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Article

Maintaining security of power supply in the context of technological change driven by low-carbon transition

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ABSTRACT

China's power system is transitioning from fossil fuels to high-penetration variable renewable energy (VRE), challenging traditional models of electricity supply security. This challenge stems from two interconnected issues: the economic viability of coal plants under declining utilization rates, and the system's escalating flexibility requirements. This study applies the Causal Loop Diagram (CLD) method to unravel dynamic feedback mechanisms between VRE deployment, storage utilization, and capacity remuneration, identifying leverage points for policy intervention. By contrasting China's coal capacity payments with the UK's technology-neutral capacity market, we derive profound insights for coordinating flexibility incentives and decarbonization goals. This study focuses on how to maintain electricity supply security while managing the orderly phase-out of coal power. Analysis reveals that the current capacity compensation mechanism has potential drawbacks, including the exclusion of emerging flexible resources, the risk of overinvestment. Based on this, we propose that China implement coordinated reforms across following domains: First, establish competitive, technology-neutral capacity markets to incentivize investments in flexible resources like energy storage and demand-side response. Second, deepen electricity market reforms to create diversified revenue streams for energy storage through energy trading, ancillary services, and capacity mechanisms. Third, implementing a fixed cap on emissions and introducing a carbon price floor to accelerate the phase-out of inefficient coal power. Finally, create strategic reserves to ensure grid reliability during extreme events, thereby strengthening system resilience throughout the energy transition.

KEYWORDS

Power system, supply security, flexible resources, capacity markets.

1 Introduction

1.1 Background

Penetration of variable renewable energy (VRE)—wind and solar—in China reached 18.2% in 2024[a], and is expected to grow to 65%–70% by 2060[b], when the country aims to achieve net zero. This growing penetration of VRE raises two major challenges for the Chinese electricity system. First, the rapid growth of VRE reduces operation of other plants, and particularly coal-fired units. Given that coal-fired generators have traditionally earned revenues through electricity sales, declining load factors may undermine the economic viability of new and existing plants without other support[1]. This creates the risk, or at least the perceived risk, of premature shutdowns of coal plants leading to insufficient dispatchable capacity during periods of low VRE generation and potentially threatening grid reliability. Second, higher penetration of VRE, and particularly solar, requires stronger operational flexibility across the system: flexible generators will need to ramp up and down faster and more frequently to accommodate variable generation (see Figure 1). Figure 1(c) illustrates how the peak-valley difference in net load is expected to widen significantly over time as VRE penetration increases, concretely demonstrating the growing flexibility requirement[2]. China's small deployment of natural gas will further complicate the ability to balance the system as compared to the UK.

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[a] See National Bureau of Statistics (2025). People's Republic of China national report on economic and social development 2024. Note that this annual statistic includes distributed (rooftop) solar and wind. Monthly datasets often do not, which can lead to issues of underestimating VRE penetration, as noted in Myllyvirta (2024). Analysis: Monthly drop hints that China's CO_2 emissions may have peaked in 2023. Carbon Brief.

[b] Per projections in Tsinghua University (2024). Technology Outlook on Wind and Solar Power Towards China's Carbon Neutrality Goal.

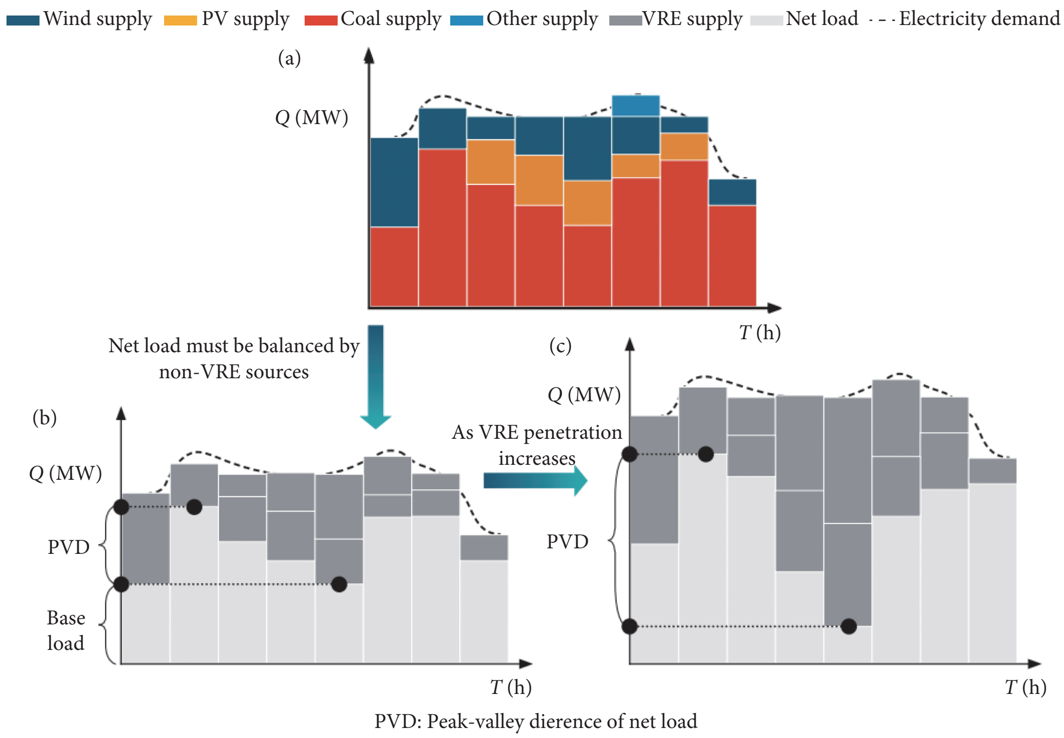

Fig. 1 Trend in net load peak-valley difference amid growing VRE penetration. Note: A typical daily dispatch mix and load curve is shown in **(a)**. The net load in this scenario is highlighted in **(b)**, along with the daily maximum and minimum net loads to show peak–valley difference. Over time, as both demand and VRE penetration increase, the peak-valley difference is expected to widen, as shown in **(c)**.

In June 2024, the National Development and Reform Commission (NDRC) and the National Energy Administration (NEA) released the “Action Plan for the Low-Carbon Transformation and Construction of Coal-fired Power Plants (2024–2027)”. The document states that a mechanism for the coordinated transformation of low carbon and flexibility should be established. According to this document, China’s solution to the first problem, to date, has been to introduce fixed payments for coal power capacity. While this may shore up thermal plants’ economic viability for now, this approach risks introducing tension between the goals of security and decarbonisation, and does little to respond to the second problem given the flexibility limitations of coal-fired generators. Another approach has been to retrofit coal plants to increase operational flexibility.

This paper responds to these two challenges by first contrasting capacity remuneration mechanisms in China and the UK, then discussing policy mechanisms to support flexible low-carbon generation in the form of short-duration energy storage. The analysis leverages the Causal Loop Diagram (CLD) methodology to pinpoint key leverage points within the power system’s policy landscape. This is achieved by delineating the system’s causal structures, specifically the reinforcing and balancing feedback loops that characterize dynamics such as energy storage integration and its impact on market price signals and investment viability. This systems-level mapping reveals strategic intervention points where targeted reforms can generate disproportionate policy impacts. Following this, we consider more closely options for maintaining security of supply while reducing or eliminating the need for investment in new coal plants including improving regional connectivity and deploying long-duration energy storage to incentivise a stable phase-down of coal-fired power.

1.2 Literature review

The rapid growth of VRE has stimulated extensive research on the implications for power system reliability and flexibility[3]. Recent studies emphasise that as VRE penetration increases, traditional thermal-based adequacy models are increasingly insufficient to guarantee supply security, particularly in systems with limited interconnection or natural gas flexibility[4–7]. Scholars have highlighted that VRE-dominant systems require a wider portfolio of flexibility resources—including demand-side response, interregional transmission, short-duration battery storage, and long-duration storage—to maintain reliability while minimising investment in fossil capacity[3,8]. These findings align with system modelling research showing that without market reforms to compensate flexibility and firm capacity, power systems face elevated risks of stranded assets and inefficient curtailment[9,10].

