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The Development of Energy Storage in China: Policy Evolution and Public Attitude

Bi Fan[1], Tingting Wu[1], Yufen Zhuang[1], Jiaxuan Peng[2] and Kaishan Huang[3]*

[1]College of Management, Research Institute of Business Analytics and Supply Chain Management, Shenzhen University, Shenzhen, China, [2]School of Computer Science, University of St. Andrews, St. Andrews, United Kingdom, [3]Innovation and Entrepreneurship Education Center, Shenzhen University, Shenzhen, China

With the challenges posed by the intermittent nature of renewable energy, energy storage technology is the key to effectively utilize renewable energy. China's energy storage industry has experienced rapid growth in recent years. In order to reveal how China develops the energy storage industry, this study explores the promotion of energy storage from the perspective of policy support and public acceptance. Accordingly, by tracing the evolution of the energy storage policies during 2010–2020 comprehensively, a better understanding of the policy intention and implementation can be obtained. Meanwhile, this paper collects the information of Weibo users and posts related to energy storage by web crawler technology. The status of public attention and sentiment orientation toward energy storage are investigated with a text mining method. The main results are as follows. 1) The evolution of energy storage is characterized by three stages: the foundation stage, the nurturing stage, and the commercialization stage. 2) Most people have a positive attitude towards energy storage and recognize the potential of the energy storage industry, and it is discovered that the public attitudes towards energy storage exist cognitive bias. 3) More policies concerning market mechanism, R&D, and subsidies should be introduced to enhance the effect of energy storage policies and increase public recognition. These findings help to understand the energy storage policy and provide better strategies for policymaking.

Keywords: energy storage policy, policy evolution, public attitude, cognitive bias, sentiment analysis

Edited by:
Lin Zhang,
City University of Hong Kong, Hong Kong SAR, China

Reviewed by:
Chengjiang Li,
Guizhou University, China
Yongxiang Li,
Shanghai Jiao Tong University, China

****Correspondence:***
Kaishan Huang
hks@szu.edu.cn

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INTRODUCTION

With continued growth in economic development and energy demand in the past decade, environmental deterioration and the energy crisis are becoming more prominent around the world (Zhang and Qin, 2018). China is a pivotal country in the energy sector and is taking proactive action to build a sustainable energy system. According to the data from China energy development report 2018 (Lin, 2019), coal and fossil oil energy consumption accounted for 59 and 18.8% separately of China's primary energy consumption. **Figure 1** showed the structure of China's energy consumption in 2018. The economic growth in China depends largely on coal power, which brings serious air pollution (Li and Li, 2011; Shang et al., 2018; Zafar et al., 2021). Solid fuels consumption such as coal will increase the concentration of PM2.5 in the air. Study has shown that air pollution caused by solid fuel burning was responsible for near 1.04 million premature deaths (Shen, 2016). Solid fuel substitution will help reduce PM2.5 emission and exposure, which will significantly reduce air pollution (Meng et al., 2019). Moreover, with the depletion of coal resources in advance, China is facing the dilemma of energy shortages for its coal-based energy structure (Zhang et al., 2016). Therefore, many energy policies have been issued by the Chinese government to

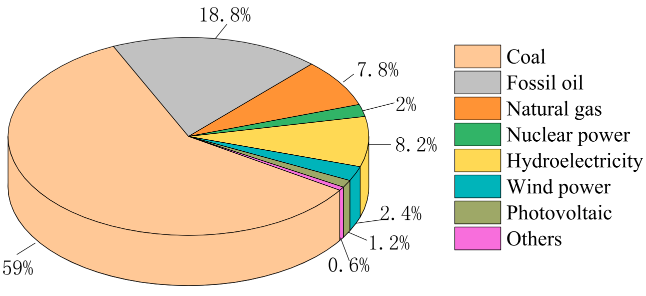

FIGURE 1 | China's energy consumption structure in 2018.

establish a clean, low-carbon, efficient and sustainable energy system. The Energy Production and Consumption Revolution Strategy proposed the targets of energy transformation as "safety, conservation, green and low carbon" (National Development and Reform Commission, National Energy Administration, 2017). However, natural and meteorological conditions make renewable energy sources such as wind and solar power intermittent and unstable (Alotto et al., 2014; Sun et al., 2019). Hence created a lot of integration and power fluctuation issues (Venkataramani et al., 2016), which limits its application in the grid (Li J. et al., 2021). In addition, these weaknesses also hold back the massive introduction of renewable systems (Yang and Zhao, 2018; Kulyk and Zgurovets, 2020). The large-scale integration of renewable energy will bring the negative impact on the safe and stable operation of the grid (Das et al., 2020). To expand the use of renewable energy, energy storage is essential. Energy storage technologies provide opportunities to solve the intermittent and unstable behavior of renewable energy (Teleke et al., 2010; Panwar et al., 2011; Kear et al., 2012; Mahlia et al., 2014). Energy storage can effectively realize peak shaving regulation and smooth out moment-to-moment variations in electricity demand, thereby reducing the impact of the grid connection of renewable energy and improving the stability of the grid (Li et al., 2016). The development of energy storage in China can help increase the proportion of renewable energy in the energy structure to build a low-carbon sustainable energy system.

Energy storage is the key to facilitating the development of smart electric grids and renewable energy (Kaldellis and Zafirakis, 2007; Zame et al., 2018). Electric demand is unstable during the day, which requires the continuous operation of power plants to meet the minimum demand (Dell and Rand, 2001; Ibrahim et al., 2008). Some large plants like thermal power units, thermal power stations, and hydropower bases, generate large amounts of electricity (Newcomb et al., 2013; Qin et al., 2020b). If the excess electricity cannot be stored, it will be lost. Energy storage can absorb the excess electricity to reduce extra waste, and facilitate arbitrage by charging during off-peak times and discharging during peak times (Zafirakis et al., 2016). Moreover, energy storage is also a potential solution to cope with the challenges that stem from the intermittency of renewable resources, such as solar and wind (Gür, 2018). These renewable resources cannot produce electricity if there is no sunlight or wind. Energy storage can smooth out their output throughout the day and can help to solve the problem of abandoning wind and sunlight (Yu et al., 2017). Therefore, the energy storage benefits the related renewable energy deployment.

