Research on the Coupling Mechanism between Policy and Its Impact on Energy Storage Market Development

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Abstract. The construction of new power system centered on renewable energy is a comprehensive task requiring the synchronization of power generation, distribution, consumption, and energy storage. With the development of energy storage market, and the policy is always a significant and challenging factor to the market development. Towards the goal of a well-developed market-drived energy storage development, there is still a magnificent gap, currently development policy plays the key enrollment. With the evolution of China's national energy strategy, there has been a surge in energy storage policies and market activities. National and local governments have introduced policies to promote the development of energy storage. These policies aim to harness the functional advantages of the energy storage, enhance market operations, and secure economic gains. This paper conducts an in-depth analysis of the impact of China's existing energy storage policies on promoting the development of energy storage. It proposes a model for the market-oriented operation of the energy storage market in China and preliminarily establishes a mathematical model of the impact of policy on the development of energy storage. This provides a reference for the formulation of energy storage policies in China and the investment and construction of energy storage projects.

Keywords: Energy storage policies, Energy storage operation mode, Dynamic gain regression model

1 Introduction

China is advancing its energy strategy, emphasizing a shift towards a modern, clean, low-carbon, secure, and efficient system, in line with President Xi Jinping's climate goals announced in 2020 for carbon peak by 2030 and neutrality by 2060. The government's strategy, highlighted since the 18th National Congress, focuses on green development, pushing for a transition from fossil fuels to renewable sources and reforming power systems towards energy storage and new energy systems [1].

Energy storage, crucial for the new power system and achieving carbon neutrality, faces challenges like high costs and immature technology, requiring substantial policy support. China has implemented a range of policies, from national to local levels, to promote energy storage development. These policies aim at overcoming technological and market barriers, integrating renewable energy, and ensuring power system reliability. They include financial incentives such

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as operation subsidies, tax breaks, and support for market participation to stimulate investment and commercial viability [2]–[4].

Despite the reliance on policy subsidies, China is working towards a comprehensive power market and stable revenue models for energy storage, emphasizing the development of auxiliary services and reducing market entry barriers [5] [6]. The focus extends to user-side storage, though it is less developed compared to other international examples, indicating potential for growth and economic benefits for end users [7].

In summary, China's energy strategy and policies are designed to foster a clean, low-carbon transition with a significant focus on energy storage as a linchpin for a new power system and carbon neutrality. The government's comprehensive approach, including financial and market reforms, aims to enhance renewable energy utilization, system reliability, and pave the way for commercial operations in the energy storage sector.

2 China National Policies on Energy Storage Development

Energy storage development is steered by market economics and technical standards, facing challenges like high initial investments, long return periods, and an underdeveloped electricity market in China. Additionally, emerging power system construction and immature technologies highlight the need for national policy support. Various government departments have issued policies to aid energy storage technology advancement, emphasizing design, implementation, and management strategies. Key documents include the "14th Five-Year Plan for a Modern Energy System" and the "14th Five-Year Development Plan for New Energy Storage," which set the direction for energy storage's role in future energy systems and its development pathway, respectively.

2.1 Top-Level Design of Energy Storage Planning

The push towards energy storage is propelled by the global transition from fossil fuels to renewable energy, driven by the scarcity of traditional fossil fuels, environmental considerations, and the quest for national energy security. Energy storage is pivotal for mitigating the variability of renewable energy production and ensuring the stable operation of new power systems predominantly powered by renewable sources. The "Action Plan for Carbon Peaking Before 2030" issued by the State Council on October 24, 2021, underscores the importance of energy stability and the enhancement of renewable energy to foster a clean, low-carbon, safe, and efficient energy structure. With the anticipated growth in renewable energy capacity, energy storage systems' bidirectional regulation capabilities become essential. By 2025, the goal is for new energy storage installations to surpass 30 million kilowatts, boosting the grid's peak load response and overall stability [8]. The "14th Five-Year Plan for a Modern Energy System," issued in January 2022, advocates for proactive energy storage development on the generation side, strategic deployment on the grid side, and supportive construction on the consumer side [9]. It also highlights the need for breakthroughs in key energy storage technologies, mastery of core technologies, cost reduction, and promotion of widespread application.