A second strand of literature examines capacity remuneration mechanisms (CRMs) as tools to sustain adequacy during decarbonisation[11,12]. Comparative analyses of CRM design across Europe and the US indicate that technology-neutral auctions can lower system costs and encourage innovation but also risk over-procurement and entrenching incumbent fossil generators when carbon pricing is weak[11,12]. The UK capacity market has received particular scholarly attention for its role in enabling coal phase-out while supporting the emergence of battery storage; however, recent work shows that absence of duration requirements has led to insufficient long-duration storage investment, prompting discussions of multi-category auctions and minimum clean capacity obligations[12,13]. In contrast, China’s fixed capacity payments for coal—introduced to stabilise revenue following falling utilisation hours—are viewed by multiple authors as potentially conflicting with decarbonisation goals by reinforcing coal lock-in and distorting investment signals[14].

Finally, an emerging literature focuses on the economics and market integration of energy storage[15–18]. Short-duration battery energy storage systems (BESS) are widely recognised as essential for balancing VRE variability, yet their profitability depends sensitively on arbitrage spreads, ancillary service design, and capacity remuneration[15–17,19]. Scholars emphasise that market saturation can erode arbitrage revenues, reinforcing the need for diversified revenue stacking or explicit capacity mechanisms[16,17]. Long-duration energy storage (LDES) has been identified as critical for deep decarbonisation beyond 60%–70% VRE, though investment barriers remain high due to large upfront costs and revenue uncertainty[18]. Several recent papers highlight the potential of cap-and-floor mechanisms—modelled after UK interconnector regulation—to de-risk LDES investment while retaining market efficiency. Collectively, this literature underscores the need for coordinated reforms integrating VRE policy, capacity mechanisms, carbon pricing, and storage market design to maintain security of supply during fossil fuel phase-down[16–18,20].

The UK is used in this study as the primary international comparator because it represents one of the earliest and most comprehensive examples of reconciling high VRE penetration with security-of-supply objectives through market-based mechanisms[21,22]. Unlike other OECD electricity markets, the UK has already phased out coal, introduced a long-standing capacity market, and integrated large volumes of battery storage within a liberalized market environment[21,22]. These features make the UK a highly relevant reference case for China, which is now facing similar challenges—declining coal utilisation, growing flexibility needs, and the need to redesign market incentives during the energy transition[23,24]. The UK's experience thus offers policy insights directly transferable to China's context, particularly regarding capacity market design[21], storage remuneration[22], and the management of coal phase-down risks[24].

2 Capacity payments and capacity markets

2.1 China's experience with coal power capacity payments

A capacity payment scheme for coal (and gas) power plants was launched in 2024 to address concerns that declining operating hours would threaten generators' financial viability[25]. Under this mechanism, coal power plants are paid a monthly flat rate based on their capacity, independent of generation. The payment is set at a level designed to enable the recovery of a certain percentage of generators' fixed costs (assumed to be ¥330/(kWh·year): 30% in most provinces (For simplicity, "province" is used throughout to refer to province-level administrative regions.) and 50% in provinces making faster progress on decarbonisation. By 2026, this proportion is to rise to at least 50% in all provinces. The cost of the payment scheme is recovered via industrial and commercial user tariffs. The policy states that generators must meet environmental and flexibility requirements to be eligible for the payments, but information on what these comprise in practice has not yet been specified.

Whilst this mechanism may shore up financial viability of the thermal power sector, there are several potential drawbacks to this approach. First, the current capacity payment scheme focuses on incumbent technologies, excluding emerging solutions like energy storage and demand-side response, promoting lock-in and discouraging innovation. Local pilot projects for battery energy storage (e.g., in Shandong and Zhejiang) remain fragmented. Second, the scope and scale of payments are not calibrated to planned capacity needs, risking overpayment, as all coal plants are eligible for support. This is evidenced by the uniform capacity price applied across most in Table 1, which does not reflect differing local capacity adequacy conditions. Third, the flat payment mechanism cannot discover the market price that generators are willing to accept to provide capacity, again risking overpayment and inefficiency. Fourth, while intended to support the financial viability of thermal plants, it fails to incentivise a shift to backup roles and may even encourage unnecessary generation. Finally, the payment scheme strengthens the business case for new coal power capacity additions and delayed retirements, which risks sinking capital into polluting assets that may become stranded. This entrenches the financial interests of state-owned enterprises (SOEs) and local governments in prolonging the operating life of thermal power assets, which could compromise efforts to achieve national climate targets.

Table 1 Coal-fired power capacity payments, by provinces (2024–2025). Hong Kong, Macao, and Taiwan are not included due to data available.

Province	Capacity price (CNY/(kW·year))	Province	Capacity price (CNY/(kW·year))
Beijing	100	Hubei	100
Tianjin	100	Hunan	165
Hebei	100	Guangdong	100
Shanxi	100	Guangxi	165
Inner Mongolia	100	Hainan	100
Liaoning	100	Chongqing	165
Jilin	100	Sichuan	165
Heilongjiang	100	Guizhou	100
Shanghai	100	Yunnan	165
Jiangsu	100	Xizang	100
Zhejiang	100	Shaanxi	100
Anhui	100	Gansu	100
Fujian	100	Qinghai	165
Jiangxi	100	Ningxia	100
Shandong	100	Xinjiang	100
Henan	165		

These five issues suggest that the coal power capacity remuneration mechanism is an inefficient means of promoting capacity adequacy, and risks unnecessary expansion, or delayed retirement, of polluting coal power assets. Strategically, the policy risks being in conflict with the government's goals for carbon peaking and carbon neutrality. The policy reflects the overriding need for security of supply, however, so the rest of this paper explores many dimensions and policy options for sustaining security of electricity supplies in a world of rising renewables, starting with a review of the UK approach to security with some lessons from its experience with a capacity market.

2.2 The UK's experience with a capacity market

The UK case is examined not as a prescriptive model but as a diagnostic reference that illustrates the operational and institutional challenges China is likely to confront as VRE penetration rises. Its long-running capacity market, shift from coal to flexible gas and storage, and recent reforms targeting long-duration storage provide a rich empirical basis for analyzing the strengths and weaknesses of different security-of-supply mechanisms.

2.2.1 Context on the UK capacity market

The UK's Capacity Market (CM), established in 2014 as a core part of its Electricity Market Reform, addresses capacity adequacy concerns in a system phasing out coal and integrating high shares of variable renewables. Its analysis offers key insights for China. The CM's design is built on several principles: it employs technology-neutral, competitive auctions (T-4 for long-term planning and T-1 for short-term adjustments) to procure reliable capacity. A critical institutional feature to mitigate the risk of political over-procurement is the independent Panel of Technical Experts (PTE), which reviews the system operator's capacity assessment before the government sets the final procurement target. This separation of technical assessment from political decision-making is a central analytical point for designing a credible mechanism that balances reliability with cost-effectiveness and decarbonization goals.

2.2.2 Current functioning of the CM

The evolution of the UK CM's outcomes provides critical analytical insights into the dynamics of a technology-neutral capacity mechanism. As shown in Figure 2, the consistently lower-than-expected clearing prices across delivery years highlight the market's effectiveness in revealing the true marginal cost of capacity, dispelling initial concerns about excessive costs to consumers. Figure 3 and Figure 4 reveal the consequential resource mix: the sustained dominance of existing gas generation and interconnectors, coupled with the rising share of battery storage and demand-side response, demonstrates that the CM has primarily facilitated a cost-effective, incremental transition towards system flexibility rather than triggering a wave of new thermal capacity. This outcome analytically underscores a key finding: a well-designed capacity mechanism can secure adequacy while fostering a diverse portfolio.

However, this analysis also uncovers a critical, self-reinforcing feedback loop inherent in the initial design. By treating all capacity as equal without duration differentiation, the auction inherently favored the lowest-cost option: short-duration BESS. As BESS penetration grew (evident in the rising "Storage" share in Figure 4), a new adequacy challenge—energy limitation during prolonged system stress—emerged. This, in turn, necessitated a policy correction: the reduction of de-rating factors for short-duration storage. This sequence—from a uniform design, to a skewed procurement outcome, to the recognition of a new risk, and finally to a corrective rule change—is a quintessential example of the reinforcing (R) and balancing (B) feedback loops that our CLD methodology is designed to capture (see Section 3). It underscores that a static market design can produce unintended consequences, highlighting the analytical necessity of anticipating such dynamic interactions from the outset.