The Chinese government has promulgated many policies to promote the development of energy storage. The energy storage industry had ushered in a period of development with the release of the 13th Five Year Plan (National Development and Reform Commission, 2016; China Energy Storage Alliance, 2021). The government proposed to build a batch of pilot demonstration projects of different technology types in "Guiding Opinions on Promoting Energy Storage Technology and Industry Development (2017)," to promote the development of energy storage technology and industry (National Energy Administration, 2017). In 2018, the "Opinions on Innovating and Improving the Price Mechanism for Promoting Green Development" was issued by the National Development and Reform Commission, aiming to increase subsidies for the participation of electricity storage facilities in peak shaving and valley filling (National Development and Reform Commission, 2018). The government made efforts in demonstration, subsidies and other aspects, but some problems have certainly existed (Ilieva and Rajasekharan, 2018). For example, some energy storage products exist problems with high prices and safety issues such as heat generation and combustion. The industrial policies for energy storage are complex and diverse. The development of energy storage industry requires promotion of the government in the aspect of technology, subsidies, safety and so on, thereby a complex energy storage policy system has developed. A lack of systematic research specifically regarding energy storage policies in China still prevails. This paper summarizes the evolution of energy storage policies, in order to explore the development of the energy storage industry and discover the practical problems that must be solved.

The public is the recipient of the government's energy storage policies, and their psychological perceptions and opinions of policies, that is, how they evaluate energy storage policies, will affect their wishes and behaviors. Hence, public attitudes are a potentially important factor that may determine whether storage is widely accepted (Gissey et al., 2018; Hoffmann and Mohaupt, 2020). Wu et al. (2021) argued that attitude is an important factor affecting public's municipal solid waste (MSW) sorting behavior, so the data of Sina Weibo users and their comments on related posts were analyzed to provide a better theoretical basis for subsequent decisions. Liu and Hu (2019) explored the Chinese public's attention and sentiment orientation toward green buildings from Weibo, to provide effective suggestions to popularize green buildings in China. Additionally, the public attitude toward off-site construction (Wang et al., 2019), recycled water (Li L. et al., 2021) have also been studied to help policy promotion. However, no relevant study has utilized social media data to analyze public attitude toward energy storage. Meanwhile, research showed that public's energy behavior can be influenced by the interactions between cognitive norms, energy practices, and material culture (Stephenson et al., 2015). Ambrosio-Albalá et al. (2019) argued that previous experiences, perceptions of government, and expectations about the technologies, are likely to affect the acceptance and adoption of battery storage. There is no doubt that the behaviors related to energy storage are extremely complex and are affected by many factors. Some of which are personal cognitive bias, and cognitive bias affect their attitudes. Cognitive bias refers to the situation in which human cognition reliably produces representations that are systematically distorted compared to certain aspects of objective reality (Haselton et al., 2015). For example, the choice of home heating technologies will be affected by cognitive bias (Stephenson et al., 2010). Based on technology acceptance model, sufficient understanding of the public attitude is of importance to the advancement of new technologies (Davis, 1989; Stieglitz and Dang-Xuan, 2013). Therefore, understanding the public attitudes and sentiments towards energy storage is of great significance to promoting the development of energy storage.

With the development of energy storage, policy makers need to design policies more scientifically and take a systematic approach to promote the development of energy storage. There are few comprehensive studies of Chinese energy storage policies. Therefore, this study examines energy storage policies from the perspective of the government and public. Therefore, this study will trace the evolution of energy storage policies issued by Chinese national and provincial departments from 2010 to 2020. Meanwhile, public attitudes toward energy storage are examined to look for the improvement measures for policy implementation to promote the development of the energy storage industry. Our study contributes to the existing literature in three ways. First, we provide a comprehensive understanding on the changing pattern of energy storage policies by revealing the evolution of inherent intentions adopted by the policy makers. The lack of a comprehensive introduction about energy storage policies has been a bottleneck in policy research. Second, this study utilizes social media data to analyze public opinions about energy storage policies, which can help to improve policy. Third, the research provides suggestions for China's energy storage promotion.

The remainder of the study is structured as follows: **Section 2** introduces methodology. **Section 3** demonstrates the progress of energy storage in China. **Section 4** explains public sentiment orientation. **Section 5** and **section 6** include a discussion on research findings and provides some suggestions for future work.

METHODOLOGY

Data Collection

In order to analyze energy storage policies, this paper collected 254 policies promulgated by the Chinese government from 2010 to 2020. At the same time, the public attitude towards energy storage was conducted by analyzing the collected Sina Weibo user data and comments.

Energy Storage Policy

This paper applies quantitative methods to analyze the evolution of energy storage policies and to summarize these policies. The energy storage policies selected in this paper were all from the state and provincial committees from 2010 to 2020. A total of 254 policy documents were retrieved.

To ensure the representativeness and reliability of the policies analyzed in this study, we have screened the policies on the basis of the following principles: 1) the selected policies are closely related to energy storage and 2) the type of policies retrieved comprise laws, regulations, outlines, notices, plans, and opinions. We have searched official websites of government departments, such as the State Council, the National Energy Administration, the State Grid, the Ministry of Science and Technology, the Ministry of Industry and Information Technology and other departments related to energy storage. To find more policies, we expanded the search keywords by inputting "smart grid", "energy", "solar energy", "photovoltaic" and other keywords, in order to ensure a comprehensive search.

Web Crawlers

Social networks have provided platforms for exchanging information on the Internet. More people now post real-time messages about their opinions on various topics on social networks, which express their positive or negative sentiments. Having such a large amount of social data provides an opportunity to study the public's attitudes on certain topics. In order to make full use of the social data, web crawlers as an important information retrieval tool, used to download web documents that suit the needs of users (Kausar et al., 2013). A web crawler is an important part of web search engines, which is used to collect a corpus of web pages indexed by search engines, in other words, it can efficiently and conveniently collect data from web pages or applications (Najork, 2009). Web crawlers have been used in different fields, such as data mining and social event monitoring (Wang et al., 2019). On the basis of user's purpose web crawlers can be divided into general purpose crawling and focused crawling (Hu et al., 2014). This study chooses the focused crawling to obtain the required information, as it can select and download the web pages relevant to the specific theme.

This research adopted web crawler technology to obtain public opinion from Sina Weibo, which is the largest social media platform in China (Jiang, et al., 2016). The collection process is described as follows. We initially set the crawler rules. Then filter and download were operated according to keywords in the initial information collection link. The term "energy storage" was selected as a keyword in order to understand the public's perception of energy storage. Finally, a total of 64,887 posts were obtained from January 1, 2010 to December 31, 2020.

Policy Content Analysis

A semi-quantitative analysis will be constructed to reveal the rationality of China's energy storage policy. The keywords in the policies can be determined by analyzing the policy content. These keywords present the overall evolution of the government's focus on the energy storage industry. The policy number is subjected to a descriptive statistical analysis to illustrate the policy intensity over time. To investigate the stages of energy storage policy evolution, an overall statistical analysis is performed on the keywords.

