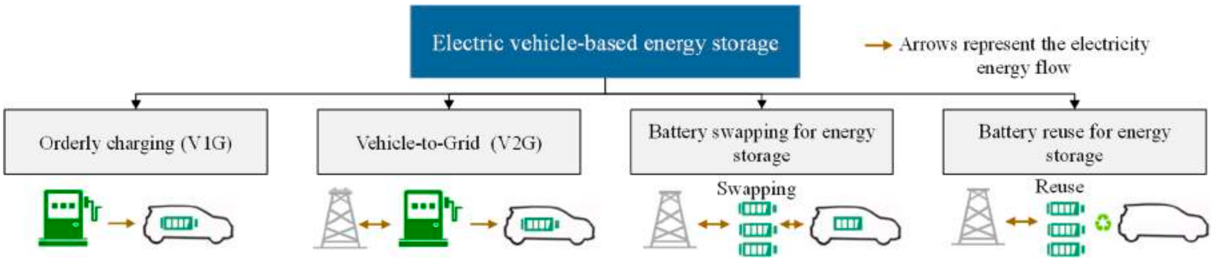

Figure 2. EV-based energy storage concept.

In recent years, EV-based energy storage has attracted a significant amount of attention from scholars and institutions at home and abroad. Hannan et al. studied the problems and challenges of EVs regarding their role as energy storage systems [14]. They contended that when electric vehicles are used as energy storage systems, significant challenges remain in terms of battery materials, battery size and cost, electronic power units, energy management systems, system safety, and environmental impacts. Although EVs can currently be used to store energy, this process's maximum value cannot be tapped using the existing technologies. Liu et al. from the Energy Research Institute of the National Development and Reform Commission quantitatively analyzed the potential of EV-based energy storage and its synergy with renewable energy [15]. They contended that technical and policy obstacles still hinder the application of electric vehicles as energy storage systems in China. Hence, it is necessary to accelerate the research and development of power distribution technology and adjust the policies regarding the positioning mechanism of auxiliary services for electric vehicles, the price mechanism of electricity prices during peak and off-peak hours, and the energy storage market transaction mechanism. Zhao et al. researched the mainstream EV-based energy storage models, key technologies, and development strategies for V2G [16]. In terms of developing V2G technology in China, they contend that challenges such as inadequate top-level design, insufficient key technologies, and a less-developed market environment have not yet been solved.

In addition, we summarized the review articles on electric vehicle energy storage published between 2012–2022, as shown in Table 1. After an analysis, it was found that most reviews focused on the technological problems and difficulties regarding EV-based energy storage. At the same time, we determined that there is a lack of research on the necessity of, feasible measures for, and strategic-level policy suggestions in relation to realizing the dual-carbon goal. To this end, this paper analyzes the strategies for developing EV-based energy storage in China at the level of fulfilling the dual-carbon goal and aims to answer the following questions:

(1) Is it feasible to develop electric vehicle energy storage technology? What is the scale of electric vehicle energy storage technology in China in the future?
(2) Are there any opportunities for China to develop electric vehicle energy storage technology?
(3) What are the challenges regarding China's current large-scale development of electric vehicle energy storage?
(4) What is China's response strategy if it develops electric vehicle energy storage technology on a large scale?

Table 1. The analyzed review articles on EV-based energy storage.

Author and Year	Publication Title	Research Contents
Yilmaz M et al. (2012) [17]	*Review of benefits and challenges of vehicle-to-grid technology*	This paper reviews the benefits and challenges of V2G technology for both individual vehicles and vehicle fleets.
Francis et al. (2014) [18]	*Electric vehicles and smart grid interaction: A review on vehicle to grid and renewable energy sources integration*	In this paper, EVs' interactions with the smart grid as a model of future energy systems are extensively discussed, and a research gap is revealed to inspire possible solutions
Salman et al. (2015) [19]	*Impact analysis of vehicle-to-grid technology and charging strategies of electric vehicles on distribution networks—A review*	This paper presents a detailed review of vehicle-to-grid (V2G) technology in conjunction with various charging strategies for electric vehicles (EVs) and analyzes their impacts on power distribution networks.
Kang et al. (2016) [20]	*Integration of electric vehicles in smart grid: A review on vehicle to grid technologies and optimization techniques*	This paper reviews the framework, benefits, and challenges of vehicle-to-grid technology and summarizes the main optimization techniques to achieve different V2G objectives while satisfying multiple constraints.
Hannan et al. (2017) [14]	*Review of energy storage systems for electric vehicle applications: Issues and challenges*	This paper comprehensively reviews ESS technologies and their classifications, characteristics, constructions, electricity conversion, and evaluation processes, delineating their advantages and disadvantages for EV applications.
Benjamin et al. (2018) [21]	*The neglected social dimensions to a vehicle-to-grid (V2G) transition: a critical and systematic review*	This paper reviews the neglected social dimensions of the V2G transition such as natural resource use and externalities, discourses and narratives, and social justice, gender, and urban resilience considerations.
Zeeshan et al. (2019) [22]	*En route of electric vehicles with the vehicle to grid technique in distribution networks: Status and technological review*	This paper depicts the anticipated problems that occur when drawing power from the grid to a vehicle in a charging scenario and analyzes EVs as a form of dynamic storage that simultaneously feeds the power grid in the discharging status.
Angshuman et al. (2019) [23]	*Review of power electronics in vehicle-to-grid systems*	This paper reviews and compares the various bidirectional AC–DC and DC–DC converter topologies that facilitate V2G and G2V active power flows.
Benjamin et al. (2020) [24]	*Actors, business models, and innovation activity systems for vehicle-to-grid (V2G) technology: A comprehensive review*	This paper reviews the potential types of actors and stakeholder groups, business models, and resulting innovation activity systems that vehicle-to-grid (V2G) technology might create or accelerate.
Abdulgader et al. (2021) [25]	*A comprehensive review of energy management strategy in Vehicle-to-Grid technology integrated with renewable energy sources*	This article reviews the achievements of EMSs implemented in EV systems with respect to reducing fuel consumption and carbon dioxide emissions.
Heilmann et al. (2021) [26]	*Factors influencing the economic success of grid-to-vehicle and vehicle-to-grid applications—A review and meta-analysis*	This paper uses a quantitative meta-analysis to identify key drivers of economic benefits based on 340 cases published between 2010 and 2018.
Mustafa et al. (2022) [27]	*Integrating electric vehicles as virtual power plants: A comprehensive review on vehicle-to-grid (V2G) concepts, interface topologies, marketing and future prospects*	This paper aims to provide an extensive overview on the system configurations, interface topologies, marketing aspects, and future perspectives regarding integrating EVs as virtual power plants.