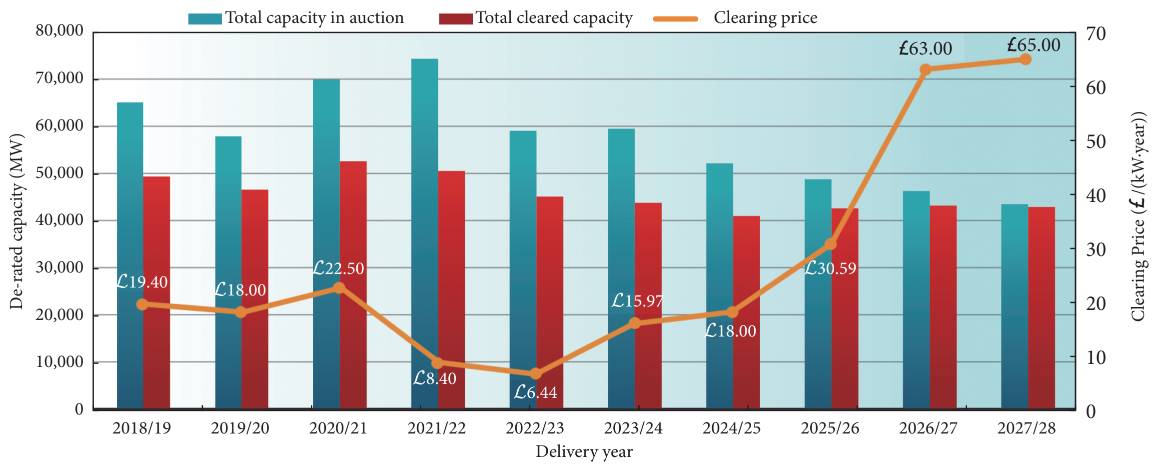

Fig. 2 Historical overview of T-4 and T-1 auctions.

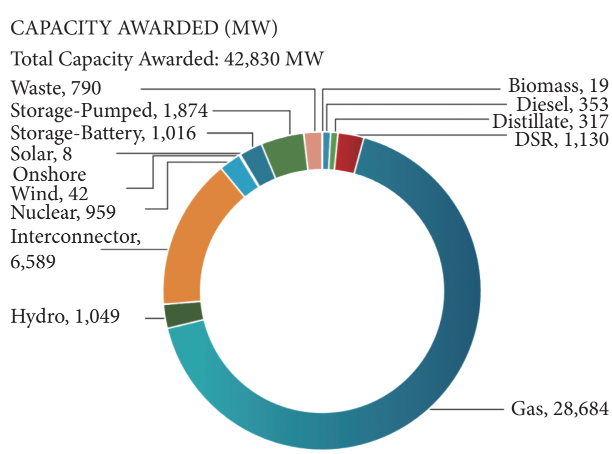

Fig. 3 Capacity awarded in the 2024 T-4 auction by primary fuel type.

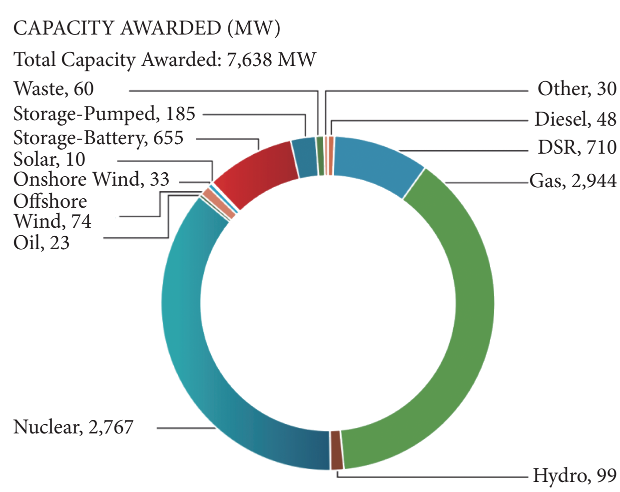

Fig. 4 Capacity awarded in the 2024 T-1 auction by primary fuel type.

2.2.3 Future challenges and reforms

The UK government designed the CM to ensure reliable generation at least cost, a goal it has largely achieved while also facilitating the deployment of low-cost BESS. Over time, emerging challenges have prompted continuous design adjustments. Early auctions attracted substantial diesel capacity, raising political concerns over high emissions and leading to rule changes that excluded diesel units. Although BESS performed strongly in initial rounds, the absence of duration requirements resulted in a prevalence of short-duration systems with limited value during prolonged stress events. Consequently, de-rating factors for one-hour BESS were reduced from 96% in 2017 to 19% in 2023[c], underscoring their limited reliability contribution. Yet, the CM still provides insufficient incentives for LDES, prompting the Department for Energy Security and Net Zero (DESNZ) to introduce a revenue cap-and-floor mechanism. As VRE penetration rises, the CM's equal treatment of all generators increasingly constrains flexibility and response speed. The continued reliance on gas capacity and the lack of incentives for low-carbon, long-duration storage have emerged as key barriers, driving government consideration of new design options—such as introducing dedicated "windows" within the CM—to better integrate zero-carbon and flexible resources.

3 Methodology

The transition toward a power system characterised by high penetration of variable renewable energy fundamentally reshapes the economic and operational logic governing capacity adequacy, flexibility provision, and investment behaviour. Unlike conventional power systems dominated by dispatchable thermal generation, high-VRE systems are driven by endogenous interactions among market prices, utilisation rates, policy interventions, and investor expectations. These interactions evolve dynamically over time and are characterised by feedback effects, time delays, and nonlinear responses.

In this context, CLDs are particularly well suited for analysing power system transitions. First, capacity adequacy and flexibility challenges under high VRE penetration are not static optimisation problems, but path-dependent processes in which today's policy choices influence future market outcomes, which in turn reshape subsequent policy responses. Static equilibrium models or single-period cost-minimisation frameworks struggle to capture such evolving feedback structures. CLDs, by contrast, explicitly represent how reinforcing (R) and balancing (B) feedback loops govern long-term system trajectories, making them especially valuable for diagnosing unintended consequences of market design and regulatory interventions.

Second, CLDs enable the integration of institutional and behavioural factors—such as capacity remuneration mechanisms, de-rating rules, and investment incentives—alongside physical system variables. This feature is critical for analysing capacity markets, where outcomes are shaped not only by technical adequacy needs but also by regulatory design choices and investor responses. As illustrated by the UK experience discussed in Section 2, seemingly technology-neutral rules can generate self-reinforcing dynamics that favour specific resource types, necessitating subsequent corrective reforms. CLDs provide a transparent framework for tracing these cause–effect chains and identifying the structural origins of policy-induced lock-ins.

To illustrate the analytical value of CLDs in this study, consider the feedback loop linking storage deployment, price spreads, and investment incentives. Increased deployment of BESS enhances short-term system flexibility and reduces price volatility, thereby narrowing wholesale price spreads. While this effect improves operational efficiency and reduces curtailment, it simultaneously erodes arbitrage revenues, weakening the investment incentives for additional storage capacity. This constitutes a balancing feedback loop (B): higher storage penetration dampens the very price signals that initially motivated investment. When embedded within a capacity market framework that does not differentiate by duration, this loop can interact with a reinforcing feedback (R) favouring short-duration storage—low capital costs lead to higher auction success, which further accelerates deployment, even as system-level adequacy risks emerge during prolonged stress events. Such interacting feedbacks are difficult to identify through linear analysis but are readily exposed through CLD representation.

Building on these insights, the CLD developed in this study maps the key feedback structures connecting VRE deployment, storage utilisation, capacity remuneration mechanisms and coal retirement decisions. The objective is not to predict precise quantitative outcomes, but to identify dominant feedback loops and leverage points where targeted reforms—such as duration-sensitive capacity products or complementary support mechanisms for long-duration storage—can realign investment incentives with long-term system reliability and decarbonisation objectives. In this sense, CLDs serve as an analytical bridge between empirical market experience, such as that of the UK capacity market, and forward-looking institutional design for power systems undergoing deep structural transition[26].

