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Powering China's New Era of Green Electrification

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About Ember

Ember is an independent, not-for-profit energy think tank that aims to shift the world to clean electricity using data. It gathers, curates and analyses data on the global power sector and its impact on the climate, using cutting edge technologies and making data and research as open as possible. It uses data-driven insights to shift the conversation towards high impact policies and empower other advocates to do the same. Founded in 2008 as Sandbag, it formerly focused on analysing, monitoring and reforming the EU carbon market, before rebranding as Ember in 2020. Its team of electricity analysts and other support staff are based around the world in the EU, UK, Turkey, India, China and Indonesia.

Summary

As China's energy transition deepens, breakthroughs in emerging technologies will do far more than enable systemic energy transformation — they will reinforce the "growing by greening" cycle. This dynamic can help sustain the policy commitment, necessary to drive deep structural changes — essential for building a clean electricity future.

While headlines in 2025 have been dominated by geopolitical competition and security crises, climate change — often seen as a distant threat — has receded from public discourse. Yet it is no longer a distant risk but an unfolding catastrophe, already affecting lives globally.

The numbers speak plainly: 2024 shattered records as the hottest year in modern history, with global temperatures hitting 1.55°C above pre-industrial levels — crossing the critical 1.5°C threshold for the first time. From record heatwaves in China to devastating flooding in Brazil, extreme weather has become the "new norm". In 2024 alone, water-related disasters claimed over 8,000 lives, displaced 40 million people, and caused economic losses exceeding $550 billion.

As the climate crisis escalates, the urgency for decisive action has never been greater. For China — the world's largest annual emitter — this urgency intersects with a pivotal juncture in its energy transition, at which breakthroughs beyond wind and solar will determine whether its progress accelerates or stalls.

- **China's "more renewables, more coal" era is ending.** Record-breaking solar (278 GW) and wind (79.8 GW) additions in 2024 propelled total capacity to over 1,400 GW — six years ahead of its 2030 target — enabling

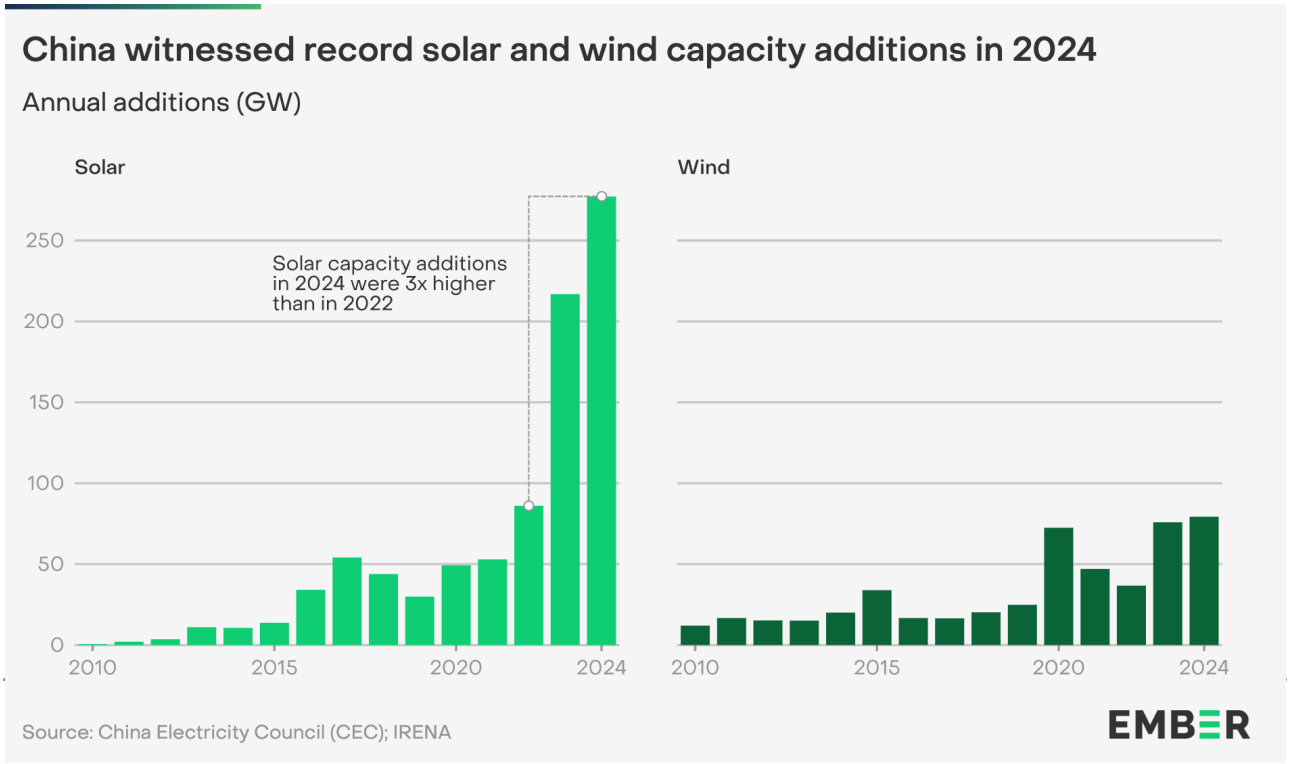
clean electricity to meet more than 80% of surging demand. If the current trends continue, clean electricity will fully satisfy annual demand growth before 2030, locking in coal's irreversible decline.

