Executive Summary by Niklas Klingel

Energy storage is a cornerstone of the global energy transition. Both China and Germany face growing shares of intermittent renewables that challenge grid stability and security of supply. Germany struggles with north–south transmission bottlenecks, social opposition, and import dependence, while China contends with large-scale curtailment, coal reliance, and provincial fragmentation. Storage solutions, from batteries and pumped hydro to hydrogen-based Power-to-X, are essential to address these issues. Comparatively, China pursues rapid scale-up through centralized planning, whereas Germany relies on incremental, market-driven integration. Effective policy must therefore combine technology deployment with governance reforms, stable incentives, and international cooperation.

Background: *Why Storage Matters*

The accelerating deployment of renewable energy is transforming the structure of power systems. Unlike conventional dispatchable plants, wind and solar are inherently variable, creating intermittency that challenges grids designed for centralized and controllable generation. As renewable penetration rises, mismatches between production and consumption intensify, leading to curtailment, greater reliance on fossil backup, and risks to security of supply.

Meeting these challenges requires not only new generation but also a systemic shift toward flexibility. Flexibility means the capacity to balance fluctuations across multiple time horizons through grid expansion, cross-border interconnection, demand-side management, and sector coupling. Among these, energy storage plays a unique role: it decouples generation and consumption, shifting surplus renewable energy to times of scarcity. Storage is thus a cornerstone of the transition to a resilient, low-carbon system.

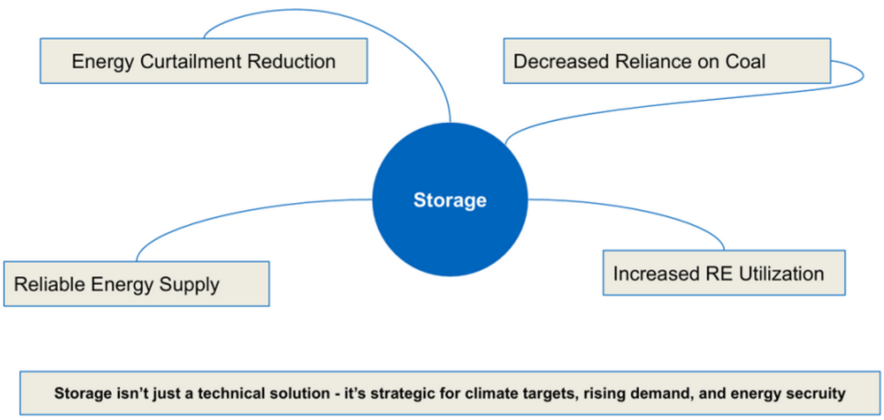

Figure 1: Role of Storage in RET Integration

Technologies contribute in complementary ways: short-term batteries (BESS) deliver rapid balancing and frequency control; medium-term solutions like pumped hydro and flow batteries enable daily load shifting; and long-term Power-to-X pathways (hydrogen, ammonia, synthetic fuels) provide seasonal storage to cover extended low-output periods (Dunkelflaute).

In both Germany and China, insufficient storage already results in curtailment, inefficient grids, and fossil reliance. A diversified storage portfolio, by contrast, can maximize renewable use, limit costly transmission expansion, and strengthen energy security: making storage a central enabler of climate neutrality.

Facing the Challenges: Storage Bottlenecks in Germany and China

Case Study Germany

Germany's energy transition has achieved world-leading renewable deployment, with wind and solar capacity exceeding 150 GW in 2024. Yet integration is hindered by structural imbalances and infrastructure bottlenecks. A persistent north–south divide exists: wind power is concentrated in the north, while demand lies in the industrial south. Transmission projects such as SüdLink and SüdOstLink face long delays, causing congestion and frequent redispatch. Further barriers include slow permitting (7–10 years), strong local opposition, and continued reliance on natural gas after the nuclear phase-out. Curtailment remains significant: around 9.4 TWh of renewable electricity was lost in 2024, while negative wholesale prices occur increasingly often.