2.2 Implementation Plan of Energy Storage Development

In China's energy storage sector, strategic planning has adapted to the grid's needs, differentiating development paths for generation, grid, and user sides. The "Guidance for Accelerating the Development of New Energy Storage" issued on July 15, 2021, underscores the importance of expanding generation-side storage projects, optimizing grid-side storage distribution, and encouraging diverse user-side storage solutions [10]. This approach prioritizes integrating storage with renewable energies to enhance grid compatibility, support new energy consumption, and provide system stability and capacity support. It also promotes the strategic placement of storage in the grid to improve flexibility and security, and advocates for user-side storage innovations around microgrids and electric vehicles, using advanced technologies to explore new business models like virtual power plants.

Following the transition from demonstration to commercialization in the 13th Five-Year Plan, the "14th Five-Year Plan for the Development and Implementation of New Energy Storage," released on January 29, 2022, focuses on R&D of core technologies and market-oriented operations of energy storage [11]. It sets forth a comprehensive strategy for quality and scaled development of new energy storage, emphasizing innovation, industry guidance through demonstration projects, support for a new power system infrastructure, marketization enhancement, management framework improvement, and strengthening international cooperation to increase competitiveness.

2.3 Management and Operation of Energy Storage

The safety and efficiency of energy storage projects necessitate a collaborative approach, particularly in enhancing the safety protocols for electrochemical storage batteries. Key areas include developing comprehensive inspection processes, establishing standards for daily management, and ensuring fire safety. Additionally, aligning grid integration, operation dispatch, and market participation with new energy storage systems is crucial.

Policies advocate for fair and efficient grid access for energy storage, highlighted by the National Energy Administration's "Interim Management Norms for New Energy Storage Projects" in September 2021, which detail grid companies' responsibilities in facilitating energy storage integration [12]. The focus is on equitable services and streamlining connection processes for registered projects.

Improving management procedures, technical standards, and safety measures is emphasized to ensure energy storage projects' safety and reliability. This includes establishing a traceability system for electrochemical batteries, ensuring compliance with safety and environmental standards, and promoting regular maintenance and safety assessments.

Sustainable development in energy storage, with its high upfront costs and long return periods, relies on a robust electricity market framework and strategic revenue models. The "Notice on Further Promoting New Energy Storage Participation in the Electricity Market and Dispatching" from May 24, 2022, underlines the role of new energy storage in enhancing grid flexibility and efficiency. It calls for market mechanisms to support storage integration and optimize returns [13], ensuring the sector's healthy growth. Moreover, a State Council notice from May 30, 2022, underscores the importance of devising cost recovery strategies for energy storage to foster its high-quality development [14].

3 Regional Policies on Energy Storage Development

Under the encouragement of various national energy storage promotion policies, local governments have also gradually introduced relevant policy documents to support the construction and operation of energy storage projects. Local policies mainly revolve around the construction of energy storage projects in their areas, providing support in land use, taxation, investment, and operation. These policy documents cover subsidies for energy storage construction and operation, as well as regulations related to the allocation of energy storage for new energy projects such as photovoltaic and wind power, aiming to reduce energy wastage and minimize the impact of new energy generation fluctuations on the grid.

3.1 Policy Support and Subsidies for Energy Storage Projects

Energy storage systems compensate for the randomness and fluctuation of new energy generation and can participate in grid peak shaving. For grids with high penetration of new energy, energy storage is crucial for stabilizing their operation and improving the quality of electricity. By releasing electricity when needed by the grid, energy storage systems can mitigate the fluctuation of new energy generation and maintain grid frequency during peak usage, bringing significant economic and social value. Local governments typically provide a subsidy of 0.3 yuan/kWh for energy storage discharge. Large energy storage systems, more suitable for grid peak shaving, can provide longer discharge times for the grid when new energy generation is disrupted. Local governments also set subsidies for energy storage capacity, generally ranging from 100 to 200 yuan per kilowatt-hour. Additionally, some areas provide investment subsidies for energy storage projects, including subsidies based on a certain percentage of the total project investment or fixed amount of financial subsidies.

