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Perspective

Application Prospect, Development Status and Key Technologies of Shared Energy Storage toward Renewable Energy Accommodation Scenario in the Context of China

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Abstract: With the promotion of carbon peaking and carbon neutrality goals and the construction of renewable-dominated electric power systems, renewable energy will become the main power source of power systems in China. How to ensure the accommodation of renewable energy will also be the core issue in the future development process of renewable-dominated electric power systems. In this context, shared energy storage (SES), a novel business model combined with energy storage technologies and the sharing economy, has the potential to play an important role in renewable energy accommodation scenarios. This paper systematically organizes the application prospect, development status and key technologies of SES in the renewable energy accommodation scenario in the context of China, providing helpful references for the promotion of the business model. Firstly, a typical SES framework for renewable energy accommodation is described, and three basic forms of SES in this scenario are presented. Moreover, the application prospect of SES in the renewable energy accommodation scenario is quantitatively analyzed based on the renewable energy generation planning under the carbon peaking goal and the current guarantee mechanism of renewable energy accommodation. Furthermore, the rules for energy storage systems that provide the peak-regulation ancillary service in typical regions and provincial administrative regions in China are summarized, and the development status of SES in the renewable energy accommodation scenario is analyzed, combined with the actual market data. Finally, the key technologies to promote the further development of SES for renewable energy accommodation are presented.

Keywords: shared energy storage; renewable energy accommodation; peak-regulation ancillary services; business model; energy policy

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1. Introduction

With the establishment of carbon peaking and carbon neutrality goals, renewable energy generation (REG) represented by photovoltaic (PV) and wind turbine (WT) will continue to maintain a rapid development trend in China and gradually become the main power source of renewable-dominated electric power systems [1,2]. In the past 10 years, the installed capacity of PV and WT in China increased 10 times to 640 GW, accounting for 26.9% of the total installed capacity of power generation [3]. According to the estimation of the Global Energy Interconnection Development and Cooperation Organization (GEIDCO), the installed capacity of PV and WT will reach 1825 GW and 6300 GW, respectively, in 2030 and 2060. The randomness, volatility and intermittence introduced by a high proportion of REG pose a huge challenge to the balance of supply and demand [4]. Therefore, how to accommodate the massive renewable energy will be a core problem to be solved in the power system for a long time in the future [5]. In this context, it is a key means to promote renewable energy accommodation by tapping into flexible resources to enhance the regulation capability of power systems.

As a novel power technology, energy storage can realize the decoupling of power generation and consumption in time and space, and alleviate the contradiction caused by the imbalance between REG and local loads [6,7]. In recent years, the energy storage systems (ESSs) represented by the lithium-ion battery have been widely deployed in the power system and the installed capacity is increasing year by year due to the significantly decreased investment cost [8]. However, contrary to the soaring enthusiasm for ESS construction is the lack of energy storage business models, resulting in seriously idle energy storage resources. In this instance, the shared energy storage (SES) business model has the potential to become a breakthrough to realize the commercialization of energy storage by combining energy technology with the sharing economy [9–11]. At present, there are research works on SES involving many fields, such as optimal sizing and real-time control for community energy storage, the energy management of integrated energy systems and the regulation of power systems [12–18]. As an important application scenario, renewable energy accommodation is also considered in the research works. Based on geographic information systems and multi-criteria decision-making methods, a two-stage evaluation method for the site selection of WT-PV-SES projects is developed in [12]. For the original WT-PV projects, the integration of SES can store and release renewable energy to be curtailed. In [13], the cost-saving energy consumption and less solar power spillage are realized by shifting the curtailed renewable energy by applying SES in the residential community. A hybrid SES framework is proposed in [14], where the private ESSs and independent energy storage operators jointly provide SES services, including accommodating renewable energy and countering the wind and solar uncertainty, for REG users. In [15], an SES trading pilot project for renewable energy accommodation in Qinghai, China, is introduced, where SES users can trade with REG users for energy storage resources. Moreover, an evaluation index system of the SES market for renewable energy accommodation is proposed in [15], which can reflect the market states from the perspectives of the market structure, user conduct and operation performance. The practicability and effectiveness of SES in the renewable energy accommodation scenario have been verified by the existing research works. However, to our knowledge, the SES business model in the renewable energy accommodation scenario is not sufficiently and systematically analyzed in these works.

In the context of China, the application prospect, development status and key technologies of SES for renewable energy accommodation are systematically organized, analyzed and described in this paper. The main contributions of this paper are identified as follows:

1. The application prospect of SES in the renewable energy accommodation scenario, i.e., the renewable energy that can be accommodated by SES, in China in 2030, is quantitatively analyzed according to the REG planning under the carbon peaking goal and the guarantee mechanism of renewable energy accommodation.
2. Combined with the rules of ESSs for the peak-regulation ancillary service and the actual market data of Qinghai province and Gansu province, the latest development status of SES for renewable energy accommodation in China is summarized.
3. To counter the existing issues and deficiencies, three key technologies of SES in the renewable energy accommodation scenario are presented, aiming at the further development and promotion of the SES business model.

The rest of this paper is organized as follows. The business philosophy of SES is introduced as well as the typical framework and the basic forms of SES for renewable energy accommodation are introduced in Section 1. In Sections 2 and 3, the development trend of REG in China under the carbon peaking goal is described, and the application prospect of SES in the renewable energy accommodation scenario is quantitatively analyzed. In Section 4, the development status of SES for renewable energy accommodation in China is summarized. The three key technologies are presented in Section 5 to promote the SES business model. In Section 6, the conclusions of this work are drawn.

2. SES Business Model toward Renewable Energy Accommodation Scenario

2.1. Energy Storage Business Model under the Concept of Sharing Economy

Jeremy Rifkin, an American economist and sociologist as well as the proponent of the concept of the energy Internet, once predicted in the book *The Zero Marginal Cost Society* that the sharing economy will bring a resource revolution, changing the economic lifestyle of humans [19]. Sharing economy refers to a novel business model in which individuals or institutions temporarily transfer the right to use idle resources to demanders for fees [20]. Recently, benefiting from the development of communication technologies and the mobile Internet, the sharing economy has begun to be practiced and applied in transportation, finance, healthcare, energy and other fields [21]. According to the report released by the State Information Center, the trade size of China's sharing economy in 2021 reached 3688.1 billion CNY. The sharing economy has changed residents' living and consumption habits to a certain extent. In the sharing process of idle resources, the utilization rate of resources can be improved, and both the suppliers and the demanders can obtain benefits from it, increasing the total social welfare.

SES can be seen as a typical application scenario of the sharing economy in the energy sector [10,21]. In general, there are three reasons for choosing to combine energy storage technology with the sharing economy:

1. The problem of idle energy storage resources is serious. The functional orientation of ESSs in the power system is to provide energy storage services, including emergency power supply, electricity price management, load tracking and power quality regulation [7]. The energy storage services provided by ESSs are generally intermittent. Moreover, the great majority of ESSs only provide energy storage services to a single user, i.e., the owner of the ESS [22]. Therefore, the utilization hours of ESSs are relatively low in most application scenarios. It is difficult for the owners of ESSs to quickly recover the investment cost through self-use energy storage services.
2. The potential of the energy storage services market is huge. Currently, REG users, traditional thermal generation (TG) users and power users with distributed generation constitute the core consumer group of the energy storage services market due to the frequent demands for energy storage services. Actually, massive power entities outside the core consumer group also have the demands for energy storage services to improve their electric behaviors. However, for the non-core consumer group, the economy is the main reason that hinders the investment and deployment of ESSs because of the low frequency of use. In this context, the non-core consumer group is eager for a market that can provide a short-term lease of the use rights of energy storage resources. On the other hand, energy storage services have certain heterogeneous characteristics due to the different equipment parameters of energy storage technologies [23]. In some special scenarios, power entities may generate demands for heterogeneous energy storage services that cannot be fully satisfied by their own ESSs. At this time, the above demands will constitute the long-tailed market of energy storage services, which also has great commercial potential.
3. An effective business model for energy storage technologies is lacking. The profit channel of energy storage is restricted in the current power systems, which can only bring a very limited return on energy storage investment. Peak-valley electricity price arbitrage is the more mature business model of energy storage [24], but its profit is highly dependent on the difference between the electricity prices at peak time and valley time. With the rapid decline of energy storage costs in recent years and the growth of the installed capacity of REG, many provinces in China have begun to require new grid-connected REG users to deploy a certain proportion of energy storage resources [15]. However, the revenue from the increasing on-grid electricity and the reduced penalty costs cannot fully cover the investment costs of energy storage. Moreover, the investment and construction of large-scale ESSs have become an important measure to stimulate the local economy and create jobs in some

cities. Based on this, exploring an effective business model has become the key to the sustainable development of these ESSs.