4 Results and discussions

4.1 Capacity mechanism

4.1.1 Capacity markets as an alternative to coal capacity payments

Given the limitations of China's current coal installed capacity payment plan, as indicated in the "Notice on Further Deepening the Market-oriented Reform of On-Grid Electricity Prices for Coal-fired Power Generation" issued by the National Development and Reform Commission in October 2021, piloting an installed capacity market is a feasible alternative solution. International experience—most notably the UK—suggests that capacity markets can enhance supply adequacy while improving cost efficiency, though implementation challenges remain. In China, capacity targets could be set at the provincial or regional level to

[c] To account for duration limits when calculating the contribution to security of supply, the revisions use an Equivalent Firm Capacity metric (EFC), defined based on the question "for a given penetration of that resource, what is the amount of perfectly reliable infinite duration firm capacity it can displace while maintaining the exact same reliability level?" (National Grid, 2017). These values will continue to decline over time, especially for BESS, as more storage comes into the system, which has been explored by Holness-Mckenzie (2024).

inform auction design, while central oversight would be required to ensure consistency with national decarbonisation objectives. Such a layered governance structure could help limit over-procurement driven by local security concerns and reduce the risk of excess payments for surplus capacity.

Compared with administratively determined payments, competitive auctions could strengthen incentives for verified performance and availability, while delivering adequacy at lower cost. Opening auctions to a broader portfolio of resources—including flexible low-carbon generation, storage, distributed resources, and demand-side response—would address the current under-representation of non-coal flexibility options. However, the ability of emerging low-carbon technologies to compete directly with incumbent coal in a unified capacity market remains uncertain, particularly in the absence of a robust carbon pricing framework. While technology-neutral auctions are most efficient for mature resources with similar reliability characteristics, their effectiveness in prioritising low-carbon capacity ultimately depends on complementary climate policy instruments.

4.1.2 Technology differentiation and auction design during the energy transition

In the context of a rapid energy transition and weak carbon price signals, a fully technology-neutral capacity market may be inappropriate. The UK's REMA process has therefore explored differentiated auction designs along two dimensions: operational characteristics (e.g. response time, duration, and locational constraints) and carbon intensity, reflecting the need to support innovation and avoid bias towards incumbent technologies. Undifferentiated auctions risk favouring mature, high-emissions resources, potentially undermining decarbonisation objectives.

Under such an approach, different "windows" within a single auction could be defined, each with distinct clearing prices and procurement targets. This would allow policymakers to specify the types of capacity required for system reliability during the transition, while preserving the benefits of competitive allocation. In China, one option would be to replace coal-specific capacity payments with a capacity market featuring a dedicated window for coal (possibly competing with pumped hydro), alongside separate windows for flexibility technologies such as storage, demand-side response, and virtual power plants. Comparing clearing prices across windows could also improve transparency regarding relative costs.

The choice between technology-neutral and differentiated auctions involves clear trade-offs. While unified auctions offer stronger price discovery and lower administrative intervention, differentiated designs may better support nascent technologies in China's coal-dominated system. As technology costs evolve and decarbonisation progresses, auction structures could be adjusted by altering the number of windows or reallocating technologies between them. Experience from the UK further suggests that capacity markets can be progressively aligned with climate objectives through emissions limits, strategic reserves, and support for gas-to-hydrogen or CCUS-enabled generation, providing useful lessons for China's longer-term market design.

4.2 Short-duration energy storage

4.2.1 The rise and roles of battery storage

In systems with rapidly rising VRE penetration, electricity storage becomes more valuable for multiple reasons. Recently, storage additions worldwide have been dominated by BESS. BESS has become a key technology to shift power supply and demand to optimal times and reduce the role of fossil generation in the electricity system. Crucially, unlike thermal generators, BESS can also soak up excess VRE generation and discharge it when required, providing an opportunity for the economic utilisation of clean power that would otherwise be curtailed. Most BESS today is made up of lithium-ion batteries with 1–2-hour duration.

The UK has not deployed any technology-specific mechanisms for supporting storage, but BESS can technically participate in three main markets: ancillary services (of which participating in the system balancing mechanism is sometimes part), capacity markets, and arbitrage in the wholesale market, i.e. charging at times of low power prices, and discharging at times of higher prices.

BESS's role in ancillary services today is generally to provide frequency control services, as it can provide these more rapidly and cheaply than other generators. This enables fossil fuel generators to be retired with less risk to system stability. BESS can also play an important role in ensuring security of supply, both dynamically (it can be called on rapidly, protecting the system against the possibility of a sudden major plant or interconnector outage), and more generally in terms of additional potential generating capacity. These points justify the technology's inclusion in capacity markets.

BESS's biggest long-term contribution to system decarbonisation, however, is likely related to its function when profiting from arbitrage. When there are periods of surplus VRE, or when VRE would otherwise be curtailed due to transmission constraints, BESS can absorb this energy and transfer it to moments when demand outpaces VRE generation. As noted, BESS is likely to be particularly valuable in solar-dominated systems with much greater and more regular variability, as storage of only a few hours of duration could provide relatively secure supply, particularly to meet peak evening demand. It still plays a valuable role in wind-dominant systems, but the need for longer durations is likely greater to meet prolonged periods of low/no wind output.

In the UK and many European markets, VRE output is already rising to levels which create very low or negative wholesale prices, and/or lead to renewable output being curtailed behind transmission bottlenecks. BESS can increase the value of additional renewables in the electricity system and potentially enable fuller use of transmission capacity, neither of which can be provided by pure generating assets. There is thus a key reinforcing feedback dynamic between BESS and VRE deployment (Figure 5).

Combined with the potential for continued battery cost reductions, this self-strengthening feedback could be a powerful dynamic driving progress towards a power system that is carbon neutral, low-cost, and secure. The strength of these feedbacks will depend on many aspects of market design. Notwithstanding this potentially powerful reinforcing dynamic, storage deployment may be subject to a self-limiting feedback insofar as it relies on revenues from wholesale market arbitrage. These arbitrage revenues rely on deep price spreads. However, over time, as BESS capacity increases, its absorptive arbitrage activity may reduce price spreads (which policymakers and the public may welcome), potentially cannibalising its revenues and weakening the case for further investment (see Figure 6).

In any technology transition, deployment of a new technology will inevitably slow as it approaches a saturation point. However,

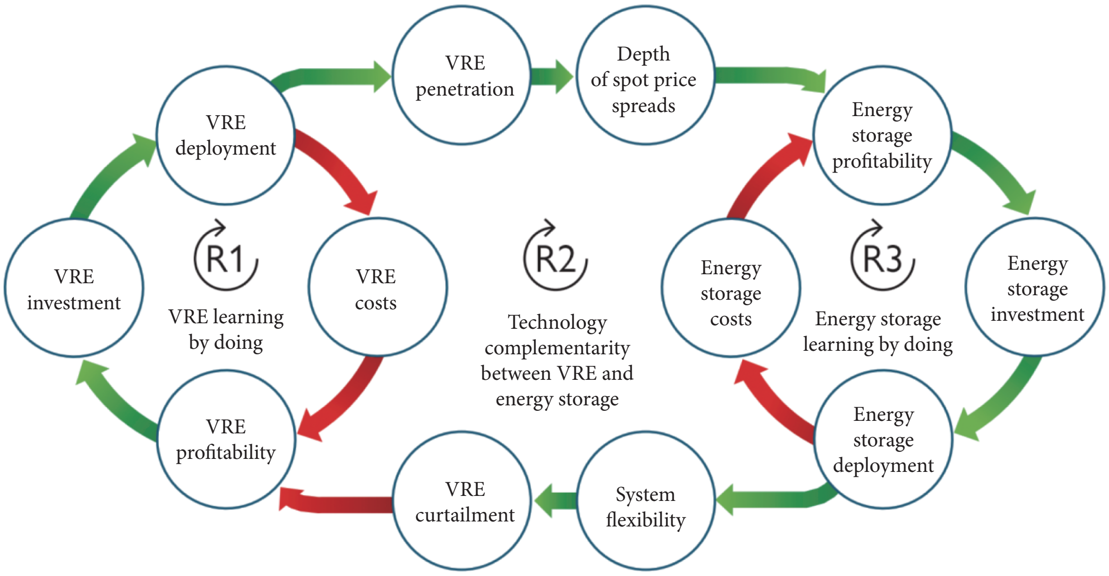

Fig. 5 CLD of synergy effects between VRE deployment and storage deployment. Note: Green arrows indicate a positive relationship (i.e. factors move in the same direction) and red arrows indicate a negative relationship (i.e. factors move in opposite directions). The letter "R" denotes a reinforcing feedback loop. Each feedback loop is accompanied by a brief explanation.