3.2 Requirements for New Energy Storage Allocation

In addition to supporting standalone energy storage projects, to further promote the construction of new power systems centered on new energy, various regions have introduced requirements for new energy generation projects to include energy storage allocations. Regions have proposed integrated development models of "new energy + storage" and the use of energy storage to facilitate "province-wide consumption of new energy electricity." Depending on the proportion of new energy generation capacity to the total capacity in each region, as well as the local supporting power sources and other regulatory measures' ability to peak shave and frequency regulate the grid, reasonable requirements for energy storage capacity allocation are made, generally ranging from 5% to 20% of the new energy rated capacity.

On the regulatory side, efforts to integrate energy storage with new energy projects have varied regionally, often following a uniform approach that does not fully consider the specific needs of smoothing renewable energy output and minimizing curtailment. The current pricing mechanisms for new energy connections complicate the economic feasibility of energy storage projects[15]. However, innovative approaches like the one adopted by the State Grid Qinghai Provincial Electric Power Company in 2019, which allows shared energy storage to participate in market transactions independently, offer a glimpse into potential solutions [16]. This model, encouraging the on-demand purchase of shared storage capacity based on seasonal variations and real-time generation data, presents a more efficient and financially sustainable method for allocating energy storage, highlighting the importance of flexible, tailored strategies to improve utilization rates and accelerate the economic viability of energy storage investments.

4 Improvement and Promotion of Energy Storage Market Business Models

National policies have streamlined energy storage integration into the grid, enhancing operational standards and supporting construction with local incentives for land, tax, and financing. This has spurred advancements across the energy storage value chain, reducing costs and accelerating sector growth. Despite this, the inherent high initial costs and lengthy ROI period for energy storage projects persist, and policy reliance alone doesn't ensure profitability. Between 2017 and 2019, some projects were suspended due to cost recovery challenges. Establishing a clear role for energy storage, developing viable market participation models, and fostering market-driven sustainable growth are crucial for the sector's health.

4.1 Construction and Improvement of the Energy Storage Market

Energy storage market operations hinge on a mature electricity market, a challenge for the traditional grid planning and dispatch model. Since the 21st century, China's reforms have introduced competition into the electricity system to enhance operational efficiency. While electricity market construction has progressed, it still falls short in fully recognizing electricity's commodity nature, especially in spot trading. Key reforms, like the "Electricity System Reform Plan" (2002) and the "Opinions on Further Deepening the Reform of the Electric Power System" (2015), have significantly advanced China's electricity market, moving towards a "unified market, dual-layer operation" model. Currently, the market emphasizes medium to long-term trades, with spot and auxiliary services markets facing integration challenges [17]. The "Guidance on Accelerating the Construction of a Unified National Electricity Market System" (2022) aims to adapt the market to renewable energy, setting goals for a unified national system by 2025 and completing its framework by 2030 [8]. This guidance addresses electricity market reform challenges, promoting new energy consumption and flexible adjustment resources like energy storage.

4.2 Mechanisms for Energy Storage Participation in the Electricity Market

Energy storage supports grid stability, new energy integration, and peak regulation, benefiting from policies encouraging its construction. Yet, the underdeveloped electricity market limits profitable participation models, with current incentives focused on discharge subsidies. In the long run, energy storage's participation in market transactions and auxiliary services will be vital for revenue generation and sustainable project development, as is shown in **Figure 1**. Energy storage is divided into front-of-meter (grid and new energy support) and behind-the-meter (commercial and residential use) systems. Policies mandate new energy projects to include storage capacity, promoting grid stability and efficient energy use. Front-of-meter storage revenue streams include capacity, wholesale, and frequency regulation services, drawing from international examples like the UK and USA, where energy storage benefits from market participation and auxiliary services. Recent regional policies in China support energy storage's independent participation in the electricity market, emphasizing its role in load balancing and system stability. This focus on long-term profitability and commercial viability underscores the importance of sustainable energy storage development.