In summary, SES is a novel business model combined with energy storage technology and the sharing economy. The core idea of SES is to realize the separation of the ownership and the use rights of energy storage resources, i.e., the owners can lease the use rights with respect to the idle energy storage resources out to the demanders of energy storage services. In the sharing process, the utilization rate of energy storage resources can be improved so that the owners obtain additional benefits and the cost recovery period will be shortened. On the other hand, the demanders who purchase the use rights can obtain the corresponding energy storage services at the agreed time to promote their industrial production and daily life. The schematic diagram of the SES business model is shown in Figure 1. It can be seen that SES is not limited to a specific energy storage technology. When policies and technical conditions permit, different types of energy storage technologies, such as lithium battery-based energy storage, flow battery-based energy storage, flywheel energy storage (FES) and compressed-air energy storage (CAES), can be shared with the demanders [25].

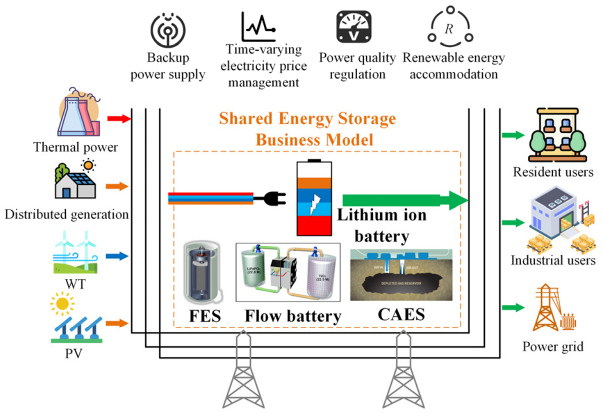

Figure 1. Schematic diagram of SES business model.

2.2. Typical Framework and Basic Forms of SES for Renewable Energy Accommodation

Due to the characteristics of randomness, volatility and intermittence for PV and WT, the regulation capability needs to be dispatched to match the generated power with the loads when REG is connected to the power system. With the increase in the proportion of REG in the power system, when the power generated by REG users is high, the traditional regulation capability of the power systems, e.g., reducing the output of TG and changing the pumped storage facilities belonging to the power company to the motor state, will be exhausted. At this time, the power system cannot accommodate renewable energy completely, resulting in wind and solar power curtailment. To sum up, if the regulation means of the power system to improve the regulation capability are not greatly expanded, it will be difficult to further increase the proportion of REG on the basis of security and stability, hindering the realization of the carbon peaking and carbon neutrality goals [26]. To address the above issue, a special power ancillary service, i.e., a peak-regulation ancillary service, is designed in China. A peak-regulation ancillary service is when the grid-connected entities, including generators, ESSs and adjustable loads, adjust the output power according to the dispatching instructions to track the changes in the loads and REG [27]. In this process, the grid-connected entities providing the peak-regulation ancillary service can obtain economic compensation, and the power system can obtain a more adequate regulation capability. In the current rules of the peak-regulation ancillary service in China, only the grid-connected entities that accommodate renewable energy during wind and solar power curtailment can obtain economic compensation [28,29]. Therefore, it can be considered that the peak-regulation ancillary service is equivalent to a power service for renewable energy accommodation. It is worth noting that many regions and provincial administrative regions have established peak-regulation ancillary service markets, where the allocation of peak-regulation resources can be optimized through marketization.

Since the peak-regulation ancillary service is not constrained by the deployment location of the grid-connected entities, the ESSs of the whole power system can provide the regulation capability in the form of SES [30]. Thus, driven by the carbon peaking and carbon neutrality goals, renewable energy accommodation has become the application scenario of SES with the best development potential and landing conditions in China at this stage. A typical framework of SES in the renewable energy accommodation scenario is shown in Figure 2. It can be seen that REG users can store the curtailed energy in the energy storage resources of SES users when the power system cannot accommodate all the renewable energy. After the power system has enough accommodation capacity, i.e., the power system is during peak loads or low power generation, the SES users will release the stored renewable energy. In the whole circulating process, SES users, as the energy transfer station, realize the space–time translation of the curtailed renewable energy, so that the curtailed renewable energy is finally accommodated by the power system. The essence of renewable energy accommodation is that SES users sell the additional power generation rights to REG users. The power generation rights can be considered as the non-peak power generation rights obtained from traditional TG users for free due to the priority of renewable energy in the power system and the characteristics of SES users. Therefore, the premise for accommodating the curtailed renewable energy is that REG users purchase the use rights of idle energy storage resources, i.e., additional power generation rights, from SES users. At this time, the SES market is the infrastructure for energy storage resource sharing, providing the functions of matching, clearing, trading and settlement [31]. In the current stage, independent SES markets are not established in China. Instead, SES markets are integrated into the ancillary service markets, that is, the trade of the use rights of idle energy storage resources is regarded as a kind of commodity of the ancillary service markets. In the ancillary service markets, the use rights of idle energy storage resources are determined for specific purposes and are cleared together with other power resources participating in the auxiliary service markets. In this context, the SES trading in the renewable energy accommodation scenario can be seen as a part of the peak-regulation auxiliary service market.

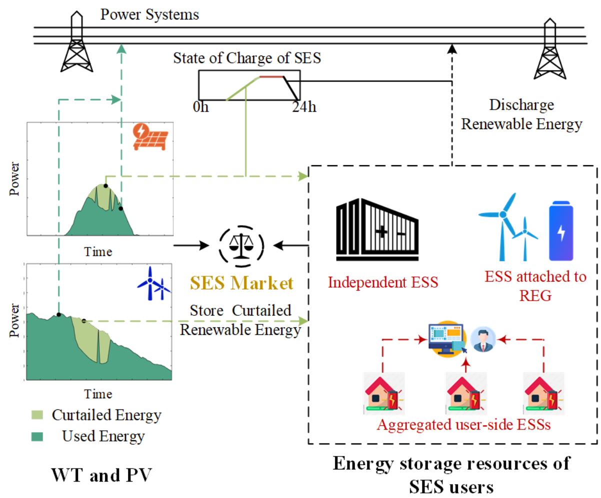

Figure 2. A typical framework of SES in the renewable energy accommodation scenario.