Sentiment Analysis

Sentiment analysis on social media platform data provides an economical and effective way to detect public opinion in a timely manner (Delen and Crossland, 2008); Tan et al., 2013). Text sentiment analysis refers to the analysis of sentimental subjective

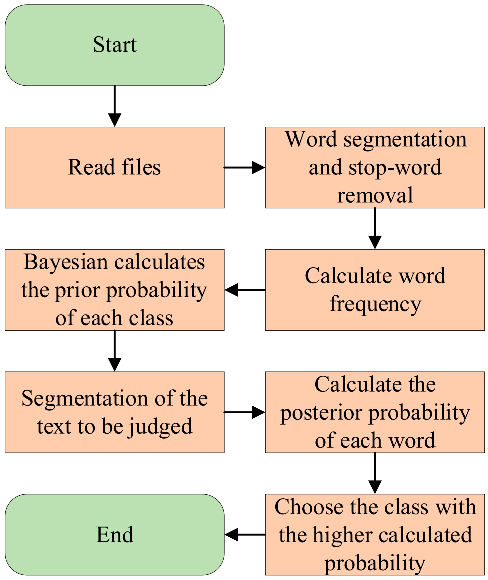

FIGURE 2 | The step of SnowNLP sentiment analysis.

texts (Chaturvedi et al., 2018), in order to find opinions, identify sentiments they express, and then classify their polarities (Medhat et al., 2014). In this study, three-class sentimental subjective texts of positive, neutral and negative reviews were mainly considered.

In this paper, sentiment analysis is performed with SnowNLP. SnowNLP is a Chinese text analysis library based on Python and all codes are completed by Unicode (Zhang et al., 2017). The basic model of sentiment classification in SnowNLP is Naive Bayes, and it provides positive and negative libraries. First, enough sample data are trained, then the appropriate classification model is selected, and sentiment classification is performed on the data according to the model. Finally, the trend probability is calculated.

The Naive Bayes classifier was used to obtain sentiment orientation of the text, which is based on Bayes' theorem and is widely used in text classification (Zhang and Gao, 2011). The principle of Naïve Bayes classifier is introduced as follows.

Assuming that A and B are two random events, if A has occurred, then the probability of occurrence of event B is as follows:

$$P(B|A) = \frac{P(AB)}{P(A)} \tag{1}$$

where $P(AB)$ is the probability of events A and B occurring at the same time; $P(A)$ is the probability of event A.

Suppose we have a set of data, X represents the characteristics of the sample; C means the class of the sample, and the Bayesian formula is as follows:

$$P(C|X) = \frac{P(X|C)P(C)}{P(X)} \tag{2}$$

Assuming that the feature X is divided into N dimensions, $X = [X_1, X_2, \ldots, X_N]$, and the Bayes' theorem can be extended to:

$$P(C|X_1, X_2, \ldots, X_N) = \frac{P(X_1, X_2, \ldots, X_N|C)P(C)}{P(X_1, X_2, \ldots, X_N)} \tag{3}$$

Using conditional independence assumption, it can be simplified to the following formula:

$$P(C|X_1, X_2, \ldots, X_N) = P(C)\prod_{j=1}^{N} P\left(X_j|C\right) \tag{4}$$

In the text tendency analysis of this study, class C consists of C_1, C_2, C_3. C_1 is expressed as positive class; C_2 is expressed as neutral class, and C_3 is expressed as negative class, so

$$P(C_i|X_1, X_2, \ldots, X_N) = P(C_i)\prod_{j=1}^{N} P\left(X_j|C_i\right),\ i = 1, 2, 3 \tag{5}$$

$P(X_j|C_i)$ means the probability of X_j in the different sample space. By solving the above formula, we can infer if X_j is in this class.

The general process of SnowNLP's sentiment analysis is shown in **Figure 2**.

The steps of the sentiment analysis were as follows:

1) Sentiment values calculation. The sentiment value of the sentence was calculated on the basis of the SnowNLP, which returned the probabilities of sentiment.
2) Sentiment orientation analysis. The sentiment orientations were divided into three intervals: [0, 0.25), [0.25, 0.75] and (0.75, 1]. The first represented negative sentiment, whereas the other two expressed neutral sentiment and positive sentiment respectively.
3) Sentiment focus analysis. Word frequency analysis on sentences with different sentiment orientations in order to obtain the sentiment focus of the public.

PROGRESS OF ENERGY STORAGE IN CHINA

Energy storage is important to achieve a low-carbon future (Landry and Gagnon, 2015). In order to clarify the development of the energy storage industry, this paper first analyzed energy storage policies from 2010 to 2020 to obtain the overall understanding of the government's attention on the energy storage industry. Then, a statistical analysis was performed on the policy keywords, revealing the priority of the energy storage policy in various periods. On the basis of the above analysis, the evolutionary stage of energy storage policy can be divided according to the specific background of the entire evolutionary process.

An Overview of China's Energy Storage Policies From 2010 to 2020

In recent years, China's economy has obtained significant achievement, accompanied with rapid development (Kong et al., 2020). At the same time, China has used resources and paid an environmental price (Qin et al., 2020a). The coal-based energy structure is inseparable from air pollution and water pollution. Therefore, energy transformation has become the

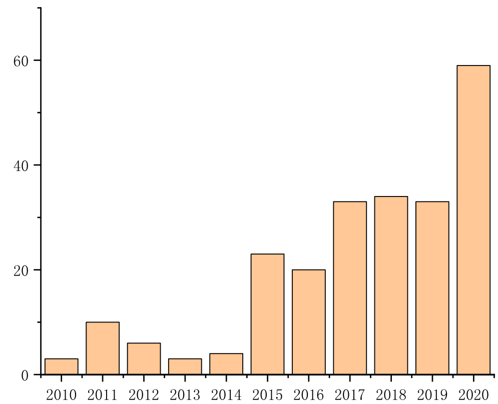

FIGURE 3 | The number of China's energy storage policies from 2010 to 2020.

core issue of the Chinese government. The energy storage industry, as a supporting industry for the adjustment of energy structure, is still in the early stages of development, with problems such as high costs, few standards, and complicated technical route (Li et al., 2015). China has encouraged the development of distributed energy. At the same time, the energy storage systems market is gradually expanding. As shown in **Figure 3**, from 2010 to 2014, the energy storage policies issued by the government were insufficient. Since 2015, the number of China's energy storage policies has shown a slow growth trend, continuing until 2019. By analyzing the content of energy storage policies, we can summarize the keywords of each policy. These keywords represent the government focus of energy storage industry in different periods. It shows the emerging trend of energy storage development. The policy keywords related to energy storage from 2010 to 2020 are given in **Figure 4**.