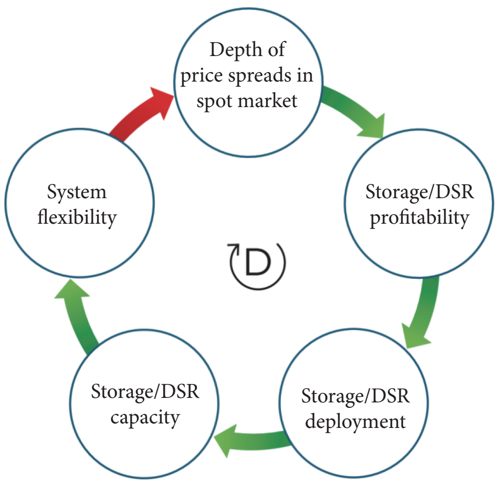

Fig. 6 CLD showing dampening feedback on storage deployment. Note: Green arrows indicate a positive relationship (i.e. factors move in the same direction) and red arrows indicate a negative relationship (i.e. factors move in opposite directions). White nodes represent variables in the system. The letter "D" denotes a dampening feedback loop.

investment incentives associated with arbitrage revenues may be weakened before deployment is sufficient to enable a zero-carbon system. Relying on arbitrage incentives alone to drive investment may therefore be inadequate. This implies that establishing multiple revenue channels to reflect the different roles played by BESS (e.g. capacity, ancillary services) may be necessary to ensure ongoing investment.

4.2.2 China's energy storage mandate

Chinese provinces began implementing energy storage mandates in 2017. These policies required all developers of wind and solar capacity to deploy energy storage together with any new solar plants or wind farms. In February 2025, the NDRC and NEA issued Document 136, which called on local governments to remove their mandatory storage installation requirements from VRE project approval processes, effectively cancelling the storage mandate policy. Whether or not local governments follow through and annul their mandate policies remains to be seen. We retain our discussion of this policy here, as the dynamics we analyse are likely to remain relevant in the context of future storage policy development. The specifics of storage mandate policies vary between provinces, as seen in Table 2. The ratio of energy storage capacity to VRE capacity is in the range of 10%–20% in most regions, though the full range varies from 5% to 55%. The duration of storage required is generally in the range of 2–4 hours.

The energy storage mandate has led to the physical deployment of batteries on a large scale. However, a significant early challenge has been ensuring this equipment is actually used. The average utilisation rate of storage capacity covered by this policy was just 9% in 2023[d]—far lower than the same figures for other storage models (e.g. standalone or user-side).

The core problem has been a lack of ways for energy storage to participate in markets and earn revenues. In provinces where spot markets are undeveloped or in early stages, and most output from renewables is sold through guaranteed purchase and the MLT market, there is relatively little opportunity for renewable operators to increase their revenues by using storage to vary the timing of their output. Grid operators generally rely on coal plants to provide security of supply and to support the stability of the grid, meaning BESS is not called on. Per NEA data, thermal power generators received 91.4% of all ancillary service market revenues in H1 2023, or ¥25.4 billion yuan in absolute terms[e]. This contrasts with the UK and some (not all) EU countries, where BESS is utilised for its ancillary services. However, in the UK, the system

[d] See 2023 Electrochemical energy storage station industry statistics and data.

[e] See NEA (2023). The scale of market-traded electricity grew steadily in H1.

Table 2 Requirements for mandated energy storage co-installation with VRE projects[f].

Province	ES deployment ratio (ratio of BESS capacity to VRE generation capacity)	Storage duration required (hour)
Tianjin	15%	
Hebei	15%–20%	2–4
Shanxi	50% (Generator-Grid-Load-Storage integration)	
Inner Mongolia	15%	4
Liaoning	10%	
Jilin	15%	2
Shanghai	20%	2
Jiangsu	10%	2
Zhejiang	10%	2
Anhui	5%	2
Fujian	10%	2
Shandong	20%	2
Henan	50% (Generator-Grid-Load-Storage integration)	2
Hubei	Wind 30%, Solar 25%	2
Guangdong	10%	2
Guangxi	Wind 20%, Solar 10%	2
Sichuan	15%	2
Guizhou	10%	
Yunnan	10%	
Xizang	20%	4
Gansu	10%–15%	2–4
Qinghai	15%	2
Ningxia	10%	2
Xinjiang	10%–20%	2

operator (then National Grid) acknowledged that for some years its computer systems had, in practice, continued to prioritise natural gas before utilising BESS for system stability.

As a consequence, in China the energy storage mandate has initially had a mixed effect on the reinforcing feedback between deployment of renewables and deployment of storage. It has not strengthened this feedback as much as it could, because underutilisation of assets means that physical deployment is not necessarily translating into increased system balancing ability. At the same time, it has somewhat weakened this feedback by increasing the costs of renewables deployment (see Figure 7).

Note that the causal link from "VRE deployment" to "BESS deployment" represents the effect of the mandate policy, and is dashed to indicate that this relationship would break if the mandate were abolished, which it now has been (in February 2025). The arrow between "BESS deployment" and "System flexibility" is dashed to indicate that this relationship only holds if installed BESS is actually utilised. Green arrows indicate a positive

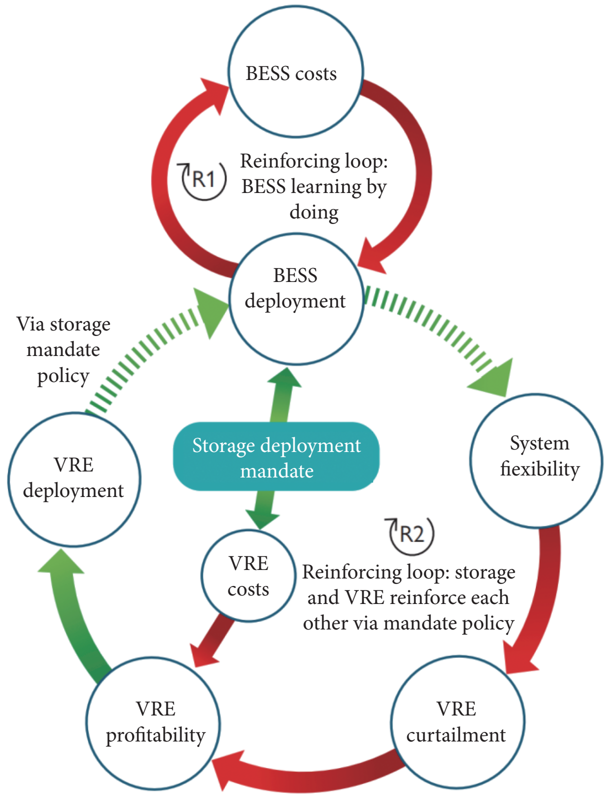

Fig. 7 CLD showing the feedback loops associated with the energy storage mandate policy.

relationship (i.e. factors move in the same direction) and red arrows indicate a negative relationship (i.e. factors move in opposite directions). White nodes represent variables in the system. Blue rectangular nodes represent policy factors. The letter "R" denotes a reinforcing feedback loop.

(1) Addressing the underutilisation problem

To address the growing problem of underutilised BESS assets, many Chinese provinces have introduced capacity leasing mechanisms that allow new VRE projects to rent or purchase storage capacity from independent BESS operators instead of constructing their own facilities. This policy design has been adopted in various provincial and municipal regulations and offers two key advantages. First, independent storage facilities can operate in response to system-level needs—subject to market participation—rather than being constrained by the contractual arrangements of individual renewable generators, thereby improving utilisation rates and mitigating the previous tendency of developers to install low-cost, underused storage. This shift transforms BESS from a generator-specific output-smoothing tool into a system-wide balancing resource, while providing independent operators with a new revenue stream through leasing payments. Second, the aggregation of independent storage capacity enables economies of scale, reducing capital and operational costs and enhancing overall system efficiency.