On the other hand, it can be seen from Figure 2 that the energy storage resources of SES users in the renewable energy accommodation scenario are generally in the following three basic forms:

1. Independent ESSs. Independent ESSs refer to energy storage facilities that are not attached to any grid-connected entities and operate independently. In terms of dis-

patching, independent ESSs can directly sign the dispatching agreement with the power dispatching agency as an independent entity, rather than be regarded as the auxiliary equipment of REG users and TG users [32]. Currently, the government of China holds a conservative attitude toward the incorporation of independent ESSs into power transmission and distribution assets to prevent the unrestricted investment of power companies. Therefore, independent ESSs cannot obtain stable revenue from the transmission and distribution price, i.e., fixed tariff. In fact, any energy storage service generated by independent ESSs can be considered as being provided to REG users, TG users, power users, power companies or all entities in the power system. In other words, the use rights of independent ESSs are shared with different entities in different periods. Thus, SES is the most common business model for independent ESSs. In many provinces in China, independent ESSs are equivalent to SES. In the renewable energy accommodation scenario, independent ESSs are allowed to sign medium and long-term lease contracts for the energy storage capacity with multiple REG users to share the use rights of energy storage resources. On the other hand, independent ESSs can participate in the peak-regulation ancillary service market as independent entities and realize the sharing of the short-term use rights through centralized bidding (CB), dispatching on demand by power systems (DDPS) and other trading methods [15].

2. ESSs attached to REG. There is no doubt that REG will occupy more and more power generation space in the future. However, while undertaking power generation rights and enjoying benefits from traditional TG, REG should also undertake various responsibilities to ensure the overall safe and stable operation of the power system, i.e., provide peak regulation, frequency regulation, voltage regulation and other ancillary services, which are formerly provided by TG [33]. Therefore, in the context of the insufficient regulation capability of power systems, many provinces and cities issue policies to require REG users to be equipped with ESSs. The power capacity of the ESSs ranges from 5% to 25% of the installed capacity of REG users, and the charging duration ranges from one hour to four hours. As we know, the deployment of ESSs can reduce the prediction error and stabilize the output of REG, and renewable energy to be curtailed can be stored to improve the accommodation level [12]. However, there may be no demand for storing the curtailed renewable energy every day for an REG user. In addition, there is also some regularity in the period when wind and solar power curtailment occur, making energy storage resources difficult to be fully utilized and seriously idle. In this circumstance, ESSs attached to REG can lease the short-term use rights of idle energy storage resources to different types of REG users in different regions. Moreover, several REG users can form an alliance to realize the sharing and mutual aid of energy storage resources through long-term agreements [34]. Furthermore, the ESSs attached to REG can also provide the peak-regulation ancillary service as the REG users. In summary, the SES business model will improve the utilization rate of ESSs attached to REG, increase the overall regulation capability of the power system, as well as enable REG users to obtain benefits to reduce the financial pressure caused by the deployment of ESSs.
3. Aggregated user-side ESSs. Due to the clear profit channel, user-side ESSs are the earliest development in China. The revenue of user-side ESSs is mainly from peak-valley electricity price arbitrage. The daily usage period of the user-side ESSs in the arbitrage mode is relatively fixed, which means that there are regular idle periods every day to accommodate renewable energy for different REG users [35]. In general, user-side ESSs cannot directly provide the peak-regulation ancillary service due to the smaller installed capacity. Therefore, it is necessary to aggregate several user-side ESSs to meet the access conditions of the peak-regulation ancillary service. Finally, the aggregated user-side ESSs, which can be seen as a virtual power plant, can provide the peak-regulation ancillary service as a whole.

With the development and promotion of the SES business model, more energy storage resources will participate in the renewable energy accommodation scenario in the above three basic forms, supplying the power system with massive regulation capability.

3. Application Prospect of SES in the Renewable Energy Accommodation Scenario under the Carbon Peaking Goal

3.1. Overview of REG in China under the Carbon Peaking Goal

To achieve global sustainable development, the solemn promise of "China aims to have CO_2 emissions peak before 2030 and achieve carbon neutrality before 2060" is declared. The carbon peaking and carbon neutrality goals are actually a control plan for the total carbon dioxide emissions of the whole society, which needs to be shared by all industries. According to the statistics, the carbon emissions of the power industry accounted for more than 30% of the total carbon emissions of the whole society in 2021 [36]. Considering that electric energy substitution is the main measure to reduce industrial carbon emissions in transportation, construction, manufacturing and other fields, the reduction in carbon emissions in the power industry will be the basis for the carbon peaking and carbon neutrality goals of the whole society. For the power industry, the important way to reduce carbon emissions is to promote the clean transformation of energy, which will control carbon dioxide emissions from the source [37].

In the past 10 years, the emissions intensity of GDP has decreased by 34.4% in China. It can be seen from the data released by the International Energy Agency (IEA) that the growth rate of carbon dioxide emissions is only 4.8% when China's electricity demand increased by 10% in 2021 [38]. However, the carbon peaking goal is close at hand. In the next few years, more REG installations need to be deployed in China's power system to meet both the growing power demand and the declining carbon emissions. The installed capacity of WT and PV in China is shown in Figure 3. It can be seen from Figure 3 that, from 2012 to 2021, the installed capacity of WT increased from 61.6 GW to 329 GW, and the installed capacity of PV increased from 6.7 GW to 307 GW, with an average annual growth rate of 20.5% and 52.9%, respectively. According to the estimation of GEIDCO, the installed capacity of WT and PV will reach 800 GW and 1025 GW in 2030. The average annual growth rate is still 10.4% and 14.3%. The above data show that there will be, respectively, 2.4 times and 3.3 times the current installed capacity of WT and PV in less than 10 years, resulting in exponentially increasing demands for the regulation capability of the power system. Moreover, the corresponding gross production of electricity of WT and PV is shown in Figure 4. In 2021, the gross production of electricity of WT and PV was 655.6 TWh and 325.9 TWh, and the average annual growth rate in the past 10 years is 22.8% and 61.3%, respectively. It is estimated that the gross production of electricity of WT and PV will increase to 1482.7 TWh and 1012 TWh, respectively, by 2030.

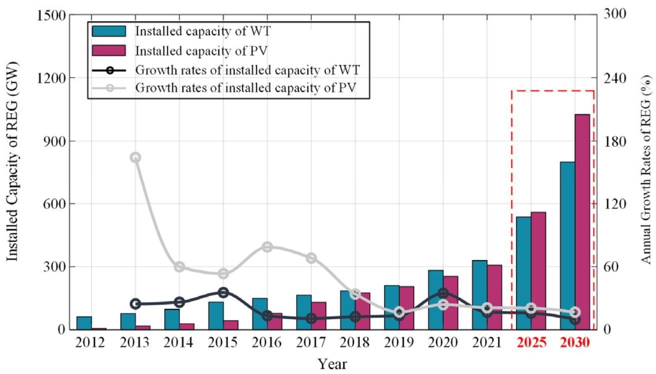

Figure 3. Installed capacity of WT and PV in China.

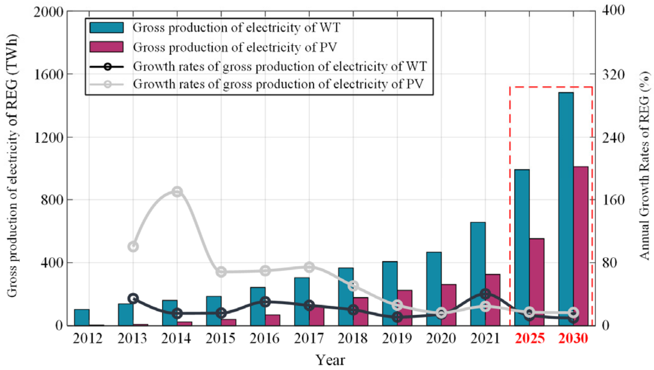

Figure 4. Gross production of electricity of WT and PV in China.

On the other hand, the power generation structure of the power system in China will undergo significant changes with the increase in the proportion of REG. The traditional power system dominated by TG turns to the power system dominated by REG [39]. The shares of the installed capacity and gross production of electricity of WT and PV are shown in Figures 5 and 6, respectively. It can be seen from Figure 5 that the share of the installed capacity of WT and PV reached 26.75% in 2021. It is estimated that the share will reach 48% in 2030, which is close to half of the total installed capacity of the power generation and exceeds 32.5% of TG (including coal power and natural gas power). In terms of the share of the gross production of electricity, the share of WT and PV was 11.81% in 2021, and will increase to 22.58% in 2030.