Of the 254 energy storage policies, some keywords appeared many times during the observation period. **Figure 4** shows that the energy storage policies emphasized "research and development (R&D)," "standards," "environmental protection," and "safety production supervision." These conformed to the aim of energy storage "industrial development" and "energy transition." As an "emerging industry," current measures mainly included "development planning," "popularization and application," "demonstration and application," "price mechanism," "improvement of auxiliary service mechanism." These policies also provided economic support, including "financial support," "encourage capital support" and so on. The government encouraged the application of large-scale energy storage systems through "smart grid," "Internet +" "distributed" and "centralized" technologies.

The Development of the Chinese Energy Storage Industry

Based on the statistical results, considering the specific timeframes and the background of key events, the evolution of energy storage industry is divided into three stages: the foundation stage, the nurturing stage and the commercialization stage. Among them, 2014 and 2017 were the big moments. Energy storage was listed as a key innovation field for the first time in 2014, and the first guiding policy for large-scale energy storage technology was released in 2017. These policies introduced the development of energy storage into a new stage.

1) The Foundation Stage, from 2010 to 2013, is the initial exploration period of the energy storage policy, laying a solid foundation for the development of the energy storage industry. In this stage, the R&D of technology became the primary problem for government. Therefore, the main task of the government at this stage was to encourage innovation in energy storage technology. In 2010, at the end of the 11th Five-Year Plan (2006–2010), the 12th Five-Year Plan (2011–2015) was issued by the government. The word "energy storage" first appeared in national documents, and proposed breakthrough technology such as energy storage, which was considered as an important part in the construction of smart grids (National Development and Reform Commission, 2010). Then more and more people recognized the importance of energy storage technology due to the guidance of the government.

With the progress of the energy industry, the energy revolution has been marked by the large-scale development and utilization of new energies, such as wind energy and electric energy. In order to further promote the innovation of energy storage technology and equipment, demonstration and application policies have attracted the attention of the government. Energy storage technology has begun to be applied in practice. China's first large-scale energy storage demonstration project, "Zhangbei landscape storage demonstration project (2011)" was issued (Ministry of Finance, 2011). This project integrated wind power generation, photovoltaic power generation, energy storage systems and smart power transmission. It enabled energy storage to lay the foundation for industrial development. In addition, in order to support the application and development of energy storage technology, the government has issued many encouraging policies. In July 2012, "Solar power development 12th Five-Year Plan" pointed out that during 2011–2015, 30 new energy microgrid demonstration projects should be built (National Energy Administration, 2012). And it is necessary to support the demonstration and application of large-scale energy storage systems, which was indicated by "Special plan of 12th Five-Year of major scientific and technological industrialization of smart grid" (Ministry of Science and Technology, 2012). Meanwhile, in the initial stage of the energy storage industry, financial support was used to reduce energy storage cost and promote large-scale applications. These policies not only created conditions for energy storage technology at large-scale popularization and application, but also removed market barriers and provided legal support.

In general, the government emphasized the necessity of continuous technical innovation, and extended strong support to the development of energy storage technologies. As a new technology, technical R&D of energy storage should be focused if it wants to be achieved rapid development. The relevant policies

2010-2012	
Word	**#**
Research and development	6
Smart grid	4
Industrial Development	4
Development planning	4
Demonstration and Application	3
Environmental protection	4
Popularization and Application	2
Scale development	1
Financial support	1
Standard	1
Power peak shaving	1

2013-2014	
Word	**#**
Safety production supervision	4
Research and development	3
Development planning	2
Industrial Development	2
Standard	1
Demonstration and Application	1
Scale development	1
Financial support	1
Smart grid	1
New mode of operation	1
Power peak shaving	1

2015-2016	
Word	**#**
Research and development	17
Development planning	7
Demonstration and Application	6
Facility construction	6
Environmental protection	5
Popularization and Application	4
Distributed	4
Internet+	4
Encourage capital support	4
Safety production supervision	3
Power peak shaving	2
Standard	2
Financial support	2
Industrial Development	1
Energy transition	1
Scale development	1
Emerging industry	1
Smart grid	1
Centralized	1

2017-2018	
Word	**#**
Research and development	23
Development planning	9
Demonstration and Application	9
Popularization and Application	9
Industrial Development	9
Price mechanism	8
Distributed	6
Environmental protection	5
Standard	5
Financial support	5
Internet+	4
improvement of auxiliary service mechanism	4
Facility construction	3
Encourage capital support	3
Power peak shaving	3
Scale development	3
Energy transition	2
Safety production supervision	1
Emerging industry	1
Smart grid	1

2019-2020	
Word	**#**
Research and development	26
Demonstration and Application	19
Popularization and Application	14
Development planning	12
Power peak shaving	11
Standard	10
Energy transition	10
Industrial Development	9
Environmental protection	8
Facility construction	8
Price mechanism	7
Financial support	6
Safety production supervision	6
improvement of auxiliary service mechanism	5
Emerging industry	4
Scale development	3
Distributed	3
Encourage capital support	1
Smart grid	1
Centralized	1

FIGURE 4 | Energy storage policy keywords from 2010 to 2020.

during this period were mainly about R&D on the power grids that incorporate energy storage technologies, and demonstration application of energy storage technologies in the field of renewable energy. These have laid a solid foundation for the development of energy storage.

2) The Nurturing Stage, from 2014 to 2016, is the nurturing stage of the energy storage industry. In order to promote the development of the energy storage industry, during this period, the number of energy storage policies in China increased. These policies involved power system reform, ancillary services, technical R&D, and environmental protection. In 2014, the State Council officially issued the "Energy Development Strategic Action Plan (2014–2020)". This plan was proposed to build a clean, efficient, safe, and sustainable modern energy system, and focused on the implementation of four strategies: saving, domestic, green, and innovative (General Office of the State Council, 2014). A new round of energy revolution and transitional development was booming. In order to achieve energy savings and emission reductions, the R&D of energy storage technology was still necessary at this stage.