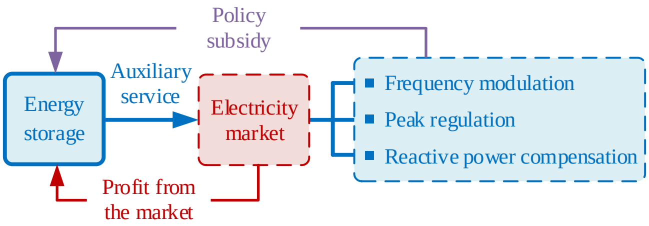

Figure 1. The model of energy storage participating in the electricity market for profit.

5 The mathematical model of the impact of energy storage policy on energy storage market development

Various factors will influence the investment and construction of energy storage projects, including energy storage policy, the development level of energy storage technology, geographical environment, market environment, etc. These factors can ultimately be attributed to the cost and revenue level of energy storage project construction. For example, some policies provide subsidies for the operation of energy storage, which will directly affect the revenue level of energy storage project operations. The level of energy storage technology will directly affect the cost of energy storage construction, and other factors will also directly or indirectly affect the cost and revenue of energy storage as well as its long-term market prospects.

Define the variable P_t as the policy support index at time t, reflecting the direct support from the government for energy storage projects, such as financial subsidies, tax reductions, technical research, and development support, etc. The policy support index can be quantitatively described as

$$P(t) = \frac{C_0}{C_1} + C_E \tag{1}$$

Where C_0 is the cost of constructing unit capacity energy storage before the introduction of a policy, and C_1 is the cost of constructing unit capacity energy storage after the policy is introduced. Some policies have made plans for the future development of energy storage, not directly subsidizing the construction of energy storage projects, but these policies will create positive expectations for the future prospects of energy storage among investors, which will serve as an additional factor affecting the policy support index, denoted as C_E.

Define C_t as the unit cost of energy storage technology at time t, which is influenced by both policy support and technological progress.

Considering the impact of policy on costs:

$$C_{t+1} = f(P_t, C_t) \tag{2}$$

Wherein, the function *f* describes how policy support reduces the unit cost of energy storage technology by promoting technological innovation and providing financial subsidies.

Define D_t as the demand for energy storage in the market at time *t*, which is influenced by policy support, cost changes, and market perception.

Since most new energy power installations require the configuration of a certain capacity of energy storage, the installed capacity of new energy will have a direct impact on the installed capacity of energy storage. Considering the dynamics of new energy installed capacity:

$$N_{t+1} = N_t(1+\lambda P_{nt}) \tag{3}$$

Wherein, P_{nt} is the policy support index for new energy generation at time *t*, N_t represents the installed capacity of new energy generation at time *t*.

The dynamics of energy storage demand can be expressed as:

$$D_{t+1} = g(P_t, D_t, C_{t+1}, N_{t+1}) \tag{4}$$

Wherein, the function *g* describes how policy support increases market demand by improving the cost-benefit ratio, enhancing market perception, and other means.

Define S_t as the total installed capacity of energy storage at time *t*. The dynamic changes in installed capacity can be described as:

$$S_{t+1} = S_t + h(D_{t+1}) \tag{5}$$

Wherein, the function *h* describes how market demand translates into changes in the installed capacity of energy storage. The five equations mentioned above constitute the mathematical model of the impact of policy on the development of energy storage. A diagram of the model is shown in **Figure 2**.