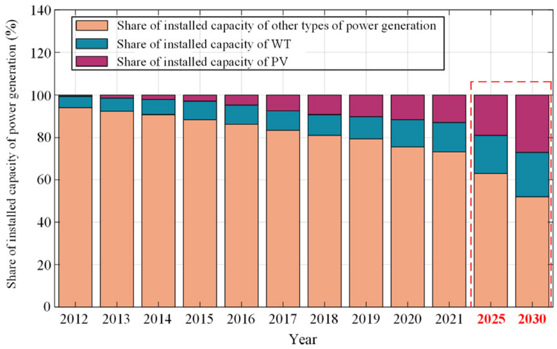

Figure 5. Share of installed capacity of WT and PV in China.

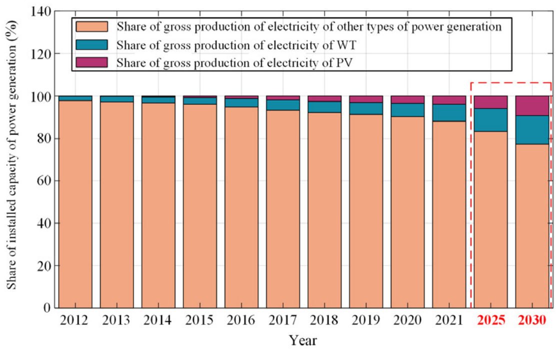

Figure 6. Share of gross production of electricity of WT and PV in China.

3.2. Analysis of the Application Prospect of SES in China Considering the Guarantee Mechanism of Renewable Energy Accommodation

In the next few years, the installed capacity of REG, especially WT and PV, will significantly increase on the existing basis and occupy a higher share in the power system in order to achieve the carbon peaking goal in 2030. Different from thermal power, hydropower and other types of controllable power generation, while increasing the installed capacity of WT and PV, it is necessary to ensure their utilization rate to realize the replacement of clean energy for fossil energy. Based on the installed capacity and gross production of electricity given in Figures 3 and 4, the utilization hours of WT and PV in 2030 will be 1850 h and 1000 h, respectively, if the utilization hours of other types of power generation remain unchanged. The utilization hours of WT and PV in 2021 were, respectively, 1993 h and 1061 h, which were not much different from those in 2030. This means that the utilization hours of WT and PV in China cannot decrease significantly in the context of increasing the installed capacity of WT and PV, that is, a high proportion of renewable energy needs to be accommodated.

To address the above issue, China formally proposed to establish and improve the guarantee mechanism of renewable energy accommodation in May 2019 [40]. The responsibility weights of renewable energy accommodation of the provincial administrative regions are determined in the mechanism. Moreover, market entities are obliged to accommodate renewable energy, and their electricity sales or electricity consumption should correspond to the minimum responsibility weights in provincial administrative regions. It is worth mentioning that the mechanism includes two types of indices, namely, the responsibility weight of total renewable energy accommodation and the responsibility weight of non-water renewable energy accommodation (RWNWREA) [5], and the latter includes other types of renewable energy power generation except hydropower, such as wind power, solar power, biomass power and geothermal power. For every provincial administrative region, the above two types of indices need to be completed simultaneously. In summary, under the pressure of the guarantee mechanism of renewable energy accommodation, all provincial administrative regions will actively improve the regulation capability of the power system to accommodate the renewable energy that can complete the responsibility weights. Figure 7 shows the completed RWNWREA of China in 2021. It can be seen that the RWNWREA shows a trend of being high in the north and low in the south, which is basically consistent with the distribution of non-water renewable energy resources in China. The highest RWNWREA of 29.3% lies in Qinghai province. However, the wind and solar power curtailment rates of Qinghai province in 2021 were, respectively, 10.7% and 13.8%, far exceeding the national average rates of 3.1% and 2%. The above data indicate that the regulation capability of Qinghai province has been basically exhausted, and, thus, it is difficult to accommodate more renewable energy.

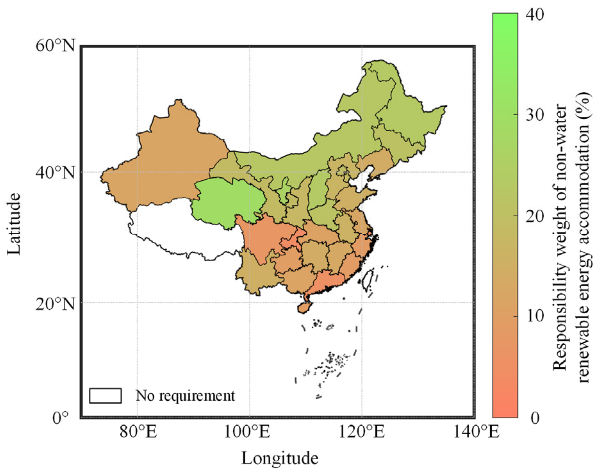

Figure 7. Completed RWNWREA of China in 2021.

As shown in Figure 8, the target RWNWREA of China in 2030 is given. Each provincial administrative region needs to accommodate 9% to 15.3% of non-water renewable energy on the basis of 2021. At this time, renewable energy accommodation will become a problem faced by all provincial administrative regions, and the deployment of regulation resources will be strengthened nationwide.

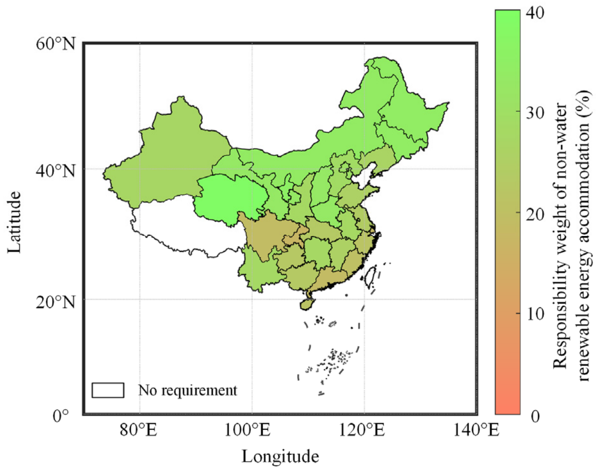

Figure 8. Target RWNWREA of China in 2030.

In this context, SES can release the regulation capability of idle energy storage resources and will be an important part of the incremental regulation resources of future power systems. In order to quantitatively analyze the application prospect of SES in the renewable energy accommodation scenario, according to the RWNWREA data, the renewable energy accommodated by SES in all provincial administrative regions in 2030 is simply estimated, which can be expressed as

$$E_i^{\mathrm{SES}} = (E_i^{\mathrm{C-30}}\omega_i^{30} - E_i^{\mathrm{C-21}}\omega_i^{21})\eta_i\mu_i\gamma_i^{\mathrm{SES}} \tag{1}$$

where E_i^{SES} denotes the renewable energy accommodated by SES in the provincial administrative region i in 2030. $E_i^{\mathrm{C-30}}$ and $E_i^{\mathrm{C-21}}$ denote the total electricity consumption in the provincial administrative region i in 2030 and 2021, respectively. ω_i^{30} and ω_i^{21} denote the target RWNWREA in 2030 and the completed RWNWREA in 2021 in the provincial administrative region i, respectively. η_i denotes the proportion of wind energy and solar energy in non-water renewable energy in the provincial administrative region i. μ_i denotes the proportion of wind energy and solar energy to be accommodated by dispatching the regulation capability in the provincial administrative region i. γ_i^{SES} denotes the proportion of the renewable energy accommodated by SES in the provincial administrative region i. Considering the incomplete data, this work adopts a more conservative estimation method and the assumptions are given for the parameters of (1) as follows.