To answer these questions, we constructed the following research framework shown in Figure 3.

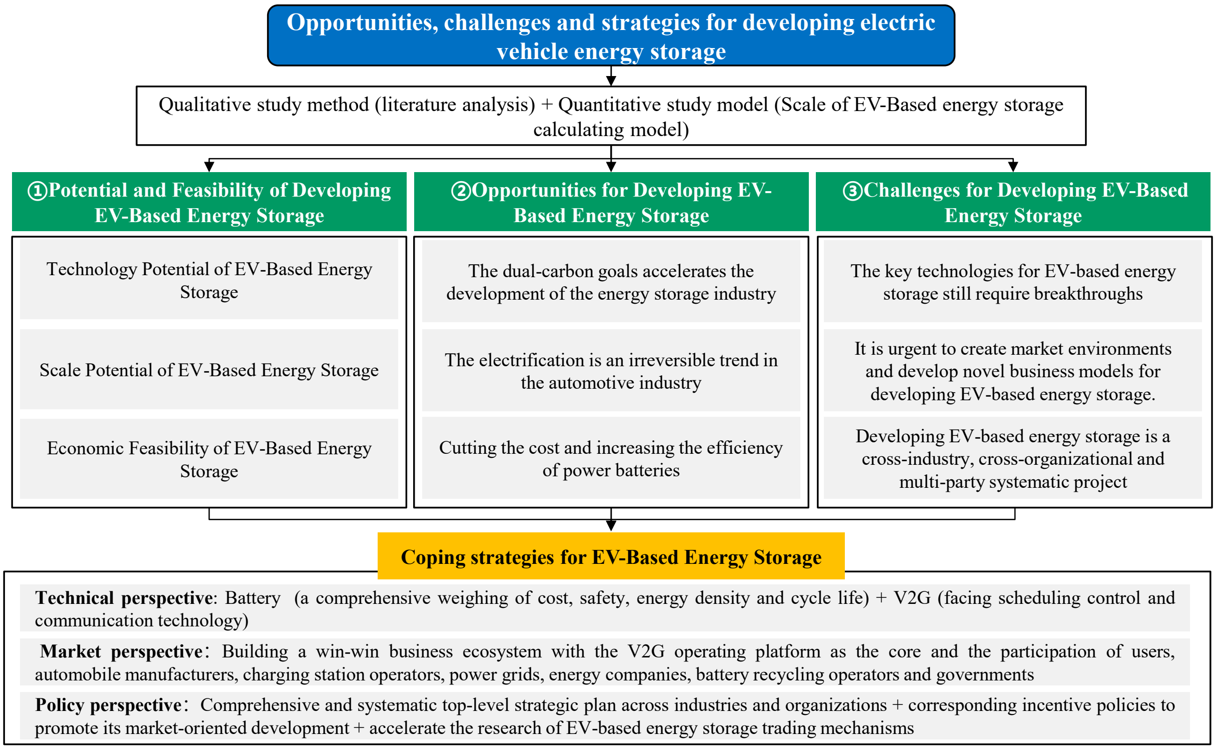

Figure 3. The research framework of this study.

First, we conducted a quantitative analysis of the feasibility of developing EV-based energy storage systems. Second, we elaborated on the strategic opportunities for developing EV-based energy storage systems from the perspectives of policy trends and the characteristics of automotive industry development in China. Third, we analyzed the challenges relating to electric-vehicle-based energy storage from technological, economic, and policy dimensions. Finally, we proposed specific strategies and suggestions for tackling the challenges encountered during the development of electric vehicles in all aspects. These strategies are expected to serve as references for developing the electric-vehicle-based energy storage industry in China.

2. Potential and Feasibility of Developing EV-Based Energy Storage Technology

Although developing EV-based energy storage systems will become an important strategic initiative for fulfilling the "dual-carbon goal," the public still has disputes over the feasibility of developing electric vehicles into energy storage systems. This paper studied the potential and feasibility of EV-based energy storage systems from the three perspectives of technological capability, energy storage scale, and economic efficiency.

2.1. Technology Potential of EV-Based Energy Storage Systems

The core component of developing electric-vehicle-based energy storage systems is the partial replacement of traditional energy storage methods. Therefore, it is crucial to determine whether electric-vehicle-based energy storage systems have technical advantages over other energy storage methods. Technical feasibility is determined by comparing the cost and technical characteristics of EV-based energy storage systems (currently, V2G) and other energy storage methods. At present, the primary energy storage methods include mechanical, electrochemical, chemical, and electrical methods [28]. The costs and features of the current popular energy storage technologies are listed in Table 2.