Moreover, ancillary services were necessary functions to maintain the safe and stable operation of the power system. In order to fully develop and apply energy storage technology, it is essential to explore the application prospects of the ancillary service market for energy storage (Shang, 2019). Thus, ancillary services such as frequency modulation and peak shaving received attention at this stage. In 2016, the National Energy Administration issued a policy to further explore the role of electric energy storage in the peak and frequency modulation of the power system. This policy first combined energy storage with electricity market reform after taking energy storage into innovation account. It encouraged the market to accept the dominant position of auxiliary services for energy storage, and stimulated companies to search for a new business model for energy storage on both the power generation side and user side. It also promoted the commercial development of China's energy storage industry. Due to the lack of policies related to the price mechanism and having few clear business models, the development of the energy storage industry is still in the cultivating stage.

Overall, with respect to technology, energy storage basically has a foundation of industrialization in China. In order to build a healthy and orderly environment for energy storage, government has made a lot of effort in accelerating the construction of the auxiliary service market, while attaching great importance to technical R&D. The government has focused on verifying the application characteristics and prospects of various energy storage technologies in frequency modulation and peak shaving in completed energy storage projects.

3) The Commercialization Stage. From 2017 to 2020, China experienced a preliminary exploration period for the commercialization of energy storage industry. The National Energy Administration promulgated the "Guiding Opinions on Promoting Energy Storage Technology and Industry Development (2017)," which first clarified the strategic position of energy storage. Since this policy was published, the number of energy storage policies has risen steadily (National Energy Administration, 2017). In this stage, keywords like "popularization and application," "standard," "distributed" and "price mechanism" showed that the government was actively promoting the commercialization of energy storage, and paid more attention to energy storage in "scale development" and "industrial development." The establishment of the price mechanism provided a certain support for advancement of commercialization. In the process of commercialization of the energy storage industry, the establishment of technical standards plays an important role. If there is no technical standardization system, it is easy to cause security and other issues, and the process of commercialization will also be hindered. In addition, to solve the problem that it was difficult to guarantee profit after energy storage participating ancillary service markets, the government promoted the commercial application of energy storage industry by improving the price mechanism for ancillary service. Although the government focused on technical R&D, still, energy storage equipment innovation and development capacity were relatively weak. Energy storage technologies were in the early stage of industrialization (Tan et al., 2018). Thus, technical R&D cannot be ignored at this stage, exploring large-scale and industrial production technologies to lower the fabrication cost were urgent (Liu et al., 2017). The government also made other efforts for the commercialization of energy storage. During the 13th Five-Year Plan (2016–2020), a number of key technical specifications and standards would be formed to establish a standardization system for energy storage technology (National Development and Reform Commission, 2016). In addition, the government encouraged companies to explore a batch of generalizable business models. At this time, all this evidence showed that energy storage industry entered the initial stage of commercialization. With the support of these policies, many energy storage pilot demonstration projects were conducted, which focused on technological innovation, exploration of operating modes and institutional mechanisms, leading the energy storage industry to commercialization.

The evolution of energy storage industry is divided into three stages: the foundation stage, the nurturing stage and the commercialization stage. The government has created conditions for energy storage to participate in peak shaving and market promotion. Under the guidance of policies, the energy storage industry has stepped into a new era. However, as an emerging technology, energy storage still has a long way to go.

PUBLIC SENTIMENT ORIENTATION

In this section, sentiment analysis of the energy storage policies using the Weibo comments are conducted. Based on the result of sentiment analysis, we obtained the public sentiment orientation and emotion distribution toward energy storage policies.

The Characteristics of Public Sentiments

The Weibo posts from 2010 to 2020 were obtained by using the keyword "energy storage." From Sina Weibo, a total of 117,455 posts were retrieved. By removing non-related posts such as advertisements and articles with less than 15 words, we finally obtained 64,887 posts about energy storage. The number of posts per year has been counted and summarized in **Table 1**. Overall, the number of posts on energy storage is unstable, but showed an increasing trend. In different periods, the number of posts on energy storage is different. In the foundation stage, the 12th Five Year Plan was released (National Development and Reform Commission, 2010). Since then, the public had a certain understanding of energy storage and the number of posts increased. During the nurturing stage, the public showed more interest in the promotion of various types of clean energy, thus their attention to energy storage had declined. In the commercialization stage, the "Guiding Opinions on Promoting the Development of Energy Storage Technology and Industry (2017)" were issued to clarify the strategic position of energy storage in China, which regained the public's attention in the following years (National Energy Administration, 2017).

The research on public sentiments on energy storage policy is of great importance for ensuring the effectiveness of the policy and improving the satisfaction of the public (Sun et al., 2020). We analyzed the social data from Sina Weibo to evaluate the energy storage policies from the perspective of public sentiments. By

TABLE 1 | Number of energy storage posts from 2010 to 2020.

Time	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Number	43	694	2,945	5,638	5,247	2,290	3,950	4,395	11,307	11,820	16,558

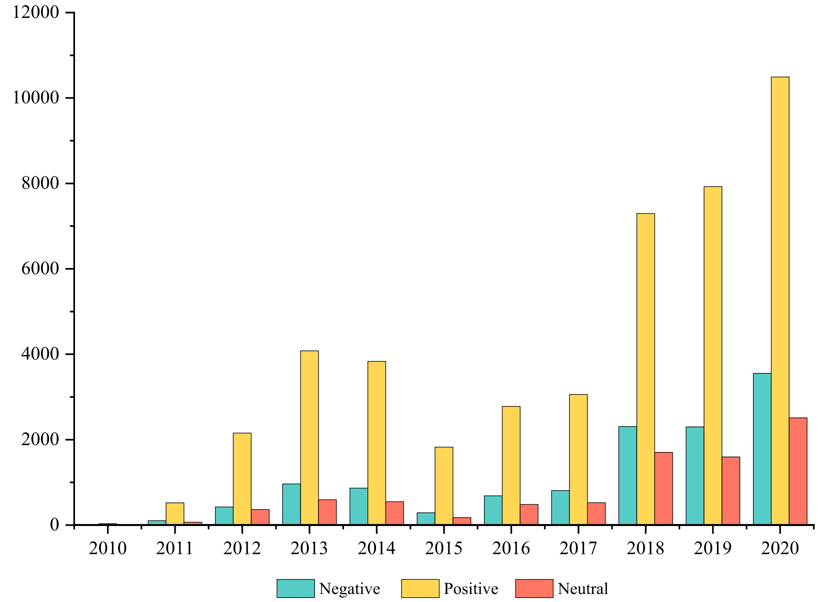

FIGURE 5 | Distribution of public sentiment towards the energy storage policies.

conducting an overall sentiment analysis, we found that the proportions of positive and negative sentiments are 67.84 and 18.98%, respectively. **Figure 5** shows the distribution of public sentiment towards energy storage policies from 2010 to 2020. The proportion of positive sentiments is greater than the proportion of negative emotions in each year. This shows that the public held a positive attitude towards the energy storage policies and recognized the role of energy storage in smart grid construction and energy transformation. However, positive sentiments showed a decreasing trend, while the proportion of negative emotions gradually increased. There are many difficulties that need to be solved in the development of energy storage, such as low technical efficiency and imperfect subsidy policies (Tong et al., 2021). These problems will inevitably impact public attitude and bring certain negative sentiment. Therefore, more efforts are needed to improve the environment of energy storage.