1. For $E_i^{\mathrm{C-30}}$, the difference in the growth rate of the total electricity consumption in different provincial administrative regions is not considered in this work. Based on the total electricity consumption of China in 2021 and the estimated total electricity consumption of China in 2030, $E_i^{\mathrm{C-30}}$ can be obtained by enlarging $E_i^{\mathrm{C-21}}$ by an equal scale, which can be expressed as

$$E_i^{\mathrm{C-30}} = \frac{E_i^{\mathrm{C-21}} E^{\mathrm{CN-30}}}{\sum\limits_{i=1}^{I} E_i^{\mathrm{C-21}}} \tag{2}$$

where $E^{\mathrm{CN-30}}$ denotes the estimated total electricity consumption of China in 2030. According to the data released by GEIDCO, $E^{\mathrm{CN-30}}$ is 10,700 TWh.

2. This work does not consider the incremental proportion of wind and solar energy in non-water renewable energy in 2030. η_i can be determined according to the actual proportion in 2021, which can be expressed as

$$\eta_i = \frac{E_i^{\mathrm{WT}} + E_i^{\mathrm{PV}}}{E_i^{\mathrm{WT}} + E_i^{\mathrm{PV}} + E_i^{\mathrm{Bio}} + E_i^{\mathrm{Ext}}} \tag{3}$$

where E_i^{WT}, E_i^{PV}, E_i^{Bio} and E_i^{Ext} denote the wind energy, the solar energy, the biomass energy and the feed-in non-water renewable energy from other regions in the provincial administrative region i in 2021, respectively. The above data have been released by the National Energy Administration (NEA) of China.

3. Considering the completeness of the data, the data of the peak-regulation ancillary service market in Shaanxi province in 2021 are utilized to calculate μ_i, which can be expressed as

$$\mu_i = \frac{E^{\mathrm{SX-DPR}} + E^{\mathrm{SX-SSPR}} + E^{\mathrm{SX-CPPR}}}{E^{\mathrm{SX-WT}} + E^{\mathrm{SX-PV}}} \tag{4}$$

where $E^{\mathrm{SX-DPR}}$, $E^{\mathrm{SX-SSPR}}$ and $E^{\mathrm{SX-CPPR}}$ denote the renewable energy accommodated by the deep peak-regulation ancillary service, start-stop peak-regulation ancillary service and cross-province peak-regulation ancillary service in Shaanxi province in 2021, respectively. $E^{\mathrm{SX-WT}}$ and $E^{\mathrm{SX-PV}}$ denote the wind energy and the solar energy in Shaanxi province in 2021, respectively. Finally, the calculated value of μ_i is 0.95%.

4. Flexibility reformation of TG units and pumped storage construction are also important means to improve the regulation capability of power systems, which can occupy the shares of accommodating renewable energy [41]. Therefore, it is assumed that γ_i^{SES} is 30%, that is, energy storage resources with the SES business model will accommodate the 30% of incremental wind and solar energy in 2030.

Based on (1)–(4), the renewable energy accommodated by SES under the carbon peaking goal is shown in Figure 9. Different from Figure 8, the renewable energy accommodated by SES is higher in the strong economy provinces, such as Shandong, Jiangsu and Guangdong. This is because the renewable energy accommodated by SES is not only related to the incremental RWNWREA, but also related to the total electricity consumption and the proportion of wind and solar energy of the provincial administrative region. Therefore, although the proportion of wind energy and solar energy in the strong economy provinces is lower than that in the Three-North region of China, the total electricity consumption and the incremental RWNWREA to be completed in 2030 are large. This means that a massive installed capacity of PV and WT will be deployed in the next few years, generating much renewable energy that needs to be accommodated through the regulation resources including SES. Among all provincial administrative regions, the renewable energy accommodated by SES in Jiangsu province is the highest, which is 1697 GWh. It is assumed that there are 300 peak-regulation days in a year, the daily charging and discharging times of SES are 2 and the average charging duration is 2 h. At this time, the SES scale required by Jiangsu province in 2030 to achieve the incremental RWNWREA is 1.41 GW/2.82 GWh. Moreover, the total renewable energy accommodated by SES nationwide is 20,470 GWh. According to the above assumptions, the total SES scale is 17.06 GW/34.12 GWh. It is worth noting that the above SES scale is the estimated result in ideal conditions, where only the energy balance principle under the RWNWREA constraint is considered. In fact, the curtailed power of WT and PV on different peak-regulation days is also very different. Therefore, the actual required and deployed SES scale may be much larger than the estimated results. To sum up, the estimated SES scale proves that the SES business model has a very broad application prospect in the renewable energy accommodation scenario, which can greatly promote the development of SES and even the entire energy storage industry.

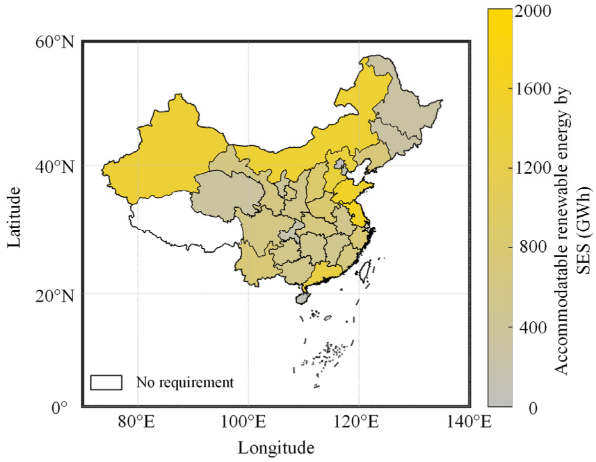

Figure 9. Renewable energy accommodated by SES of China in 2030.

4. Development Status of SES for Renewable Energy Accommodation in China

In the past few decades, as many kinds of energy storage technologies are still under investigation, the ESSs of the global power system are mainly pumped storage, accounting for the absolute majority of the installed capacity. By the end of 2021, the proportion of the installed capacity of pumped storage worldwide was less than 90% for the first time. In China, pumped storage facilities are usually incorporated into the power transmission and distribution assets. Thus, pumped storage facilities are uniformly dispatched by the power dispatching agency, and the investment cost is recovered through the transmission and distribution price [42]. Based on the above characteristics, pumped storage is not included in the scope of SES in this work even if it is technically feasible. Recently, various advanced energy storage (AES) technologies, including electrochemical energy storage, FES and CAES, have been developing rapidly. At present, electrochemical energy storage represented by a lithium battery has passed theoretical research, pilot project verification and other key nodes, entering the stage of commercial operation. Compared with other types of energy storage technologies, electrochemical energy storage has the characteristics of being free from geographical constraints, a shorter construction time and flexible investors, which is highly consistent with the demands of renewable energy accommodation scenarios and the features of the SES business model. Therefore, electrochemical energy storage has become the most common energy storage resource under the SES business model [11].