Table 2. Costs and features of energy storage technologies [13].

Name	Cost of Storage		Response Time	Energy Storage Efficiency (%)	Note
	CNY/kW	CNY/kWh			
V2G	0 (with user consent)	0~40 (cost of battery degradation)	Seconds	70~85	The cheapest system until now; long and complex promotion process; determined by consumer acceptance
Hydrogen	10,500~22,400	1820~3780	Seconds~Minutes	40	Lowest efficiency; high cost of production
Purpose-built batteries	7700~17,500	3500~5600	Seconds	70~90	Not feasible for other purposes; very high cost of batteries
Flywheel	60,900	33,600	Seconds	94	High efficiency but prohibitively expensive, thus restricting overall energy capacity; priority given to short-time energy storage
Power to gas	5950	Not Applicable	Seconds~Minutes	50	Low efficiency; establishment of natural gas infrastructure is required; generates relevant carbon emissions
Air compression	6300~9100	280~763	9~12 min	70~90	Proven technology; high cost
Pumped storage	8400	476	Seconds~Minutes	70~82	Largest scale; restricted by geographical conditions; performance dependent on environment

In theory, if electric vehicle users agree to participate in V2G activities, V2G-based energy storage will be the least expensive form of energy storage (the cost of energy is mainly determined by battery degradation and is usually not higher than CNY 40/kWh). Other energy storage forms have comparatively higher energy storage costs, the foremost of which is hydrogen, due to high costs in the production, storage, and conversion of energy storage carriers and the construction of infrastructure. Considering their technical characteristics, energy storage technologies have different advantages and disadvantages, which can be adapted to different application scenarios. For example, flywheel energy storage (FES) is suitable for short-term ancillary services, while compressed air energy storage (CAES) is fit for long-term renewable energy storage. Thanks to its fast response time and high efficiency in terms of energy storage, V2G has high applicational value and great technological potential with regard to auxiliary services such as regulating the frequency and voltage of power grids, transferring energy during peak and off-peak hours, and improving the stability of power grid systems [29]. Nevertheless, there are some technical shortcomings of V2G with respect to energy storage technology. For example, batteries, as energy storage units, are suitable for short-cycle and small-scale energy storage scenarios and are provide energy storage services on the scale of seconds to minutes, which may not be suitable for energy storage services on the daily to weekly scale when the large-scale development of renewable energy is available. In addition, the level of popularization of V2G with regard to energy storage depends on the acceptance of consumers, which is a lengthy and complex process [30].

However, considering the demand for energy storage technologies, V2G offers higher efficiency, less dependence on the external environment, and shorter response times than other energy storage technologies and can thus be flexibly used for power generation, power distribution, and power consumption, presenting remarkable technological potential. More importantly, V2G can realize flexible interactions with power grids when used for energy storage, serving as an essential part of smart power grids in the future.

2.2. Scale-Related Potential of EV-Based Energy Storage

The scale of electric-vehicle-based energy storage is mainly determined by the ownership of electric vehicles and the energy capacity of energy storage batteries [31]. When used for energy storage, electric vehicles should not only serve as a transportation tool to meet people's basic mobility needs but should also interact with the power grid. The energy stored by an electric vehicle is the energy remaining after deducting the energy used for mobility from the total battery capacity. According to the segments, the characteristics of mobility, and the features of energy consumption of electric vehicles, the formula for calculating the scale of EV-based energy storage is as follows:

$$E = \sum_{i} N_i * (Q_i - S_i * e_i) \quad (1)$$

Specifically, *i* represents a model of the process by which the capacity of batteries and electricity consumption (100 km) vary. There are five main segments of electric vehicles, namely, the A00, A0, A, B, and C segments. This paper mainly focuses on A- and C-segment electric vehicles to simplify calculations. *E* denotes the scale of EV-based energy, for which kWh is the unit of measurement. *N* stands for the ownership of EVs at different segments. *S* represents the daily traveled distance (with kilometers serving as the unit of measurement), which, in this study, is assumed to be the same for electric vehicles. *e* stands for the electricity consumption of Evs, for which kWh/100 km is the unit of measurement.

To ensure the authenticity and reliability of the data, we measured the average range, battery capacity, and electricity consumption of all A- and C-segment electric vehicles currently on sale, as shown in Table 3. Based on the statistics of 197 BEVs (private, rental, and shared BEVs) in Beijing, the average daily mileage of BEVs used for different purposes was determined. Specifically, the daily mileage of battery electric private cars among vehicles and taxis is 45 km, 114 km, and 183 km [32]. Considering that private cars will account for quite a large proportion of electric vehicles in the future, we used the average daily mileage of private cars to calculate the daily traveled distance of electric vehicles.

Table 3. Parameters of electric vehicles according to segment.