The Focus of Positive Sentiment Toward Energy Storage

To explore specific reasons the public had positive sentiments towards energy storage policy, this study analyzed the word frequency of Weibo posts with positive sentiment. The high frequency words (top 20) of each period were shown in **Figure 6**. According to the high frequency words, we can identify the mechanism of positive sentiments. **Figure 6** indicates that "energy storage," "technology," "battery," "photovoltaic," and "materials" are the most frequently used words in different development stages of energy storage industry. These words represent people's recognition of energy storage industry. Energy storage can be provided by diverse technologies like pumped hydroelectric storage, sodium, thermal storage, etc., (Chen et al., 2009). The different characteristic of technologies determines whether they are suitable for certain energy storage services. Therefore, technology innovation is critical for the application of energy storage, and people maintain a positive attitude to it. The battery storage has a broad range of uses in commercial and resident life. The public has paid more attention to the battery capacity and stability (Zheng et al., 2019). China is the largest market in the world for both photovoltaics and solar thermal energy (Huang et al., 2019). Photovoltaics is already an economic and practical option for residents to provide electricity, such as street lighting and solar water heater. Therefore, the public would hold a positive attitude toward it. The application and research of new materials like sodium in energy storage industry become more popular in recent years, which illustrated the positive sentiment toward it.

The focus on energy storage is quite different in different stages of energy storage industrial development. In the foundation stage, keywords like "sun," "distributed," "lithium" and "new energy" showed that people took a positive attitude to the development of various new clean energy sources and paid more attention to investment in "power grids," "enterprises,"

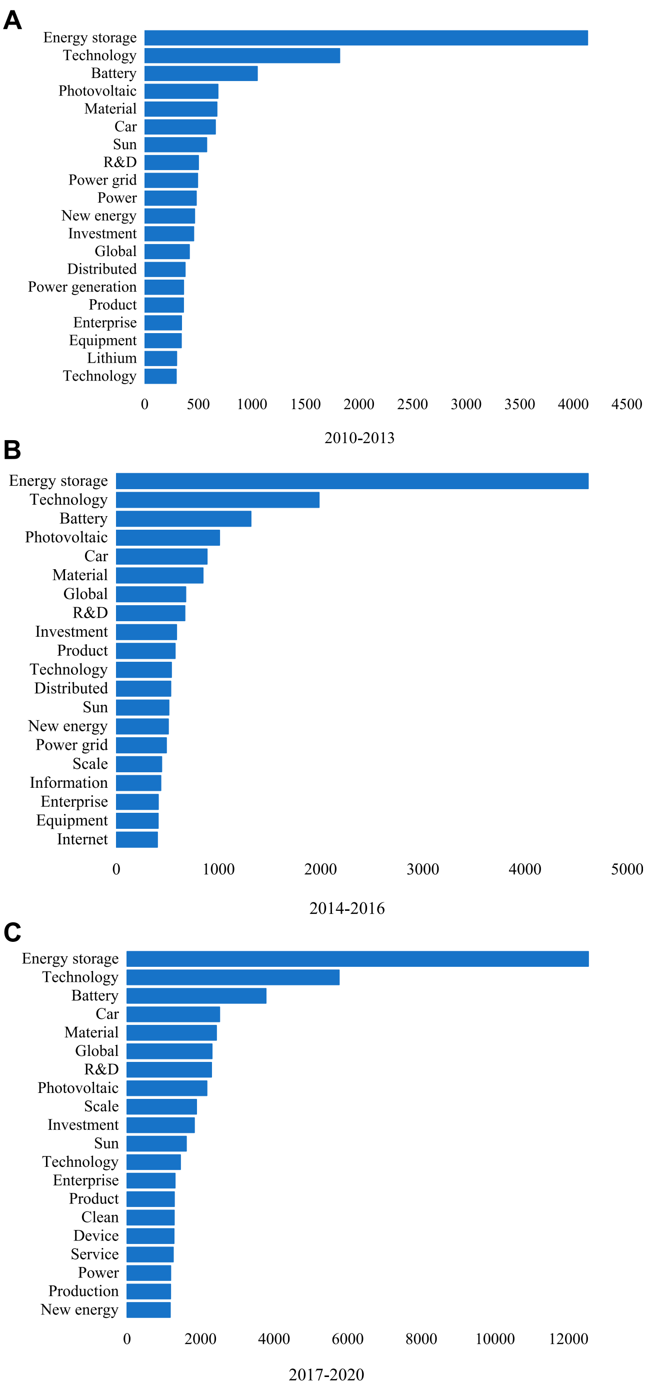

FIGURE 6 | High frequency words (top 20) of positive sentiment towards energy storage policy from 2010 to 2020.

"equipment." In the nurturing stage, the public also showed greater interest in the informatization and large-scale construction of the "grid." The intermittent characteristic of renewable energy sources hindered the power grid stability (Mohammed et al., 2014). To increase renewable energy stability, the Internet was employed in energy forecasting, leading to more effective use of renewable energy sources. In the commercialization stage, from keywords like "scale," "product," "clean," and "service," it could be seen that the public kept a positive tendency to the promotion and commercialization of energy storage. The energy storage