The guiding prices for energy storage capacity leasing announced by provincial governments pursuing this approach range from ¥150–337/(kWh·year), with an average of ¥243/(kWh·year), but the actual average price formed through the capacity leasing market is only around half that level, at

[f] See ESCN (2024). List of the latest policies in 31 provinces on new energy co-installation of storage in the era of prioritizing consumption.

¥126/(kWh·year)[g]. The leasing approach requires agreements between renewable generators and independent storage operators on how costs and revenues will be shared, but early experience suggests this is not a significant barrier.

The advantages of the capacity leasing approach to the energy storage mandate—namely increased utilisation and lower costs—strengthen the policy's effect on the helpful reinforcing feedback loop shown in Figure 7. Some provinces are addressing the underutilisation problem by asking VRE developers to hand over the operation of energy storage assets to the grid. As with the leasing approach, this allows the storage assets to be used when they are most needed by the system, instead of in response to the narrower interests of individual generators.

(2) Considering the allocation of energy storage costs

Allocating the costs of energy storage to VRE investors, as the energy storage mandate does, saddles generators with extra costs for little benefit. Equipping a solar plant with energy storage (based on 20% capacity ratio, 2 hour storage) is estimated to increase initial investment cost by 8%–10%[27]. For a wind power project equipped with energy storage of the same capacity, the investment cost could increase by 15%–20%.

This may not be the best way to allocate the costs of energy storage if the overall goal is moving cost-effectively to a power system centred on low-carbon power and minimising system costs. The UK Energy Research Centre reviewed international evidence on the costs of energy storage and concluded that it would be inefficient to require all VRE generators to self-balance by providing their own storage. Instead, it advised that security of supply, as well as system stability—which are properties of the system—could be provided most cost-effectively at the system level. For similar reasons, in its REMA programme, the UK government has decided not to pursue the option of an equivalent firm power auction in which VRE would be required to compete against thermal power plants for contracts to supply firm (fully dispatchable) power[28]. This has been assessed as likely to result in overinvestment in flexibility and balancing services, increasing consumer electricity prices.

In China, the design of the energy storage mandate has been influenced by the legacy of past policies. In provinces where developers of new renewable power plants still have access to guaranteed purchase contracts, the profits available from these can be high. The cost of storage can be passed to these developers without substantially weakening the case for renewables investment. In future, as the role of guaranteed purchase contracts continues to decline, there may be advantages to reforming or replacing the mandate so that the costs of storage are borne by the whole system, instead of solely by renewable generators.

(3) Increasing the opportunities for energy storage to participate in markets

Regulators have begun to address the market design features that limit BESS profitability and development. There are important opportunities to advance further in this direction.

First, power market design should provide arbitrage opportunities to fully leverage BESS flexibility. Advancing spot market development and loosening spot price floors and caps would be effective measures to this end (Figure 8). Data on energy storage utilisation rates is only available for 2023 at present, so it is not yet possible to assess the effect of recent spot market introductions (e.g. in Shandong and Gansu in 2024) on BESS utilisation. While allowing greater price variation by widening price limits in spot markets may strengthen dampening feedbacks related to wind and solar deployment in the short term by increasing price risk, the resultant deployment of BESS would serve to offset this effect by strengthening price signals and efficiently shifting power supply and demand.

Second, continued development of competitive ancillary service markets with fair access and participation criteria will benefit both BESS (by creating additional revenue streams), and the entire power system, by promoting lowest-cost service provision. Provinces are establishing different markets and revenue channels for BESS facilities, but progress remains uneven to date (see Table 3).

Third, BESS revenues can be supported by capacity remuneration mechanisms. In July 2021, the NDRC and the NEA issued the "Guiding Opinions on Accelerating the Development of New Energy Storage", advocating capacity remuneration mechanisms for standalone BESS. Yet to date just five provinces had followed through as of November 2024[h]. The current capacity leasing mechanism associated with the wind and solar storage mandate provides some fixed, capacity-based revenues for BESS, but risks limiting renewables deployment by imposing additional costs on developers. For this reason, a capacity remuneration

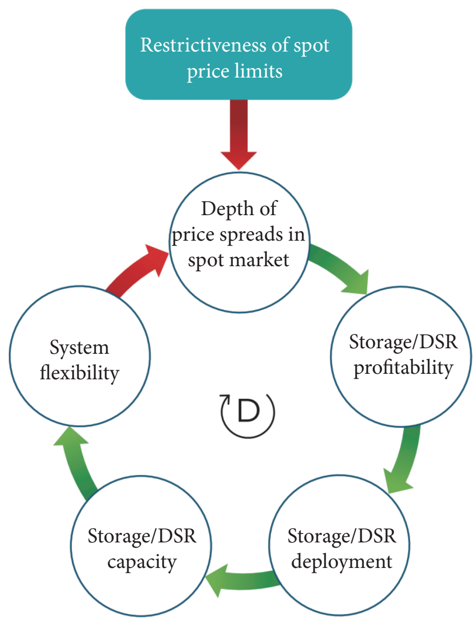

Fig. 8 CLD of spot price and storage arbitrage interactions. Note: Green arrows indicate a positive relationship (i.e. factors move in the same direction) and red arrows indicate a negative relationship (i.e. factors move in opposite directions). White nodes represent variables in the system. Blue rectangular nodes represent policy factors. The letter "D" denotes a dampening feedback loop.

[g] Data are from Energy Storage Application Branch of China Industrial Association of Power Sources (2024). 2024 White paper on development of shared energy storage in China.

[h] These provinces are Shandong, Xinjiang, Inner Mongolia, Gansu, and Hebei. See Digital Energy Storage Network (2024). New-type energy storage stations are showing a scaling-up trend.

Table 3 Revenue channels for standalone energy storage in selected provinces in 2023[i].

Area	Capacity leasing	Spot market arbitrage	Ancillary services	Capacity compensation
Shandong	√	√	√（Frequency modulation）	√
Shanxi	√	√	√（Frequency modulation + standby)	
Hunan	√		√(Peak shaving)	
Guangdong	√	√	√（Frequency modulation）	
Guangxi	√		√(Peak shaving)	
Gansu	√	√	√（Frequency modulation）	
Ningxia	√		√(Peak shaving)	
Qinghai	√	√	√（Frequency modulation + Peak shaving)	√
Zhejiang	√		√(Various)	√
Jiangsu	√		√(Peak shaving)	
Henan	√		√(Peak shaving)	
Hebei-Jinan	√			
Guizhou	√	√	√(Peak shaving)	

mechanism that treats storage flexibility as a system property, for example by transferring costs to users, may be preferable.

4.3 Key strategies for maintaining security of supply: long-duration energy storage and strategic reserves

Options for maintaining security of supply while reducing or eliminating the need for investment in new coal-fired power plants are of urgent importance. This article proposes two potential approaches: the deployment of long-duration energy storage and the establishment of a strategic reserve. LDES is widely expected to play an important role in the transition to clean power. It can contribute to balancing supply and demand over longer timescales, increase the power system's capacity to absorb large quantities of VRE generation, and help to ensure security of supply. A strategic reserve refers to the practice of keeping some generation capacity on standby, outside the electricity market, to be called on only during system stress events.

4.3.1 Long-duration energy storage

(1) LDES in China

The definition of long-duration energy storage varies internationally. A U.S. Department of Energy report defined long-duration energy storage as having a continuous operation (discharge) time of at least 10 hours and a service life of 15 to 20 years. In the UK, DESNZ defines LDES as energy storage that can continuously discharge at maximum power for at least six hours. In China, the energy storage industry association has proposed a definition of LDES as technologies that can operate for at least four hours (with several subsidiary definitions for different durations).

In China, the capacity of LDES required for a fully decarbonised power system is estimated to exceed 700 GW[29]. As VRE penetration increases, the frequency of surplus generation events is expected to rise rapidly, making LDES valuable for its absorptive capacity well before it becomes essential for supply security. However, large-scale deployment will require substantial policy support due to LDES's higher capital costs, typically slower response speeds, and infrequent utilisation, which together create significant revenue uncertainty. Pumped hydropower, currently the most mature LDES technology in China, is supported through a capacity payment mechanism introduced in 2023, analogous to the coal power capacity payment scheme. The "Notice on Further Deepening the Market-oriented Reform of On-Grid Electricity Prices for Coal-fired Power Generation" issued by the NDRC in October 2021 and the "Notice on Capacity Electricity Prices for Pumped Storage Power Stations and Related Matters" issued in May 2023 pointed out that, payment levels are determined individually for each plant by the NDRC and recovered through transmission and distribution tariffs. In the longer term, these payments may be phased down as spot and ancillary service markets mature, enabling pumped hydro and other LDES technologies to earn more stable, market-based revenues.