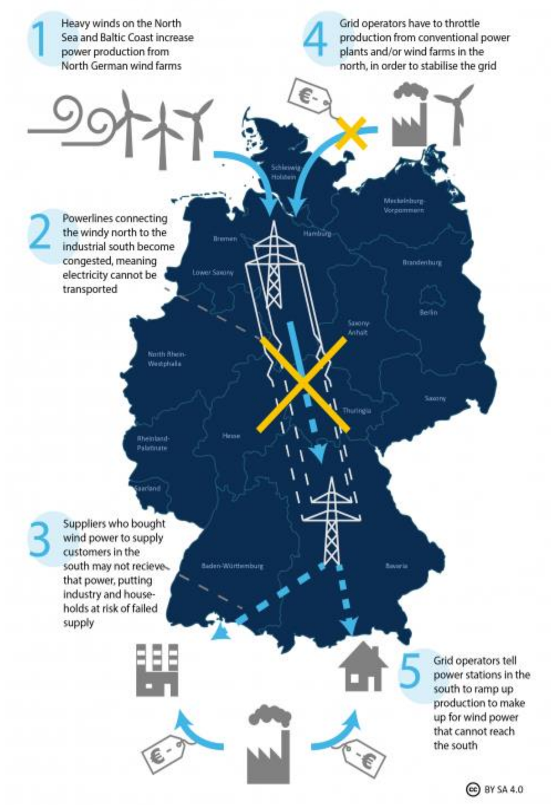

Figure 2: German electricity system

Germany's storage mix is diversifying. Pumped hydro (~10 GW / 40 GWh) offers bulk shifting and grid stability but has limited expansion potential. Battery storage (~19 GWh in 2024) has grown rapidly, becoming crucial for frequency regulation and peak shaving. Hydrogen pilots (250–600 GWh, 10 GW electrolyser target by 2030) are advancing to provide seasonal balancing during Dunkelflaute events.

The policy framework is extensive but fragmented. The Energiewende sets long-term decarbonization goals (80–95% GHG reduction, 60% renewables by

2050), while the Renewable Energy Act (EEG) shifted support from feed-in tariffs to auctions. The National Electricity Storage Strategy (2023) and the Hydrogen Acceleration Act (2024) introduced new instruments, yet no dedicated storage law exists, and "double charging" of grid fees continues to impede bankability. While Germany emphasizes market-driven solutions within the EU, regulatory and social barriers have slowed infrastructure rollout, leaving hydrogen and electricity imports as critical backstops.

Germany's approach is thus marked by incremental, market-based optimization, complemented by strategic hydrogen investments. Its challenge is not technological capacity but aligning policy, infrastructure, and public acceptance to make storage a backbone of the energy transition.

Case Study China

China's energy transition faces a structural paradox: vast renewable potential in the northwest contrasts with demand in coastal megacities like Beijing, Shanghai, and Guangdong. Despite major ultra-high-voltage (UHV) transmission projects, curtailment remains high, tens of TWh annually in the "Three North" provinces (Inner Mongolia, Gansu, Xinjiang). Provincial fragmentation aggravates the issue, as local governments prioritize revenue and security over cross-provincial coordination. At the same time, coal still provides 61% of electricity (2024), sustaining fiscal revenue and employment.

Energy storage has become central to system transformation. Pumped hydro (120–130 GW by 2030) is the backbone, providing multi-hour balancing and stability. Battery storage (95 GW / 222 GWh by mid-2025) will represent over 40% of global capacity, while pilots in compressed air, flow, and sodium-sulfur storage test medium- to long-duration options.

Policy has evolved rapidly. The 13th Five-Year Plan classified storage as a "strategic emerging industry," launching pilots across technologies. Since then, administrative quotas shifted to market mechanisms, with storage integrated into spot, ancillary, and capacity markets (2024). Yet challenges persist: commercial viability is uneven, revenue mechanisms remain uncertain, and "double charging" still undermines bankability. Current reforms aim to stabilize revenue frameworks, expand ancillary markets, and boost long-duration innovation.

China's approach combines centralized planning with gradual market liberalization. Its deployment scale in PHES and BESS far exceeds all other countries, yet coal reliance, fragmentation, and governance gaps continue to limit the efficiency of storage integration.