Vehicle Model	A Segment	C Segment
Average electric range (km)	426	610
Average battery capacity (kWh)	54	84
Average electricity consumption (kWh/100 km)	12.56	13.77

To visually quantify the scale of energy stored by electric vehicles, we used the daily power generation value of the Three Gorges Dam Hydropower Station (yielding 306 million kWh in 2020) as a reference. As shown in Table 2, which depicts the scale of energy storage according to the ownership of EVs, 6.04 million A-segment EVs or 3.79 million C-segment EVs would be needed to match the daily power generated by the Three Gorges Dam Hydropower Station as shown in Figure 4. If there were 100 million EVs by 2030, they (all of which would be A-segment EVs) could store 5 billion kWh of energy daily, which is almost equal to the power generation capacity of 16 Three Gorges Dam Hydropower Stations. If they were all C-class electric vehicles, they could store 8 billion kWh of energy every day, which is almost equal to the power generation capacity of 25 Three Gorges Dam Hydropower Stations. According to the average daily amount of power generated in China in 2020, namely, 20.32 billion kWh, if there were 100 million electric vehicles in 2030, they could store 25~39% of the electricity generated daily, constituting a tremendous scale.

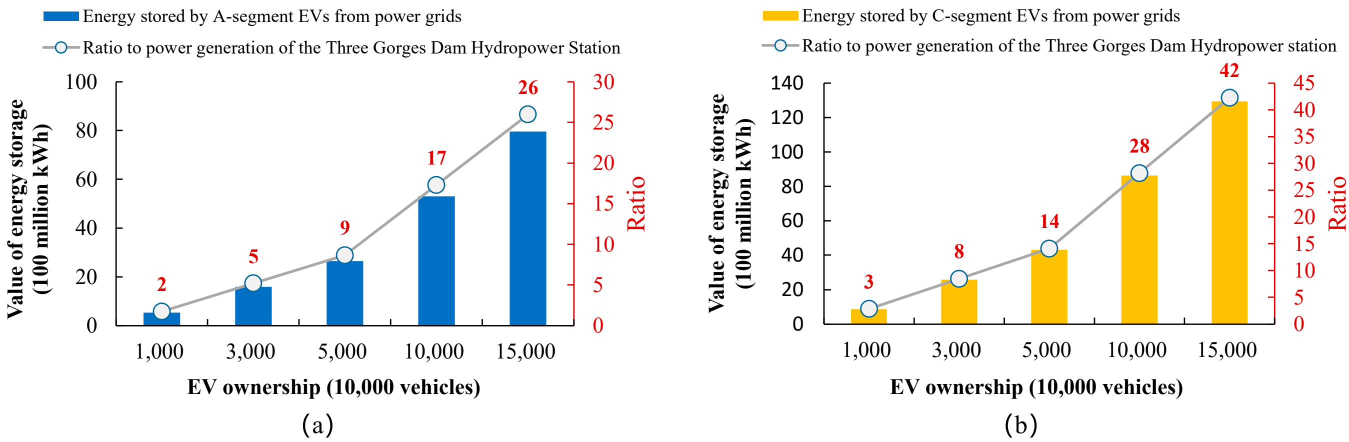

Figure 4. Scale of energy stored by electric vehicles: (**a**) A-segment scenario; (**b**) C-segment scenario.

Therefore, if electric vehicles in China were all upgraded with V2G technologies, a considerable energy storage capacity would be made available. In short, EV-based energy storage systems have the potential to facilitate large-scale energy storage. But the key lies in how to guide EV users to store energy and form large-scale V2G EV fleets. Next, the economic feasibility of V2G will be analyzed.

2.3. Economic Feasibility of EV-Based Energy Storage

Electric vehicle users can benefit economically by "shaving peaks and filling valleys" and providing auxiliary services such as frequency regulation, voltage regulation, and spinning reserve for the power grid [33]. However, the profitability mechanism of auxiliary services is still unclear. This paper only considers the economic benefits of "peak-shaving and valley-filling" for electric vehicle users.

In this paper, economic efficiency is calculated according to the research conducted by the NDRC on the technical potential and economic aspects of EV-based energy storage [7]. The following assumptions were made: there will be 100 million EVs in 2030, 15 kWh of electricity will be consumed per 100 km, the electric range will surpass 300 km, and the cost of batteries will gradually reduce, while service life will increase over time. This paper evaluates the economic efficiency of V2G while using the levelized cost of energy storage as an indicator, which includes investment cost (inverter/battery) and operation and maintenance costs (fixed and variable costs). The specific parameters and details can be found in [7,34].

Figure 5 shows the predicted result regarding the levelized cost of V2G technology. The solid black line in the figure represents the levelized cost of charging and discharging 1 kWh per unit. The area corresponding to LU 95% represents the upper and lower bounds of the levelized cost under the forecast of high and low battery investment costs. The gray, yellowish, and light blue areas indicate the price differences between peak and off-peak hours, which are 1.2, 0.8, and 0.4 CNY/kWh, respectively. The impact of the price of electricity on the technical economy of V2G was evaluated by comparing electricity price differences during different peak and off-peak hours.