Besides pumped hydro, pilot projects to demonstrate a variety of LDES technologies are underway across many of China's provinces. The technologies being tested include compressed air energy storage, liquid flow battery energy storage, flywheel energy storage, molten salt heat storage, and hydrogen energy storage. Policy support for LDES in China is perhaps most mature in Shandong, where dedicated support mechanisms were introduced in 2023[j]. The policy supports LDES pilots that meet certain eligibility criteria: (1) At least 100 MW capacity; (2) capable of discharging at full power for at least four hours; (3) round trip efficiency at least 60%; (4) project lifespan at least 25 years. Support mechanisms include grid connection priority, supporting spot market participation, dedicated capacity payments, and exemption from certain tariffs. The policy also provides for favourable conversion factors to encourage VRE developers to meet their storage mandate requirements by leasing LDES

[i] See ESCN (2024). List of the latest policies in 31 provinces on new energy co-installation of storage in the era of prioritizing consumption.

[j] See Energy Administration of Shandong Province (2023). Several measures to support pilot applications of long-duration energy storage. Lu Energy Science and Technology [2023] No. 115

capacity (instead of short-duration BESS capacity), however the storage mandate policy is set to end in 2025, per Document 136.

Policies similar to those introduced in Shandong could play a transformative role in accelerating LDES deployment. By providing predictable capacity payments, such schemes can enhance investor confidence while enabling storage assets to participate in spot markets and respond dynamically to system needs and price signals. Additional measures—such as exemptions from transmission and distribution tariffs, and waivers of government funds and surcharges during charging—further strengthen the economic case for storage by improving arbitrage opportunities and profitability. Early evidence underscores the impact of these policy innovations: in the first two months of 2025, 19 LDES projects were announced nationwide in China, totalling 5.487 GW/17.688 GWh, with Shandong alone accounting for seven projects (3.01 GW/10.404 GWh), representing nearly 55% of total national capacity additions[k]. At present, no unified national policy framework exists to support LDES deployment beyond the capacity payments provided to pumped hydro. Scaling up the types of incentives being piloted in Shandong could therefore be critical to bridging the gap between demonstration and commercialisation for emerging LDES technologies.

(2) Revenue cap-and-floor policies: possible applications to LDES in the UK

In contrast to China's emerging policy experimentation, the UK's experience highlights the consequences of insufficient LDES deployment in an advanced decarbonisation context. As the UK moves toward a net-zero power system, it has become evident that the current 2.8 GW of LDES capacity—almost entirely from ageing pumped hydro facilities built more than four decades ago—falls far short of the 11.5–15 GW estimated to be needed by 2050[30]. Persistent barriers, including high capital costs, long construction timelines, and increasing revenue volatility in a decarbonised electricity system, have discouraged new investment. To address these challenges, the UK government has consulted on mechanisms to support LDES deployment, with many stakeholders advocating for a cap-and-floor regime similar to that used for interconnectors[31] (see Figure 9). Both technologies share key economic characteristics—high upfront investment requirements and uncertain market revenues—but provide essential system value by enabling the temporal and spatial balancing of VRE and enhancing overall system reliability.

The UK's interconnector cap-and-floor regime has been highly effective, mobilising private investment without requiring public top-up payments and consistently delivering positive returns[32]. Although China's institutional setting differs, the mechanism offers a valuable model for de-risking LDES investment amid growing system uncertainty. Building on this success, the UK government plans to introduce a similar revenue cap-and-floor framework for LDES, with design modifications reflecting lessons from the interconnector scheme. Rather than using auctions, Office of Gas and Electricity Markets (Ofgem) will assess projects based on deployment speed, system benefits, and financial robustness, with the floor price aligned to the minimum revenue required for debt servicing. Eligible technologies must demonstrate additionality and provide at least eight hours of storage, with support lasting up to 25 years or until major refurbishment.

The new framework incorporates more regulatory flexibility to reduce gaming and adapt to evolving market conditions—an approach viewed as vital after recent energy price shocks. However, the absence of a defined deployment target has raised concerns about policy ambition. Core uncertainties also remain regarding the optimal storage duration and utilisation frequency. House of Lords Science and Technology Committee of UK warned that an initial six-hour threshold risked diverting investment from true long-duration technologies, prompting its increase to eight hours[33]. Further revisions may be required if longer-duration storage proves essential for system adequacy.

Technological maturity will largely determine early participation. Ofgem[34] aims to prioritise projects deliverable by 2030, implying that pumped storage hydro—currently the most advanced option, with at least 4.9 GW in development[35]—will dominate the initial phase. The first new UK pumped hydro

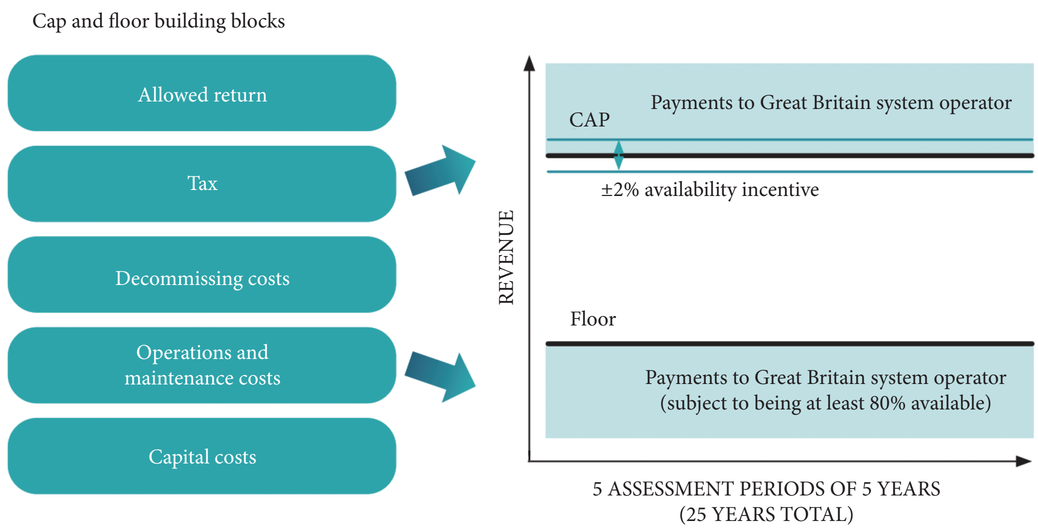

Fig. 9 Design of interconnector cap-and-floor scheme.

[k] See ESCN (2025). NEA has set the tone, 12 provinces and cities are emphasising building, and long-duration energy storage is entering the development fast lane in 2025.

project in forty years has already begun construction under this framework[36]. Other candidates, including flow batteries, compressed air, sensible thermal, and liquefied air storage, may also benefit, though their commercial competitiveness remains limited. Over time, the stable and predictable revenue pathway offered by the cap-and-floor mechanism could help accelerate innovation and the commercialisation of emerging LDES technologies, though its long-term impact remains to be tested.

4.3.2 Strategic reserve

The system operator can decide on the quantity of reserve capacity to procure, and payments are arranged, via auctions in many cases, to cover reserve generators' costs. Several European states, including Germany, Poland, and Belgium, have adopted strategic reserve policies with varying design characteristics, the main purpose being to get old, dirty but cheap coal plants (often using lignite or other low-grade coal) out of market operation. Among these, Germany's strategische reserve is a prominent and well-documented case, particularly relevant for managing the phase-out of conventional power plants. Strategic reserves are generally seen as an alternative to capacity markets, though in theory they could be complementary. Key differences between the two approaches are highlighted in Table 4.

Table 4 Comparison of strategic reserve and capacity market policies.