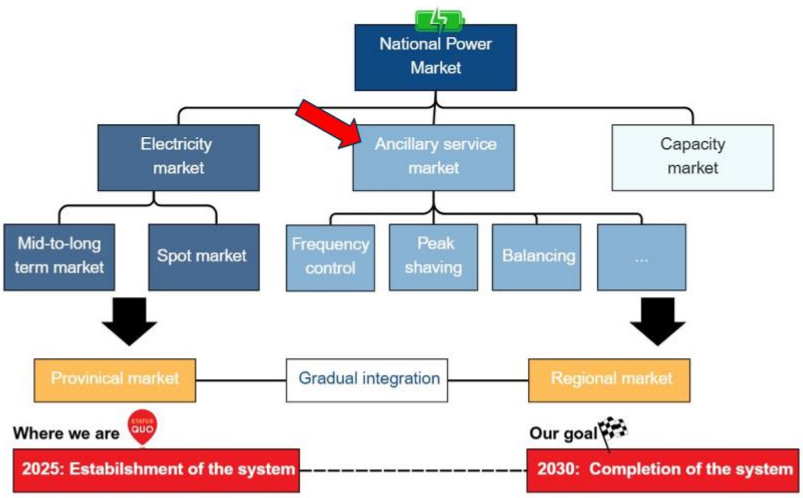

Figure 3: China Energy Transition – Power Market

Policy Recommendations

Germany

- **Support Research and Development for Next-Gen Storage Technologies**

  → **Purpose**: Stimulate innovation and enhance Germany's technological leadership in energy storage by funding the development of solid-state, sodium-ion batteries, and hydrogen storage systems.

- **Shift from fragmented subsidies to system-value-based incentives,** rewarding flexibility services (e.g., curtailment reduction, frequency regulation, and seasonal balancing).

  → **Purpose:** Ensure that both short- and long-term storage are deployed where they maximize overall grid resilience and cost efficiency.

- **Establish international cooperation and spatial planning mechanisms,** including cross-border hydrogen pipelines with North Africa and coordinated deployment signals within Germany.

  → **Purpose:** Optimize spatial allocation of storage, diversify import dependence, and secure Germany's role in the global hydrogen and storage economy.

China

- **Replace capacity quotas with system-value incentives**, rewarding services like curtailment reduction, frequency regulation and peak shaving.
  → Purpose: Ensure storage investment is guided by real system needs, not arbitrary quotas, and maximize overall grid reliability and renewable integration.

- **Establish stable revenue mechanisms** via ancillary and capacity markets to attract private investment.
  → Purpose: Improve project bankability, lower investment risks, and attract large-scale private and institutional financing into storage deployment.

- **Balance deployment through cross-provincial market signals**, reducing overcapacity in the northwest and enhancing coastal flexibility.
  → Purpose: Optimize spatial allocation of storage, reduce overcapacity in renewable-rich provinces, and enhance flexibility in urban and coastal grids.

Comparative Analysis: Germany and China

Dimension	Germany	China	Key Outcomes
Overall Approach	Market-driven, decentralized, EU-linked; incremental growth	State-led, centralized; rapid scale-up through planning	Germany fosters innovation & regulation, China achieves unmatched speed & scale
Strategic Focus	System optimization, grid efficiency, hydrogen imports	Large-scale domestic deployment, storage as backbone of RE expansion	Germany prioritizes efficiency & integration, China prioritizes quantity & speed
Storage Portfolio	Balanced: batteries, pumped hydro, Power-to-X pilots	Balanced: pumped hydro, large batteries, emerging Power-to-X	Both pursue diversified portfolios, hydrogen as long-term pillar
Key Barriers	Grid congestion, regulatory complexity, public opposition (NIMBY)	Coal reliance, regional imbalances, weak transparency	Germany hindered by regulatory/social drag, China by coal dependence & governance gaps
Commonalities	High renewable targets, hydrogen strategic, diversified storage	Same	Shared recognition: storage essential for deep RE integration

Making Storage the Backbone of Decarbonization: Sino-German Insights

Conclusion and Synthesis

Germany's market-led pluralism drives efficiency and decentralization, while China's state-led model delivers rapid scale-up; each has lessons for the other, Germany could adopt China's industrial policy and speed, while China could benefit from Germany's market signals and transparency. Storage is no stand-alone fix but must be combined with grid expansion, demand-side management, and sector coupling. The decisive challenge ahead is governance and legitimacy: Germany must overcome incrementalism, while China must reduce coal reliance, improve transparency, and balance regional disparities. Both converge on the same imperative: complementary storage portfolios, stronger grid coordination, and social acceptance, making cross-learning vital for a resilient, decarbonized energy system.

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Figures

Figure 1: Own illustration

Figure 2: Energiewende Team. (2018, March 30). *The German electricity grid: notoriously swamped?* EnergyTransition.org.

Figure 3: Own illustration based on:
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