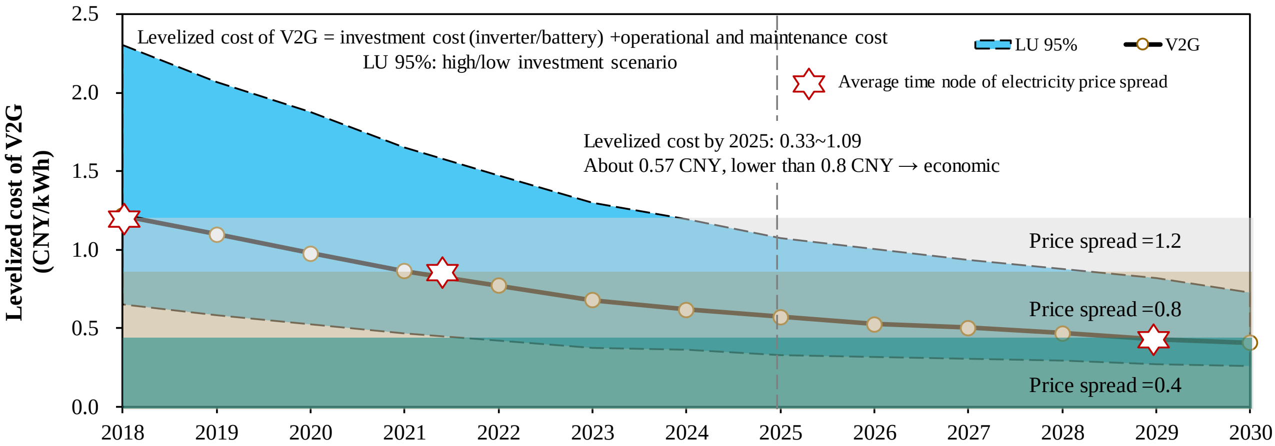

Figure 5. Economic feasibility of EV-based energy storage for users.

According to the figure, with reduced battery costs and improved technical parameters such as cycle life, the levelized cost of V2G technology would be gradually reduced. In 2025, the levelized cost would reach 0.33~1.09 CNY/kWh, about CNY 0.57, which is significantly lower than the peak-to-valley price difference of 0.8 CNY/kWh, thus presenting clear economic efficiency. Different peak-to-valley electricity price differences may affect the time points for the price parity of V2G during peak and off-peak hours. For example, if the price difference was 1.2 CNY/kWh, price parity would have been realized in 2018. If the price difference was 0.4 CNY/kWh, price parity would not be achieved until around 2029. Currently, the electricity price incurred by industrial and commercial industries in specific domestic areas is 0.8 CNY/kWh. In theory, if the large-scale development of V2G is available, it will bring economic efficiency for EV users and allow for the realization of zero-cost charging.

3. Opportunities for Developing EV-Based Energy Storage Technologies

China's strategic goal of achieving low-carbon development and its strategies for prioritizing the development of electric vehicles create the following strategic opportunities for developing EV-based energy storage technologies.

First, the "30/60 Target" accelerates the development of the energy storage industry. Compared with developed countries, China has less time to reach peak carbon emissions and achieve carbon neutrality, so it is necessary to accelerate the promotion of low-carbon technologies in the relevant industries [35]. As distributed energy storage units, electric vehicles are good carriers for the storage and consumption of renewable energy. Additionally, they can flexibly form distributed microgrids to achieve two-way interaction with the power grid. These two attributes of electric vehicles will translate into an impetus for the automotive industry to adopt low-carbon measures and for the energy industry to develop renewable energy on a large scale. Developing EV-based energy storage systems is an urgent initiative for the automotive and energy industries. To fulfill the "dual-carbon goal", it is imperative to develop EV-based energy storage systems as soon as possible, and this will also create significant strategic opportunities for the industry.

Second, electrification is an irreversible trend in the automotive industry. Adequate electric vehicles are the foundation of developing EV-based energy storage. Due to policy tailwinds, technological progress, and market maturity, the driving force of EV development is gradually shifting from policy to market factors, thus bringing about the explosive growth of EVs [36]. According to the latest statistics released by the CAAM, the penetration rate of NEVs continued to maintain a historical high of 16.4% in October 2021, for which the penetration rate of EVs was 13.6% [6]. This provides essential support for the large-scale development of V2G. It should be noted that although the large-scale development of electric vehicles will result in massively distributed energy storage units, large-scale disordered charging would also affect the stability of the power grid [37]. Therefore, the automotive and power industries need to develop EVs and power grids in a coordinated manner, for which V2G will be the best lever.

Third, cutting the costs related to and increasing the efficiency of batteries will help to significantly develop EV-based energy storage. Since 2010, the cost of batteries has dropped by about 90%; this is also one of the critical factors concerning electric vehicles' acceptance in the market and large-scale development [38]. Capacity and cycle life are the leading technical indicators concerning the use of batteries for energy storage. The energy density of batteries used for commercial applications has reached 180 wh/kg, and the cycle life of batteries has also been greatly improved. Specifically, the cycle lives of NCM/NCA and LFP batteries are about 1000 and over 2000 cycles, respectively. It can be said that the reduction in the cost of batteries has promoted the large-scale development of electric vehicles. The improvement of battery performance has bolstered the technical potential of using EVs for energy storage. Therefore, the reduction in the cost and the increase in the efficiency of batteries will help to boost the large-scale development of V2G.

Fourth, developing key V2G technologies accelerates the industrialization of vehicle–network interaction. In terms of hardware for V2G, the cycle life and safety of vehicle batteries have been further improved. Wei et al. conducted a comprehensive study on the degradation characteristics and mechanisms of commercial $Li(NiMnCo)O_2$ EV Batteries under Vehicle-To-Grid (V2G) services [39]. At the same time, with the development of power electronics technology, the charging speed and charging efficiency of bidirectional charging piles have been further improved [23]. This advancement will improve the economic aspects and operating efficiency of V2G to a certain extent [40]. With the current development of 5G technology, high-speed, safe, and efficient communication technology also plays a role in promoting the development of V2G [41]. In terms of software for V2G, actively participating in developing grid frequency/voltage regulation control strategies and orderly charge and discharge control strategies progresses the development of V2G [25,42].

4. Challenges in Developing EV-Based Energy Storage

Still in its infancy, the field of electric-vehicle-based energy storage is facing numerous challenges; thus, breakthroughs in critical technologies, improving market environments, developing innovative business models, and formulating more adequate policy standards are urgently required.