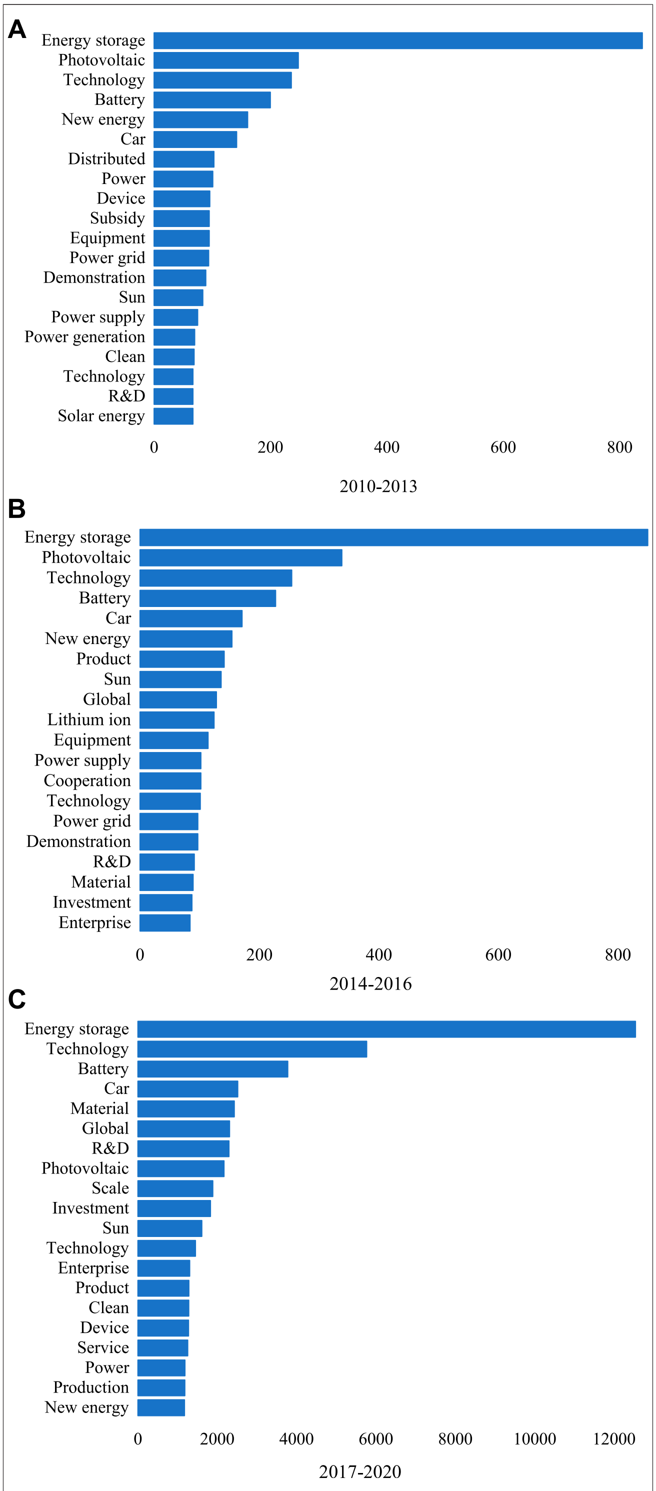

FIGURE 7 | High frequency words (top 20) of negative sentiment towards energy storage policy from 2010 to 2020.

industry had received a certain level, so how to cooperate with clean energy to carry out large-scale energy storage attracted more people's attention (Kittner et al., 2017).

The Focus of Negative Sentiment Toward Energy Storage

Word frequency analysis of the negative sentiment posts were conducted to figure out the reason that the public has negative emotions towards energy storage, and the results are presented in **Figure 7**. **Figure 7** indicates that "technology," "battery," "photovoltaic," are the main concerns expressed about energy storage. However, for the same keywords, 71% of people held a positive attitude to it. This shows the influence of cognition on public sentiments. Due to the difference in living environment, occupation, personality and others, the way the brain processes information are different (Van Overwalle, 2009). Cognitive bias arises when the person's brain attempts to simplify information processing. Therefore, opinions of energy storage are usually not the same even for the same issue, which represent the cognitive bias of the public toward energy storage. This also shows that there are still many obstacles in the development of energy storage, which leads to the cognitive bias of people. How to improve the public's perception of energy storage requires thoughtful consideration in the future.

In different periods of energy storage development, the specific reasons for the negative sentiments are not the same. In the foundation stage, the public showed negative sentiment regarding "subsidies" for various energy storage applications. The government still explored the development of energy storage, and the subsidies were sufficient at that time (Yu et al., 2017). However, the research and promotion of energy storage required huge financial funds. Without government support, enterprises would take a high risk. This caused negative sentiment among the public. In the nurturing stage, the public had negative opinions on the usage of new materials and corporate cooperation. Pumped water storage was still the main energy storage method, and progress of various new materials research was slow. Moreover, the lack of cooperation of enterprises, was not conductive to removing obstacles in technology development and promotion. These made the public hold negative sentiments on energy storage in this period. In the stage of commercialization, the public also expressed their concerns on the promotion of energy storage. From the keywords "equipment," "scale," "device," it can be seen that grid construction still faced some challenges. Also, from "Tesla," "production," "capacity" and other words, we could find that there are still many problems in the application of energy storage batteries. Therefore, the public had negative sentiments regarding the promotion of energy storage.

DISCUSSION

Energy storage is becoming a key part the electric grid as it has the advantages of absorbing excess power generation and speeding up the clean energy revolution. Through a systematic evolution analysis of energy storage policies, this study concludes that the current development of energy storage has experienced three stages: the foundation stage, the nurturing stage and the commercialization stage. At different stages, the intentions of energy policies were quite different, which shows the characteristics of industrial development. Enterprises and investors can coordinate their resources according to the characteristics of energy policies. Moreover, this study also analyzed the public attitude toward energy storage policies, which can help to improve public recognition. Sentiment analysis results showed that the public's attitude to energy storage was dominated by positive sentiments, and the proportion of positive emotions was decreasing. The decomposition of positive and negative sentiment focus can help government have a better understanding of the gap between policy intention and policy implementation, thereby optimizing policy making.

By tracing the evolution of energy storage policies, we found that China's energy storage industry remained in its infancy and has not yet reached an industrial scale. First, the inadequate policy coordination hinders the development of energy storage industry. In recent years, many energy storage policies have been introduced, covering local and central policies. However, these policies were not clarified and may confused by participants. Moreover, due to the lack of details, it was difficult to form consistency in the local and central policies. Although energy storage attracted the government's attention at the foundation stage (2010–2013), the demonstration and application of energy storage was focused in this period, thus ignoring the importance of subsidies and other detailed rules. This was one of the reasons why the public has a negative attitude towards subsidies at this stage. There was no specific implementation rules and detailed development roadmap, have been issued after the "Guiding Opinions on Promoting Energy Storage Technology and Industry Development (2017)" was promulgated at the initial stage of commercialization (2017–2020) (National Energy Administration, 2017). As a result, the implementation of the central energy storage policies in various localities lacked consistency and coordination. An external market environment conducive to the development of the energy storage industry has not yet been created. Second, there is still a lack of effective market mechanisms in energy storage industry. At present, the application of energy storage in China is mainly distributed power generation and grid connection of micro-grid and renewable energy. There were few applications of power transmission and distribution and auxiliary services. In the nurturing stage, although ancillary services have been focused gradually, the ancillary services market mechanism has not yet been formed in China. For example, the key of promoting the commercialization of energy storage, electricity spot market hasn't been established yet (Yinjun et al., 2021). Moreover, the government has proposed to combine energy storage with electricity market reforms. However, in the absence of a cost-price mechanism in the electricity market, energy storage is difficult to provide favorable conditions for large-scale development of new energy. Combined with the public negative attitude towards large-scale construction at this stage, it can be seen that the large-scale development of energy storage is indeed hindered. In addition, the compensation standards and ancillary service compensation lack a long-term mechanism, and policy guarantees are uncertain.