The installed capacity and growth of AES from 2012 to 2021 are shown in Figure 10. It can be seen from Figure 10 that the development of AES was relatively slow from 2012 to 2015, and the energy storage technologies other than a lithium battery accounted for a large share. Since 2016, the installed capacity of AES in the world has witnessed an explosive growth, and the share of lithium battery-based ESSs has taken an absolute advantage. By the end of 2021, the global installed capacity of AES was 25.4 GW, and the share of lithium battery-based ESSs was 90.9%. In China, the growth trend of the installed capacity of AES is similar to that of the world, but its annual average growth rate is higher. Moreover, the share increased from 7.5% in 2012 to 22.8% in 2021. In Figure 11, the information, including energy capacity, price of unit energy capacity, ESS type and contracting type, of 215 AES projects in China from January 2021 to October 2022 is given. All basic data come from the public bid-winning results, and, therefore, the projects in Figure 11 are incomplete. Firstly, in terms of the time distribution of these projects, the number of AES projects in 2022 is much larger than that in 2021, indicating that AES projects generated a strong growth momentum in 2022 with the gradual implementation of China's energy storage plans. Secondly, in terms of ESS type, the number of ESSs attached to REG is the largest with 118, accounting for 54.9%, followed by independent ESSs with 75, accounting for 34.9%. The total proportion of user-side ESSs and ESSs attached to TG only account for 10.2%. The above data show that renewable energy accommodation has become the most important application scenario for AES projects in China. As these projects are gradually connected to the power system, massive regulation resources can be supplied to accommodate more renewable energy. Thirdly, in terms of energy capacity, there are 106 AES projects of more than 50 MWh, accounting for 49.3%. The installed capacity of the largest project is 250 MW/1000 MWh. It means that the investors tend to build AES projects with a larger energy capacity, so that these projects meet the access conditions of the power ancillary services.

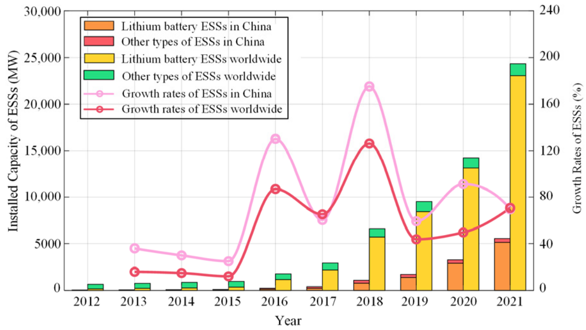

Figure 10. Installed capacity and growth rate of ESSs.

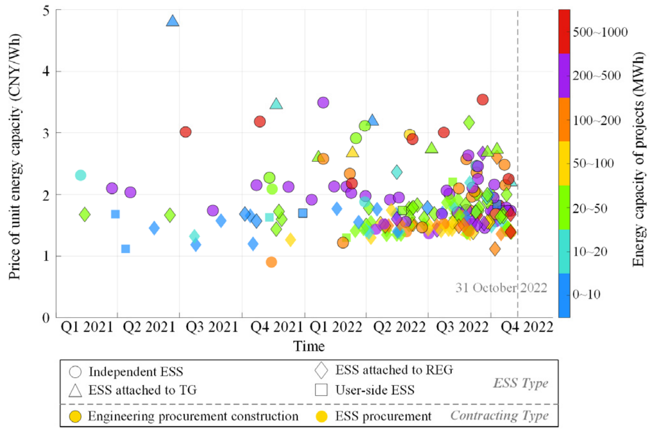

Figure 11. The 215 energy storage projects in China from January 2021 to October 2022.

Although it can be seen from Figures 10 and 11 that AES projects are developing vigorously in China, the problems of a low utilization rate and restricted profit channel need to be faced by the AES projects that have been operating and will be deployed in the future. According to the data released by the China Electricity Council (CEC), the average equivalent utilization rate of the current AES projects is 12.2%. The utilization rates of ESSs attached to REG, independent ESSs, ESSs attached to TG and user-side ESSs are 6.1%, 14.8%, 15.3% and 28.3%. In this circumstance, AES projects urgently need the support of policies and related rules to broaden the profit channel and truly implement the SES business model. For this purpose, some regions and provincial administrative regions began to incorporate the ESSs into the scope of the peak-regulation ancillary service entities while improving the paid ancillary service mode and building the peak-regulation ancillary service market [28]. The rules of ESSs to participate in the peak-regulation ancillary service market or be dispatched to provide the paid peak-regulation ancillary service in five typical regions and provincial administrative regions are summarized in Table 1. First of all, the regions and provincial administrative regions in Table 1 have set access conditions for the installed capacity of ESSs. This is due to the fact that massive small-scale ESSs may bring great control difficulties and additional cost to the power dispatching agencies. Secondly, independent ESSs are allowed to provide the peak-regulation ancillary service as independent entities in these regions and provincial administrative regions. In addition, in northeast China and Gansu province, ESSs attached to REG and ESSs attached to TG are allowed to provide the peak-regulation ancillary service as a whole with the REG users and TG users, respectively. It is worth noting that ESSs attached to TG conduct trade and settlement according to the deep peak-regulation rules of TG units rather than the rules of ESSs. User-side ESSs are also allowed for the peak-regulation ancillary service in northeast China.

Table 1. Rules of ESSs for the peak-regulation ancillary service in typical regions and provincial administrative regions of China.

	Northeast China [1]	**Qinghai** [1]	**Gansu** [1]	**Fujian** [1]	**Southern Region** [2]
Access Conditions	≥10 MW/40 MWh	≥10 MW/20 MWh	≥10 MW/40 MWh	≥10 MW/40 MWh	≥5 MW/5 MWh
ESS type	Independent ESSs; ESSs attached to REG; ESSs attached to TG; User-side ESSs	Independent ESSs	Independent ESSs; ESSs attached to REG; ESSs attached to TG	Independent ESSs	Independent ESSs
Trading Methods	BN; DDPS	BN; CB; DDPS	DDPS	DDPS	DDPS
Pricing Mechanism	BN: Negotiated decision with a price ceiling of 200 CNY/MWh and a price floor of 100 CNY/MWh. DDPS: Fixed price, i.e., 150 CNY/MWh	BN: Negotiated decision CB: ESSs and REG users declare the price. The BCB settlement price is equal to the average price of the matched ESS and REG user. DDPS: Fixed price; 700 CNY/MWh	DDPS: ESSs declare the charging price with a price ceiling of 500 (300) CNY/MWh when the spot market is running (stopping). The settlement price is the marginal clearing price.	DDPS: Settlement price is equal to the average clearing price of the deep peak regulation of TG	DDPS: Fixed price for different provinces (CNY/MWh) Guangdong: 792 Guangxi: 396 Yunnan: 662.4 Guizhou: 684 Hainan: 595.2
Settlement Revenue	charging electricity of BN × BN price + charging electricity of DDPS × DDPS price	discharging electricity of BN × BN price + discharging electricity of BCB × BCB settlement price + discharging electricity of DDPS × fixed price	charging electricity × settlement price	charging electricity × settlement price	(charging electricity × fixed price) for different provinces

[1] Northeast China includes three provinces, i.e., Heilongjiang, Jilin and Liaoning, as well as one region, i.e., eastern Neimenggu. Northeast China, Qinghai, Gansu and Fujian are supplied by State Grid Corporation of China; [2] Southern region includes five provinces, i.e., Guangdong, Guangxi, Yunnan, Guizhou and Hainan, which are supplied by China Southern Power Grid.

Thirdly, there are generally three types of trading methods for the peak-regulation ancillary service provided by ESSs, including bilateral negotiation (BN), CB and DDPS [15]. For BN, REG users and energy storage users independently determine the trading price, trading period, charging power curve and other information, and the power dispatching agency will execute the trade according to the agreed trading content. BN is applicable to medium-term and long-term trades between REG users and energy storage users. For CB, REG users and energy storage users declare the trading price in the day-ahead stage, and the power dispatching agency matches the two types of users according to the order of price difference and clears the accommodated renewable energy by a one-minute cycle on the trading day. The settlement price is generally the average price of the matched users. For DDPS, the energy storage resources will be dispatched by the power dispatching agency to accommodate the renewable energy according to the demand for the regulation capability of the power system. In terms of the settlement price of DDPS, a fixed-price mechanism is generally utilized in many regions and provincial administrative regions, such as northeast China, Qinghai province and the southern region. In Gansu province, energy storage users need to declare the trading price, and the power dispatching agency will dispatch the energy storage resources according to the order of the trading price from low to high. The settlement price is the trading price of the last dispatched energy storage user, i.e., the marginal clearing price. In Fujian province, the settlement price of the energy storage users, who can be seen as the price receivers, is the average clearing price of the TG units for the deep peak-regulation ancillary service on the trading day. Finally, the revenue of the energy storage users is settled based on the discharging energy in Qinghai province. However, in the other four regions and provincial administrative regions, the revenue of the energy storage users is settled based on the charging energy.