Firstly, the critical technologies for EV-based energy storage still require breakthroughs. Efforts in this regard should mainly be focused on batteries and V2G management. A battery is the core component of an EV-based energy storage system. As is well known, an increased number of charge–discharge cycles will lead to faster degradation. According to relevant research, the cycle life of a battery cannot be too low when the corresponding electric vehicle is used for energy storage, as low battery cycle life will reduce the number of interactions with the vehicle network. It follows that the profit of the electricity price differences would not offset the cost of battery degradation [43,44]. However, neither ternary lithium batteries nor lithium iron phosphate batteries can meet service life requirements at present. Therefore, battery attenuation and degradation may become the most challenging problems for the industry to solve. Moreover, the developers of electric vehicles should consider not only battery technologies but also battery resources [45]. With the large-scale development of electric vehicles, the demand for resources will increase dramatically. Electric-vehicle-based energy storage will shorten the cycle life of batteries, resulting in a greater demand for batteries, which will require more resources such as lithium and nickel. This lack of resources will increase the cost of batteries, greatly affecting the EV-based energy storage economy [46].

Generally, there are peak and off-peak hours with regard to electricity consumption. At the same time, the disorderly charging of large-scale EV fleets further aggravates the instability of the power grid. The impact of large-scale disorder in charging on the grid is mainly embodied by two aspects. First, large-scale disorders in charging have a significant impact on the carrying capacity of the power grid; in particular, the charging load of electric vehicles will be superimposed on the evening peak load of electricity, resulting in a "peak on top of peak" scenario. Second, large-scale disorders in charging will precipitate the construction of a distribution network with a full voltage level, which requires enormous investments. According to the research of Wei et al., the massive distributed new load brought by EV charging leads to great challenges with regard to the safe operation of power grids and economic dispatch [12]. For example, the cited authors found that if a disordered charging distribution mode is adopted, since the charging period is concentrated in the evening and peak power consumption occurs during the day, the charging load of electric vehicles will increase the maximum power load of the grid by about 9.79%, 12.19% and 20.11% [47]. Therefore, electric-vehicle-based energy storage development requires unified and coordinated control and management of EVs and power grids. Regarding V2G, priority is given to control and communication technologies. Control should secure the power grid's stability by tapping electric vehicles' power and capacity, thereby achieving economical, reliable, and efficient V2G. As massive energy storage units, electric vehicles are distributed in a disordered manner. The power grid requires more complex management and control than traditional fixed energy storage stations. Meanwhile, communication technology enables V2V, V2I, V2H, and V2G [13]. However, electric-vehicle-based energy storage involves a raft of participants and a large quantity of information, which poses a series of challenges to developing communication technology communication standards for large-scale EVs. First, since multiple participants are involved, it is necessary to ensure the consistency of communication interfaces and protocols. Second, V2V and V2G require timely data transmission, so the corresponding communication technology should be efficient and fast. The response time is usually under one second. Third, since V2V and V2G involve the transmission and collection of massive numbers of data, it is necessary to ensure communication security to avoid infringing on privacy due to potential data leakage. Therefore, electric-vehicle-based energy storage and V2G still have a long way to go.

Secondly, it is urgent to create new market environments and develop novel business models to develop electric-vehicle-based energy storage systems. First, the corresponding infrastructure is still imperfect. The development of EV-based energy storage requires a convenient charging environment to remove range anxiety caused by energy storage and sufficient charging piles that allow for long-term connection. However, the construction of charging infrastructure still falls short of the basic requirements, roadblocks to building charging piles in residential communities still exist, and the measures for fast charging and emergency energy replenishment require further improvement. Second, EV users are currently not showing high levels of enthusiasm, and the construction of the market environment is slow. EV users do not clearly understand electric-vehicle-based energy storage and are wary because energy storage will reduce battery life. In addition, they still lack a clear understanding of the profit mechanism for connecting their EVs to the power grid for energy storage. Although it is possible to profit from charging vehicles during off-peak hours and feeding electricity back to power grids during peak hours, the success of this endeavor is highly correlated with regional electricity price differences. Electric vehicles, as providers of auxiliary power services such as frequency regulation and rotating backups, cannot be profitable due to the low concentration and immaturity of the market in comparison with centralized energy storage stations. Due to multiple factors, EV users are not willing to use their EVs for energy storage, making it impossible to form a feasible market environment. Third, using electric vehicles for energy storage is a systematic project that involves EV users, vehicle manufacturers, charging station operators, power grids, energy companies, and local governments. Developing business models that ensure a mutually beneficial result is critical to sustainable electric-vehicle-based energy storage development. However, there are still no conclusions regarding the creation of an adequate commercial ecosystem for EV-based energy storage, who will serve as the subject for the construction of such an ecosystem, and how to create a sound market environment and novel business models to yield mutually beneficial results.

5. Coping Strategies for EV-Based Energy Storage

EV-based energy storage is the key to the transition to renewable energy and an important measure with which to maximize the use of EV battery resources. China will prioritize the strategic layout of EV-based energy storage in the future. Therefore, it is necessary to make corresponding adjustments to tackle EV-based energy storage challenges in terms of technology, market development, and policies and standards.