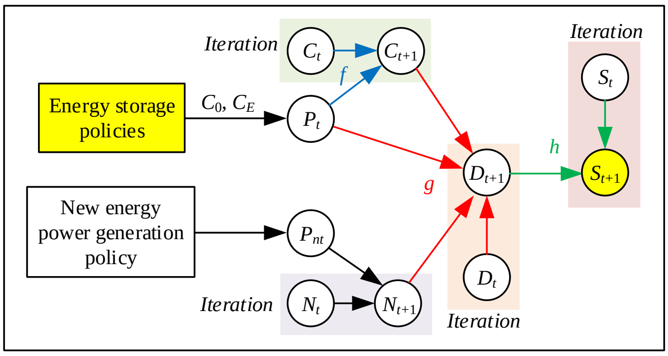

Figure 2. Mathematical model of the impact of policy on the development of energy storage.

The installed capacity of energy storage in China from 2017 to 2022 is shown in **Table 1**.

Table 1. Energy storage installed capacity data from 2017 to 2022.

Year	2017	2018	2019	2020	2021	2022
Energy storage capacity (GW)	28.9	31.3	32.4	35.6	43.4	59.4

To verify the accuracy of the proposed model, data from 2017 to 2021 is used to predict the data for 2022. At the same time, a linear regression model is used for prediction to compare the effectiveness of the model proposed in the text.

Linear regression is a statistical method used to quantify the relationship between variables. Consider a single-variable linear regression model:

$$y = \beta_0 + \beta_1 x + \varepsilon \tag{6}$$

In the model, y represents the installed capacity, x represents the year, β_0 is the intercept term, β_1 is the slope coefficient, and ε is the error term.

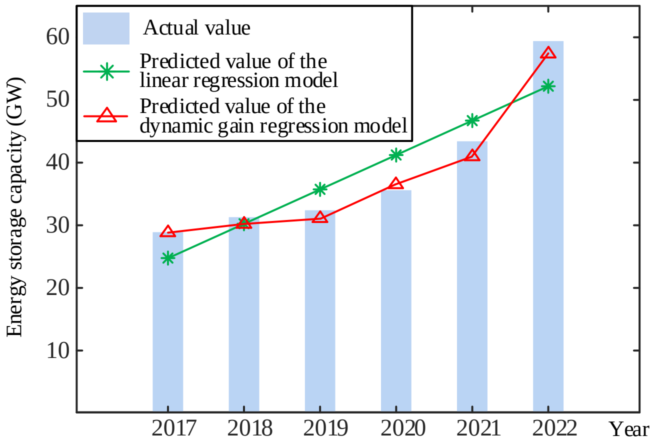

Figure 3. Predicted Energy Storage Installed Capacity by the Model.

Using the least squares method to solve the model, based on the data from 2017 to 2021, the predicted installed capacity for 2022 is 52.2 GW, with an error of 12% compared to the actual value.

By applying regression analysis to solve the mathematical model proposed in the text, a dynamic gain regression model is formed. The gain of this regression model changes with policy changes and technological developments. Based on the data from 2017 to 2021, the predicted installed capacity for 2022 is 57.5 GW, with an error of 3% compared to the actual value. The energy storage installed capacity predicted by the model is shown in Figure 3.

6 Conclusion

The paper analyzes the promotion effect of China's energy storage policies on the market development of energy storage, and provides the coupling mechanism for the market-oriented operation of the energy storage market in China, then establishes a mathematical model of the impact of policy on the market development of energy storage, which specifically includes the follows:

- The Chinese government has clarified the emphasis and future development direction of energy storage in its top-level design, indicating a broad development prospect for energy storage. Local regional governments, in line with their actual conditions, provide various subsidies for the construction of energy storage market, including financial and tax incentives.

- The market-oriented operation of energy storage will be an important path for its sustainable development. The power market system urgently needs improvement. Energy storage plays roles in frequency regulation and peak shaving, participating in the ancillary services market for profit. Guided by market supply and demand for energy storage investment and construction, this is the path to the virtuous development of energy storage.

- A mathematical model of policy impact on energy storage development was established, policy support indicators were defined, policy impact was quantified, and the relationship between policy and cost-effectiveness, installed capacity of new energy, storage market demand, and installed capacity of energy storage was deduced. It provides reference for policy formulation and energy storage investment construction.

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