It can be seen from the above analysis that many regions and provincial administrative regions have begun to explore the application of ESSs in the renewable energy accommodation scenario, and improve and innovate the related rules according to the specifics of the local power system. It is worth mentioning that energy storage users are allowed to charge and discharge by themselves except for the peak-regulation period based on the rules of the power ancillary services in some regions and provincial administrative regions. Moreover, energy storage users are allowed to provide frequency regulation, power reserve, voltage regulation and other paid ancillary services while providing the peak-regulation ancillary service [11,43]. Furthermore, energy storage users are allowed to sign the lease contracts of the use rights with many REG users through BN. Therefore, although other regions and provincial administrative regions except Qinghai province have not explicitly mentioned the SES business model, the energy storage users in the rules are essentially SES users.

The introduction of the rules for the peak-regulation ancillary service in various regions and provincial administrative regions has laid a policy foundation for SES to deeply participate in the renewable energy accommodation scenario. Currently, some provincial administrative regions have carried out the SES trading pilot projects, where SES has begun to provide the peak-regulation ancillary service. Qinghai province launched the first domestic SES trading pilot project in April 2019, and the revenue and its share of SES users in the peak-regulation ancillary service market are shown in Figure 12. It can be seen that there is only one energy storage facility, i.e., SES user LN, with an installed capacity of 50 MW/100 MWh in the peak-regulation ancillary service market from August 2019 to November 2020. The second energy storage facility, namely the SES user MH, started to participate in the peak-regulation ancillary market in December 2020, with an installed capacity of 32 MW/64 MWh. In terms of the revenue of SES users, the maximum monthly revenue of SES user LN is 1.942 million CNY and the minimum monthly revenue is 0.877 million CNY, depending on the number of peak-regulation days each month. The monthly revenue of SES user MH is lower because its installed capacity is smaller than that of SES user LN. Next, the share of the revenue of SES users in the whole peak-regulation ancillary service market is analyzed. Due to the small installed capacity of TG in Qinghai province, so far, no TG units provide the deep peak-regulation ancillary service. Therefore, the peak-regulation ancillary service market of Qinghai province consists of two parts, i.e., the peak-regulation ancillary service provided by the SES users and the cross-province peak-regulation ancillary service. The cross-province peak-regulation ancillary service is provided by the TG units in other provincial administrative regions of northwest China. In general, the share of the revenue of the SES users is relatively high, even reaching 100% in some months, such as April 2021, June 2022 and July 2022, when there is no cross-province peak-regulation ancillary service. However, considering the very high wind and solar power curtailment rates and the massive REG installations to be deployed in the future, there is still a huge market space for a peak-regulation ancillary service that can be provided by the SES users in Qinghai province.

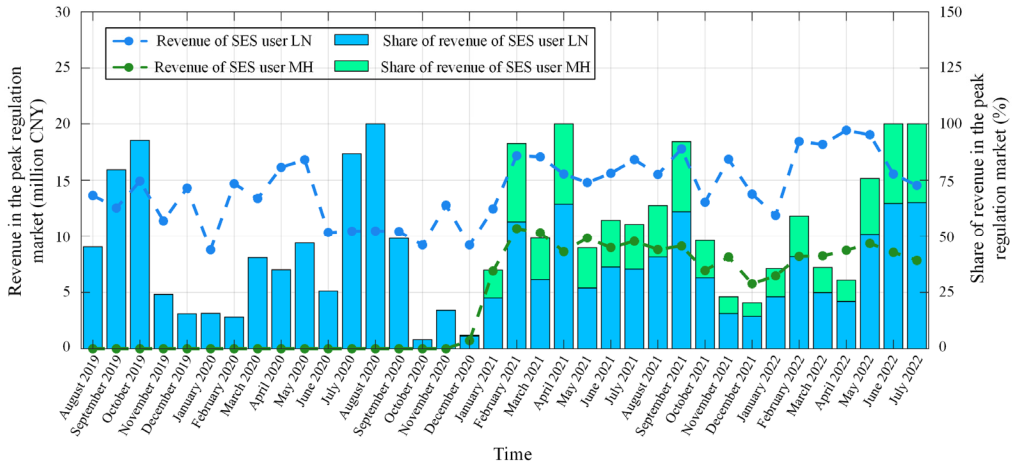

Figure 12. Revenue and its share of SES users in the peak-regulation ancillary service market in Qinghai, China.

Finally, Figure 13 shows the revenue and its share of SES users in the peak-regulation ancillary service market in Gansu province from January 2021 to July 2022. There is only one energy storage facility, i.e., SES user BLJ, with an installed capacity of 60 MW/240 MWh. The average revenue of SES user BLJ is 2.437 million CNY and is on the decline as a whole. Moreover, except for the peak-regulation ancillary service provided by the SES users, there are the deep peak-regulation ancillary service of TG units and the cross-province peak-regulation ancillary service in the market, accounting for the vast majority of revenues.

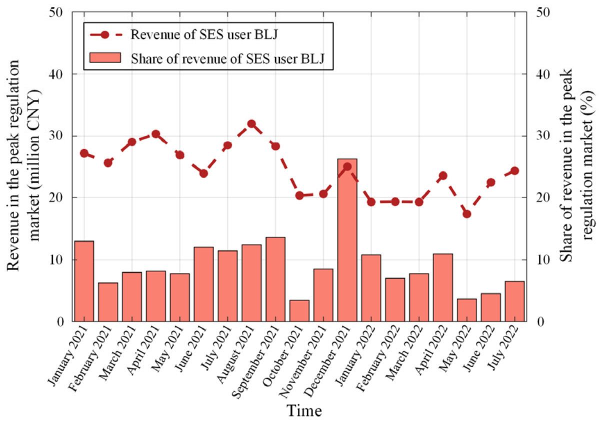

Figure 13. Revenue and its share of SES users in the peak-regulation ancillary service market in Gansu, China.

In this context, the share of the revenue of SES user BLJ is less than 10% in most months. This shows that more SES users can participate in the peak-regulation ancillary market in Gansu province so that they can gain benefits by accommodating renewable energy. It is worth noting that SES user BLJ also participates in the frequency-regulation ancillary service market in Gansu province where the obtained revenue is 1.5 times that of the peak-regulation ancillary market. It is assumed that the unit energy capacity cost of SES user BLJ is 2 CNY/Wh and return on investment is not considered. If SES user BLJ only provides the frequency-regulation ancillary service, the cost recovery period is up to 127 months. If SES user BLJ can provide the peak-regulation and frequency-regulation ancillary services in the form of SES, the cost recovery period will decrease to 77 months. This proves that the application of the SES business model can significantly increase the revenue of SES users and accelerate the recovery period of investment costs.

5. Key Technologies of SES in the Renewable Energy Accommodation Scenario

According to the analysis in the above sections, it can be clearly recognized that SES has a broad application prospect in the renewable energy accommodation scenario. However, there are still problems such as imperfect market mechanisms, great difficulty in operation and control, and unclear decision-making signals. In this context, aiming at the further development and promotion of the SES business model, the key technologies of SES for renewable energy accommodation are described in this section.