Regarding technology, we should focus on both short-term technical challenges and long-term technological development. The development of batteries requires a comprehensive weighing of cost, safety, energy density, and cycle life [48]. Given the challenges posed by EV-based energy storage with respect to batteries, we should consider upgrading battery technologies from the perspective of both short-term and long-term solutions, as shown in Figure 6. As shown in the figure, to cut the initial purchase costs of EVs and increase their penetration rate, safety and costs are given top priority in the battery design process, and energy density and cycle life are also taken into account. However, with the gradual improvement of charging and battery swapping infrastructure and the prominent energy storage role of EVs (energy storage and second-life use), greater attention should be paid to batteries' safety and cycle lives while relegating the importance of cost and energy density. Therefore, in the short term, the guiding principle is to improve batteries' safety performance and cycle lives. Meanwhile, it is necessary to consider the recycling of batteries at the beginning of the design phase. In the long run, considering the shortage of battery resources, EV batteries should be transformed into resource-rich new material batteries, such as lithium–sodium hybrid batteries, sodium-ion batteries, and aluminum–air batteries. At the same time, we should seek breakthroughs in the technical problems faced by the new material and new system batteries acting as batteries for EVs, such as improving sodium-ion batteries' energy density. In seeking breakthroughs in battery technology, the government should actively foster a healthy and orderly developmental environment and encourage automakers, battery manufacturers, and research institutions to increase investments in the R&D of the basic science and engineering applications of batteries.

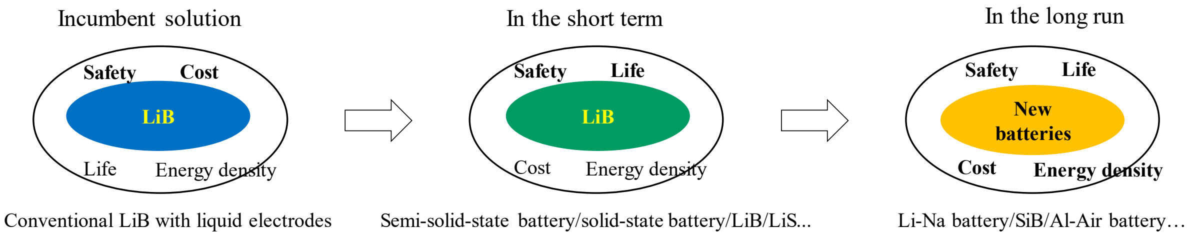

Figure 6. R&D trends in relation to batteries for EV-based energy storage.

To develop V2G technology, it is necessary to address problems facing scheduling control and communication technology [25,28]. The V2G operating platform largely solves the problem of the mismatch between supply and demand, robustly ensures the stability of the grid system, and sufficiently addresses the economic concerns of users. Therefore, the corresponding scheduling control algorithms should emphasize robustness, accuracy, and intelligence. In addition, considering the limitations of existing energy storage technologies, scheduling algorithms should be better adapted to EV-based energy storage technologies. For example, to address the short cycle lives of existing batteries, scheduling algorithms can prioritize power regulation (frequency and voltage regulation) for the shallow charging and shallow discharging of batteries and be used in peak load shifting in grids in the form of demand response. As EVs and the scale of renewable energy continue to expand, scheduling algorithms can dispatch EVs for power and energy regulation, to enable more efficient charging and discharging of batteries, and to gradually build a mobile energy internet with distributed microgrids. It is well known that China faces a high technical barrier regarding operating platforms. The V2G operating platform can leverage the mature experience of advanced operations and management platforms in China and take advantage of blockchain's decentralized, tamper-evident, and traceable features to achieve the comprehensive scheduling and management of EVs. In addition, V2G operating platforms and grid operators can implement IoT and 5G technologies in the construction of virtual power plants to ensure timely, accurate, and secure data transmission. For instance, a V2G operating platform should unify the communication technology protocols and interfaces between vehicle-to-vehicle (V2V), vehicle-to-home (V2H), and vehicle-to-grid (V2G) platforms to make the connection more efficient and convenient. Given the data security issues concerning future V2G interaction, it is necessary to upgrade cybersecurity technologies to protect the privacy and security of users.

Regarding market development and business models, the EV-based energy storage industry involves multiple sectors and organizations [27]. To realize the coordination and unification of the industry, it is necessary to build a mutually beneficial business ecosystem with the V2G operating platform serving as the core and that incorporates the participation of users, automobile manufacturers, charging station operators, power grids, energy companies, battery-recycling operators, and governments, as shown in Figure 7.