Based on the result of sentiment analysis, it was concluded that more people hold a positive attitude toward energy storage, and changes in public sentiment have obvious time-varying characteristics. In terms of positive sentiments, the focus shifted from technology to commercialization. This benefited from the government's support for companies to explore new business models in the nurturing stage and the commercialization stage. For negative sentiments, the concerns of the public shifted from subsidies to promotion. This shows that the focus of people's sentiments about energy storage in different periods changed according to external conditions. In addition, cognitive bias is also one of the main factors affecting public sentiment of energy storage. For some topics, such as technology, photovoltaics, the public's perceptions were different. Most people identified the development of energy storage technologies, while others lacked an objective understanding of energy storage technology and had cognitive bias to energy storage. This will inevitably affect public perceptions of energy storage. Moreover, cognitive bias is gradually increase as time goes by. The strategic position of energy storage has been widely emphasized by the government. However, the positive sentiments for energy storage were gradually decreasing, while the neutral and negative situations were increasing. This may be because people's cognitive biases are gradually strengthening. The government should actively strengthen the importance of energy storage in realizing energy transformation, and give more guidance for industrial development to reduce the cognitive bias of energy storage.

CONCLUSION

To reveal how China develops the energy storage industry, the promotion of energy storage is examined from the perspectives of policy support and public acceptance. The main contribution of this paper is to combine the two perspectives to address the development of the energy storage industry. At the government level, qualitative methods were used to track the evolution of energy storage policies issued by the government. At the public level, quantitative methods were used to obtain public attitudes towards energy storage policies. Through this analytical framework, not only the development of the energy storage industry can be obtained, but also the combination of the two perspectives reveals the dynamic interaction between policy and public attitude. It is helpful and new for energy storage policy analysis. This paper combined public attitude and policy evolution to get attitudes on different development stages of energy storage policies, by comparing the opinion and the energy storage policy. It can be revealed the interaction between them as the government adopted public opinion when making the energy storage policy. Therefore, the combination analysis can provide a reference for the policymaking. In doing so, policies can be better implemented to promote the development of energy storage industry. To trace the evolution of energy storage policies in China from 2010 to 2020, this study summarized the keywords of energy storage policy in different stages. Then social data were collected to explore public attitudes towards the energy storage policy. The analysis of the evolution of energy storage policies and public sentiment can enhance the recognition of energy policies and improve policy effectiveness. The main conclusions are as follows: 1) from 2010 to 2020, China's energy storage industry experienced three development stages: the foundation stage, the nurturing stage and the commercialization stage. 2) With the support of policies, energy storage has developed rapidly, but existing problems exist such as incoordination of policies and a lack of market mechanism. 3) The public shows more positive sentiment toward energy storage policies than negative sentiments. 4) The public expressed their positive attitude for technology and commercialization of energy storage. The negative sentiments toward energy storage mainly come from subsidies and promotion of energy storage. 5) The cognitive bias will impact public attitude towards energy storage, and this bias tend to increase. The government should make more effort to eliminate cognitive bias to enhance recognition of energy storage.

Based on the above conclusions, this paper proposes the following recommendations for the development of energy storage industry:

1) Improve the policy system. China's energy storage policy needs more centralized and unified rules like corporate financing policies, taxation policies, subsidies, price policies, and evaluation policies for energy storage demonstration projects. The government should establish a special department for energy storage, responsible for the unified formulation, planning and management of policies, and coordination of various policies. At the same time, a roadmap for energy storage technology development and a plan of energy storage development should be formulated. And evaluating the market potential of energy storage with respect of renewable energy grid connection, power system peak shaving and frequency modulation, which is provided by the power generation side, grid side and user side. Finally, government will guide the market to invest in an orderly manner. This will gradually form a long-lasting mechanism to support the sustainable development of energy storage.
2) Increase public recognition of energy storage. The government should guarantee their guidance and intention can value the benefits of energy storage systems and reduce cognitive bias of public, which is of great significance for promoting the correct and comprehensive understanding of energy storage.
3) Enlarge investment on R&D. At present, China's investment in technical research and development of energy storage is insufficient, and technology cost is still high. It's has been recommended that the state arrange a special funds for energy storage so as to strengthen the technical research and development of energy storage, in order to accelerate the realization of core technology autonomy. Meanwhile, the government should insist on diversified technology, and promote new energy storage technologies such as "wind power + energy storage" and "photovoltaic + energy

storage," and realize commercial applications in scale. In addition, the government can provide sustainable funding subsidies for technical research and development in stages according to the maturity of energy storage technology, so as to reduce the investment risk of enterprises and increase their enthusiasm in participating in technical research and development.

4) Reasonable design of subsidy policy. Financial subsidy, favorable taxation policy and favorable price policy are the common economic encouragement practice. Energy storage development is inseparable from subsidies, and the widening gap in fiscal subsidies is also a current problem. That is why governments at all levels should allocate subsidies more reasonably. For battery technology and other highly practical technologies, its technological breakthroughs are difficult to predict. If the subsidy design is improper, the market will be distorted, which is not conducive to the development of the industry. At present, the implementation effect of industrial policies will be greatly reduced, as the gradual development of China's energy storage market. Continuing to provide a large number of financial subsidies will put a certain burden on the national finances, and the reasonable allocation of subsidies will maximize the use of resources. Governments at all levels can also use market mechanisms to change the current system of preference in subsidies for the long-term and healthy development of the energy storage industry.

This research has some limitations. First, we mainly focused on the national and local energy storage policies and did not explore national, provincial and municipal energy storage policies separately. Second, due to the limitation of searching permission of Weibo, this study has not analyzed the geographic location, occupation and other factors that will impact the public sentiment. Therefore, future studies should analyze the different levels of energy policies and take the influence of user information into consideration.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

Research idea, data collection, BF, TW, JP; methodology, analysis, BF, KH, TW and YZ ; writingoriginal draft, BF, TW, KH; writing,review and editing, YZ and JP. All authors have read and agreed to the published version of the article.

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