5.1. Operation Mechanism of Peak-Regulation Ancillary Service Considering Multi-Form SES Participation

In the SES business model, there are huge differences in the forms of participating in the renewable energy accommodation scenario for energy storage resources with different technologies, types, ownership and operation habits. Currently, although many regions and provincial administrative regions have issued the rules of ESSs for the peak-regulation ancillary service, independent ESSs are still the main form due to their management and control. In this circumstance, it is necessary to deeply analyze the characteristics of the multi-form SES for renewable energy accommodation to improve the operation mechanism of the peak-regulation ancillary service. Firstly, the appropriate access conditions for different forms of SES, including independent ESSs, ESSs attached to REG and aggregated user-side ESSs, need to be set and adjusted dynamically considering the balance between the incremental dispatching difficulty and gap of the regulation capability of the power system. The grid-connected management rules for multi-form SES also need to be improved to standardize the behaviors of SES users. Moreover, a pricing mechanism that can reasonably reflect the value of SES resources needs to be established by introducing a variety of trading methods based on the characteristics of different forms of SES in terms of lease duration and service stability [44]. Furthermore, considering that SES users may participate in the peak-regulation ancillary service and other kinds of ancillary services at the same time [43], the dispatching and switching strategies need to be studied to improve the available regulation resources on the premise of ensuring power system security. In addition, the measurement and settlement mechanisms for multi-type ancillary services should be designed to promote the rational allocation of the energy storage resources of SES users by rewarding or punishing the behaviors of SES users. Finally, with the construction of the electricity spot market in China, the value of the power system regulation capability can be reflected through the price fluctuation in the electricity spot market [45]. In this context, the peak-regulation ancillary service may be canceled and incorporated into the electricity spot market or coexist with the electricity spot market. Thus, it is necessary for multi-form SES to design a cohesive mechanism for the transition from the peak-regulation ancillary service to the electricity spot market. Based on the cohesive mechanism, the overall revenue of SES users in the renewable energy accommodation scenario will not fluctuate sharply, which can boost and stabilize the confidence of investors and users.

5.2. SES Operation Platform Considering Diversified Power Services

With the improvement of the SES business model, idle energy storage resources will provide different power services to different entities at different times in more flexible forms. Therefore, the operation of SES is faced with some key issues such as trading, control, measurement and settlement. In the context of the high integration of information systems and power systems, large-scale communication networks, sensors and control systems can be utilized to achieve the collaboration of multi-form SES. Moreover, the platform-based operation model can be adopted to achieve the accurate matching and efficient interaction of mass SES users. It is worth mentioning that a blockchain, a novel information technology, has the potential to support the operation and development of the SES business model because it is highly consistent with the characteristics and existing issues of SES. On the one hand, on the basis of the traditional generation, transmission and distribution entities of power systems, upstream and downstream enterprises of the energy storage industrial chain, energy storage resource aggregators, platform operators and other new entities are introduced in the SES business model. Thus, the SES market will be more decentralized than the traditional electricity market. In the SES market, the new entities hope to obtain more management rights at the information level and master the increasingly important information asset, i.e., data from the SES market. At this time, a blockchain with the decentralized characteristic will be utilized as the underlying technology to build a more equal, credible and robust information system for the SES business model [46]. Moreover, the data ownership can be determined by the blockchain, making the data a controllable asset for each entity of the SES business model. On the other hand, when an SES user provides diversified power services, the output of the SES user is the sum of the power required by all power services, which makes it difficult to measure the service volume provided by the SES user. Therefore, it is impossible to directly judge whether the SES user has responded to the target power services from the output of the SES user, bringing great difficulties to the subsequent settlement and assessment. In this instance, based on the blockchain, the power curve or real-time power regulation signals issued by the demanders who purchase the use rights of energy storage resources will be stored in the blockchain as data that cannot be tampered with. The output and self-dispatching power curve of the SES user are also recorded on the blockchain. Based on the stored data, the power services provided by the SES users will be settled and assessed automatically according to the preset logic in the smart contracts. In addition to the blockchain, the existing information network of the power system will still play an important role in the SES business model, providing some key functions such as communication, data acquisition and response verification. Finally, the information network and the blockchain will be integrated to build an SES operation platform that can meet various business requirements.

5.3. Multi-Time Scale Evaluation Systems of SES Business Model for Requirements of Multiple Entities

Due to incomplete and asymmetric information, it is difficult for all entities to accurately evaluate the development status, existing problems and changing trends of the SES business model. For decision-makers, the lack of evaluation systems may cause management difficulties and the lag-behind rule revision, delaying the development of the SES business model [15]. For investors, blind decisions may be made to cause economic losses because they cannot obtain some key information about the SES business model. For SES users, it is difficult to participate in the appropriate SES markets according to the characteristics and competitiveness of the held energy storage resources, which ultimately leads to idle and the waste of resources. In this context, it is urgent to build the multi-time scale evaluation systems of the SES business model based on the information requirements of different entities. According to the evaluation results in different time scales, decision-makers can guide the macro development of the SES business model under the carbon peaking and carbon neutrality goals. Moreover, investors can make a rational investment in SES in the renewable energy accommodation scenario by selecting reasonable energy storage technology, the installed capacity and deployment location. Furthermore, based on the price fluctuation, market scale and other signals from the evaluation results, SES users can design the allocation scheme of idle energy storage resources to accommodate more renewable energy and obtain more revenues. It is worth noting that the data owned by different entities may be used in the evaluation process. Therefore, the selection of evaluation indices should fully consider the available channels of basic data. In addition, the complete data sharing and trading mechanisms can be built based on the blockchain and other technologies to meet the data demands for evaluating the SES business model [47].

6. Conclusions

Driven by the carbon peaking and carbon neutrality goals, renewable energy will gradually become the main energy of the power systems in China. REG brings clean and low-carbon power, but leads to the problem of the insufficient regulation capability of power systems. In this context, this paper analyzes and describes the typical framework, basic forms, application prospects, development status and key technologies of the SES business model in the renewable energy accommodation scenario. Based on the aforementioned analysis, the following conclusions can be drawn:

1. To achieve the carbon peaking goal in 2030, the installed capacity and share of REG will maintain the rapid growth trend in China. Constrained by the guarantee mechanism of renewable energy accommodation, all provincial administrative regions need to vigorously develop regulation resources in the power system to accommodate more renewable energy. Thus, the SES business model has a broad application prospect in the renewable energy accommodation scenario. Based on the target RWNWREA of China in 2030 and the energy balance principle, it is conservatively estimated that the total SES scale for renewable energy accommodation is 17.06 GW/34.12 GWh in China.
2. In China, AES projects have shown an explosive growth in recent years. Many regions and provincial administrative regions have successively released the rules of ESSs for the peak-regulation ancillary service, laying a policy foundation for SES users to participate in the renewable energy accommodation scenario. By analyzing the actual market data of Qinghai province and Gansu province, it can be seen that SES can effectively improve the regulation capability of the power systems and promote the accommodation of renewable energy. Meanwhile, SES users can also obtain good revenues from the peak-regulation ancillary service, as a reliable profit channel, shortening the cost recovery period.
3. To further promote the development and promotion of the SES business model in the renewable energy accommodation scenario, it is necessary to carry out research on key technologies in the operation mechanism of the peak-regulation ancillary service, SES operation platform and evaluation systems of the SES business model. These key technologies will make more energy storage users provide the regulation capability to the power system under the SES business model and improve the allocative efficiency of energy storage resources.

As market rules, operation platforms and communication technologies are further promoted, the SES business model will not only play a greater role in the renewable energy accommodation scenario, but also provide more diversified power services for the entities in the power systems to create more profit channels. Thus, a further study is to optimize the quantitative analysis method of the application prospect of the SES business model by simulating the peak-regulation process based on the daily power of REG units, TG units and loads. The runoff hydropower, an unstable REG, can be accommodated by SES when hydropower curtailment occurs, which will be considered in the future. On the other hand, the economy and prospects of primary frequency-regulation services and voltage-regulation services provided by SES users will also be analyzed and discussed in future works.

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