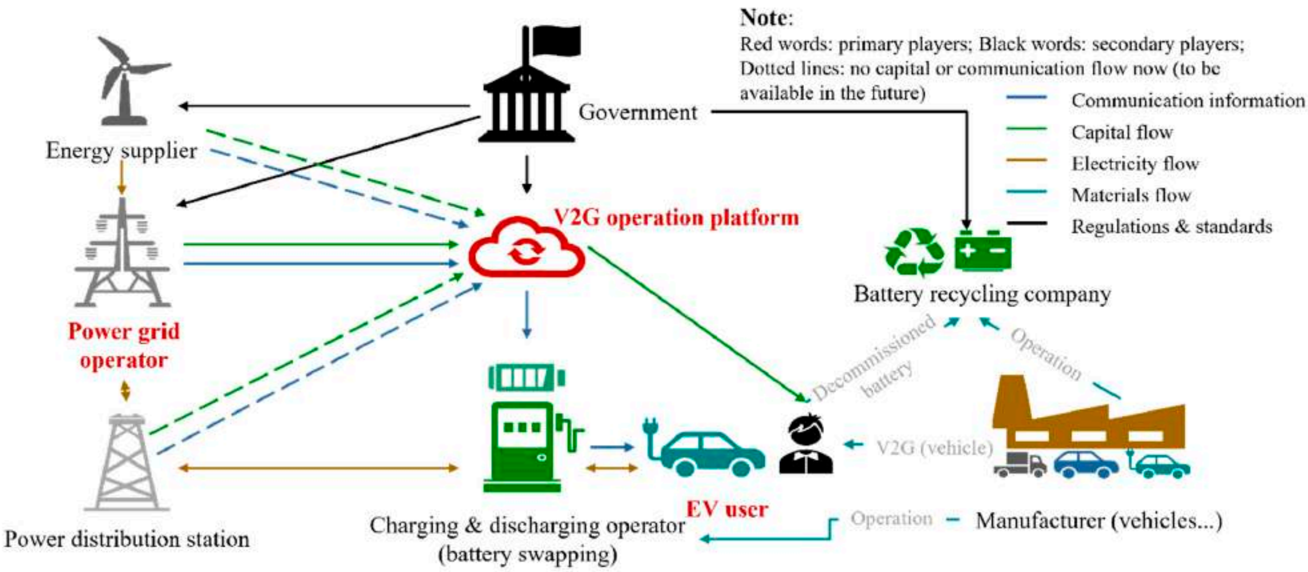

Figure 7. EV-based energy storage business ecosystem.

To ensure the coordinated development of multiple sectors, enterprises, and organizations, V2G operating platforms can be built by third-party organizations such as industry associations or grid operators. In this business ecosystem, the V2G operating platform transfers information and capital flow between users, charging station operators, power grids, energy companies, etc., by managing the scheduling of power and energy between EVs and power grids, thus establishing a fair, equitable, and mutually beneficial business model for multiple parties. At the same time, the platform needs to adopt the business model of virtual power plants in conjunction with the grid company and develop appropriate peak and trough electricity price strategies and pricing mechanisms for grid-assisted services to ensure users receive economic benefits and are motivated to participate in EV-based energy storage schemes. Charging infrastructure operators should accelerate the construction of bi-directional charging and discharging infrastructure and collaborate with the V2G operating platform and grid companies to establish methods and pricing mechanisms that can measure, audit, and trade electricity. Automakers in this business ecosystem mainly provide users with V2G services for EVs and interact with grid companies to render V2G technology more reliable and standardized. Energy producers and distribution grids do not initially interact directly with the V2G operating platform but rather transmit power through grid operators. However, as V2G technology matures, EV-based energy storage systems can directly participate in energy producers' long-cycle energy storage and distribution grids' electricity scheduling and trading. To fully exploit EV-based energy storage systems' energy- and resource-related potential, battery-recycling operators are introduced in the business ecosystem to oversee the second-life use and recycling of decommissioned batteries. In this business ecosystem, the government is mainly responsible for the macro-control and policy guidance of multiple participants and formulates corresponding technical standards and transaction mechanisms. The synergy and collaboration of all participants in the business ecosystem can facilitate a mutually beneficial situation and promote the commercialization and large-scale development of EV-based energy storage.

In terms of policies and standards, firstly, to develop EV-based energy storage, it is necessary to develop a comprehensive and systematic top-level strategic plan across industries and organizations, clarify the roles and responsibilities of various agents in the market, and determine strategic directions, development goals, and executable technology paths. Secondly, considering the barrier to the initial development of EV-based energy storage systems, the automotive and energy industries must develop corresponding incentive policies to promote these systems' market-oriented development as soon as possible [49]. For example, the government should provide subsidies and incentives to automakers who develop V2G-enabled EVs, which would thus promote the production and promotion of V2G-enabled EVs. Thirdly, given the lack of standards for EV-based energy storage technology, technical standards for communication interfaces, protocols between EVs and power grids, and safety supervision methods should be developed. The rules and standards for measuring, auditing, and trading electricity according to the mechanism behind the commercial operation of EV-based energy storage should be determined. Finally, it is necessary to accelerate research into EV-based energy storage trading mechanisms and determine the appropriate pricing mechanisms. In addition, to promote the low-carbon transformation of the automotive industry and the energy industry more directly, a carbon-inclusive policy can be introduced to give a certain percentage of carbon credits to EV users and grid operators who participate in energy storage in order to realize the connection between EV-based energy storage trading policies and carbon trading policies.

6. Conclusions

EVs can store and consume energy, enabling peak load shifting through energy transfer, frequency regulation, and rotating backups. They play a significant role in the low-carbon transformation of the automotive and energy industries. The proposal of dual-carbon goals has accelerated China's plans to implement EV-based energy storage systems. At the same time, the rising market share of EVs and the lower cost and higher efficiency of batteries provide a solid boost to the development of EV-based energy storage systems. Considering its role as energy storage technology, EV-based energy storage provides the technical advantages of a low energy storage cost, fast response times, low dependence on the environment, etc. In 2030, the average electricity stored in EVs per day is expected to be about equal to the amount generated by 16 to 25 Three Gorges Hydropower Stations, which is a large amount of stored energy. Theoretically, in case of a significant price difference between peaks and troughs, EV users can achieve certain economic benefits through V2G. Therefore, EV-based energy storage systems feature technical feasibility, economic feasibility, large-scale energy storage, and other potential affordances. However, the EV-based energy storage field still faces challenges such as the need for critical technological breakthroughs, an immature market environment and business models, and inadequate policies and standards. Among them, policies and standards, the market environment, and business model development are the critical roadblocks to promoting EV-based energy storage. Therefore, China should improve its policies and standards faster, actively foster a good market environment, and facilitate the upgrading of battery technologies and V2G management technologies.

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