	Strategic reserve (payments to capacity not normally operating in market)	Capacity market (payments to capacity free to operate in the market)
Functional positioning	As a backup mechanism, it comes into play when market operations fail to ensure sufficient generation; deals with system stress events, and safeguards the security of power supply.	Through contractual agreements on reliable sources of capacity, it ensures timely response during system stress situations and maintains the security of power supply.
Operation mode	Contracts for a certain amount of capacity are signed in advance. These capacities do not participate in normal market operations and will only be put into use when called upon by System Operator, to tackle system stress events because the wholesale market provides inadequate capacity.	Capacity is contracted in advance through auction. Generators, energy storage providers or demand-side response suppliers can receive contracts if they are considered eligible (based on their ability to respond when there is system pressure). These plants can also participate in normal market operations.
Advantages	The support is targeted, to a limited amount of capacity (usually, generators that would otherwise close), and does not affect economics of the wholesale market, thus offering full value to new entrants in the market. Administratively quite simple.	As a general payment to all generators able to support security, in theory it offers maximum efficiency and avoids political choices about which generators to support – it is a generalised payment for security.
Disadvantages	Need for government to choose which plants to support, and negotiate payments. Bigger role for system operator in choosing when to activate. Could have gaming challenges (generators threatening to close completely when in-market economics deteriorate, in hope of getting paid to enter strategic reserve).	Amounts to a generalised subsidy to all relevant capacity, which can be taken as a windfall profit by incumbents. Exaggerated capacity needs would be far more expensive than for a SR. Payments available could help some new entry, but the implicit subsidy to all existing fossil fuel plants may be particularly problematic for systems trying to decarbonise. Need for sophisticated auctions, derating factors to reflect statistical availability, and delivery mechanisms, implies complex administration.

Germany employs an auction-based reserve mechanism to enhance security of electricity supply, most notably through instruments such as the Capacity Reserve and the Security Standby. Under these mechanisms, eligible resources are selected via competitive tenders organized by the transmission system operators. In the case of the Security Standby, certain aging coal-fired power plants—particularly lignite units scheduled for retirement—are transferred into a reserve status. These plants receive fixed capacity payments in exchange for remaining available on standby and are strictly prohibited from participating in the regular electricity market.

Reserved units can only be dispatched upon instruction by the transmission system operators in situations of system stress, when market-based generation is insufficient to ensure system balance and security. The activation of these reserves is determined by system reliability considerations rather than by an automatic price-based trigger. Designed explicitly as a transitional measure, plants placed in the Security Standby remain in the reserve for a predefined period, after which they are subject to mandatory and permanent decommissioning.

A strategic reserve may offer advantages in China's coal-dominated power sector, where new capacity continues to be added amid uncertain demand. Older coal plants face declining utilisation and potential retirement, while new units risk becoming stranded. By retaining otherwise retiring units, strategic reserves could smooth the economic and social impacts of plant closures, shifting capacity into standby rather than subsidising continued operation. However, reserves also have drawbacks. Activating standby units during system stress can limit price spikes, weakening scarcity signals that incentivise new generation and storage. While politically appealing, as extreme wholesale prices are often undesirable, reserves typically target thermal generation, creating risks of over-retention and inflated system costs without transparent governance and competitive auctions. Strategic reserves and capacity markets could coexist: modest capacity targets combined with a reserve for retired thermal plants could reduce costs while safeguarding supply, though this may reduce incentives for new entrants who would benefit from extreme prices[37].

Recent policy developments illustrate this approach in practice. The National Energy Administration released the "Guiding Opinions on Energy Work in 2024" in March 2024, which pointed out that, in early 2024, the NEA recommended retired coal units serve as emergency backup. The NDRC and the NEA issued the "Notice on Establishing a Coal-Fired Power Capacity Electricity Price Mechanism" in November 2023, which pointed out, Guangdong introduced standby capacity payments at ¥260/(kW·year)—higher than standard coal payments

(¥100/(kW·year)) but below typical fixed costs (¥330/(kW·year))[1]. Costs are passed to commercial and industrial users, reflecting an emerging pilot of a strategic reserve model in China.

5 Conclusions and recommendations

This paper has highlighted the need for new approaches to ensure security of supply in the context of VRE growth, as well as to avoid unnecessary investment in thermal power as its role in the system diminishes. Having reviewed China's existing policies and the UK's capacity market, we have identified opportunities to expand the roles of short-term energy storage, long-term energy storage, and interregional transmission in increasing system flexibility and ensuring security of supply, while reducing reliance on thermal power. Our analysis suggests the following policy priorities:

(1) Pilot technology-neutral capacity markets in provinces with advanced electricity markets (e.g., Shandong, Zhejiang, Jiangsu) to gradually replace the current coal-focused capacity payment mechanism. This pilot should initially run in parallel, allowing for a phased transition. The design must incorporate independent technical assessment (like the UK's PTE) to determine capacity needs, thereby avoiding political over-procurement and creating a level playing field for flexible resources like storage and demand-side-response to compete with thermal power.

(2) Deepen spot market reforms to create diversified revenue streams for energy storage. Key actions include abolishing the inefficient storage mandate policy and instead accelerating the development of spot markets in key regions, relaxing spot price caps/floors to widen arbitrage opportunities, and establishing competitive ancillary service markets with fair access for storage. This will enable BESS to earn revenue through energy arbitrage, frequency regulation, and capacity payments, ensuring its sustainable deployment.

(3) Introduce a national revenue cap-and-floor mechanism, aligned with the objectives of China's "New Energy Storage Development Action Plan" to de-risk investment in LDES. Eligibility should require a minimum discharge duration (e.g., 4+ hours) to prioritize technologies that address prolonged scarcity events. The support scheme can be initially rolled out in regions with high VRE curtailment, building on successful provincial pilots like Shandong's, which offered grid connection priority and capacity payments. Potential resistance from incumbent thermal power interests must be acknowledged and managed through transparent cost-benefit analysis and clear communication of the long-term savings for the entire system.

(4) Establish strategic reserves as a transitional and targeted complement to the capacity market, not a substitute. This mechanism should be deployed selectively in regions with high concentrations of aging coal plants slated for retirement (e.g., Hebei, Shanxi). Its sole purpose is to keep a limited amount of this otherwise-retiring capacity on standby, outside the energy market, to be activated only during extreme system stress events. This provides a safety net during the transition, without distorting price signals in the main market for new, flexible investments.

Appendix

Abbreviations	
BESS	Battery Energy Storage System
CEGB	Central Electricity Generating Board
CfD	Contract for Difference
CLD	Causal Loop Diagram
CM	Capacity Market
CRM	Capacity Remuneration Mechanism
DESNZ	Department for Energy Security and Net Zero (UK)
DSR	Demand-Side Response
ESCN	Energy Storage China Network (source cited in the document)
EU ETS	European Union Emissions Trading System
IEA	International Energy Agency
LDES	Long-Duration Energy Storage
MLT	Medium- and Long-Term (markets)
NDRC	National Development and Reform Commission (China)
NEA	National Energy Administration (China)
Ofgem	Office of Gas and Electricity Markets (UK)
PTE	Panel of Technical Experts (UK)
REMA	Review of Electricity Market Arrangements (UK)
SOE	State-Owned Enterprise
SDEA	Energy Administration of Shandong Province
T-1	One-Year-Ahead (Auction)
T-4	Four-Years-Ahead (Auction)
VRE	Variable Renewable Energy
NDRC	National Development and Reform Commission
NEA	National Energy Administration

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Author contribution statement

Ying Zhou: writing – review & editing, writing – original draft, software, methodology, investigation, data curation. Jian Han & Yang Qu: writing – review & editing, investigation, visualization. Max Collett: writing – review & editing, validation. Max Collett: is responsible for Figures 5–8. Michael Grubb & Simon Sharpe: writing – review & editing, conceptualization, resources, funding acquisition, formal analysis. Yantong Liu: writing – review & editing. Jun-ling Huang: supervision, project administration. Da Zhang: resources, writing – review & editing, supervision, project administration.

[1] NDRC and NEA (2023). Notice on establishing a coal power capacity price mechanism. Development and Reform Commission Price [2023] No. 1501

Data availability

Not applicable.

Use of AI statement

None.

Declaration of competing interest

The authors have no competing interests to declare that are relevant to the content of this article. The author Da Zhang is the Associate Editor of this journal. The author Michael Grubb is the member of Advisory Board of this journal.

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