- **Deeper transition now hinges on breakthrough beyond wind and solar.** As China enters this transformative phase, success demands a paradigm shift — from chasing "megawatts" to engineering a "megasystem". This requires reinventing the entire electricity architecture: advanced heating systems to electrify heavy industry, AI-powered smart grids to balance supply and demand, long-duration energy storage to stabilise renewable generation, and carbon removal technologies to offset residual emissions.
- **Unlocking new frontiers for green growth.** While the "new three" sectors — solar, batteries, and EVs — have become key drivers of GDP growth, achieving double-digit expansion last year, China only narrowly met its GDP target. The challenges now confronting these sectors — including excessive competition and demand saturation — signal that their peak growth phase may be passing. This reality makes the cultivation of next-generation clean technologies imperative for sustaining China's green development momentum.
- **Sustaining momentum for China's next-phase energy transition.** By reinforcing the "growing by greening" dynamic — where deeper transition drives economic restructuring towards high-quality growth — China can foster strong policy commitment, transforming what could be seen as complex energy system challenges into catalysts for innovation — rather than excuses for delayed action.

The era of “more renewable, more coal” is nearing its end

China’s transition to clean electricity has long been characterised by dissonance, torn between encouraging progress and persistent setbacks. On the positive side, every year brings record-breaking clean energy investments and rapid expansion in wind and solar deployment. Yet despite this momentum, coal power capacity and generation have continued to rise — a stark reminder that progress remains insufficient.

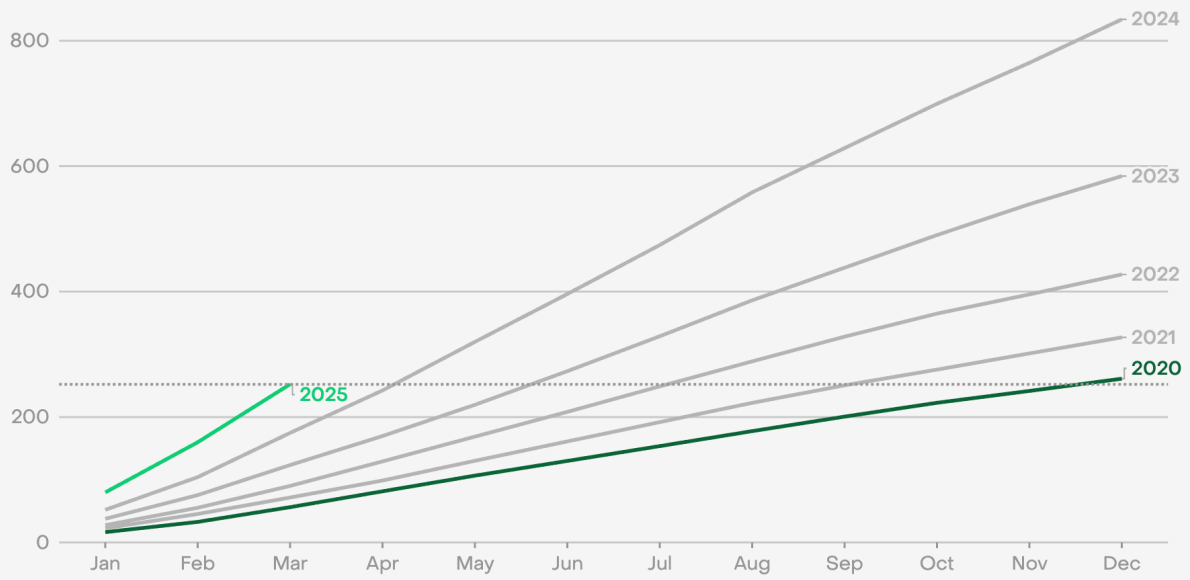
This dissonance, however, is fading. In 2024, 278 GW of new solar capacity was added to the grid, marking a 28% increase year-on-year. Approximately 57% of this growth came from utility-scale solar PV, with the remainder from distributed solar. This represents a tripling of annual installation levels within just two years. The year also saw a new record for wind capacity additions, with 79.8 GW installed. By the end of 2024, China’s combined solar and wind capacity surpassed 1,400 gigawatts (GW), smashing its 2030 target six years earlier.



Driven by this exponential growth, total solar generation exceeded 200 TWh in the first three months of 2025, almost as much as in the whole of 2020 — just five years earlier. China now generates over 3,300 TWh of clean electricity a year, sufficient to power India, the world's third-largest electricity consumer, which used just over 2,000 TWh in 2024.

China produced almost as much solar power in the first three months of 2025 as in the whole of 2020

Cumulative solar generation (TWh)



Source: Monthly electricity data, Ember

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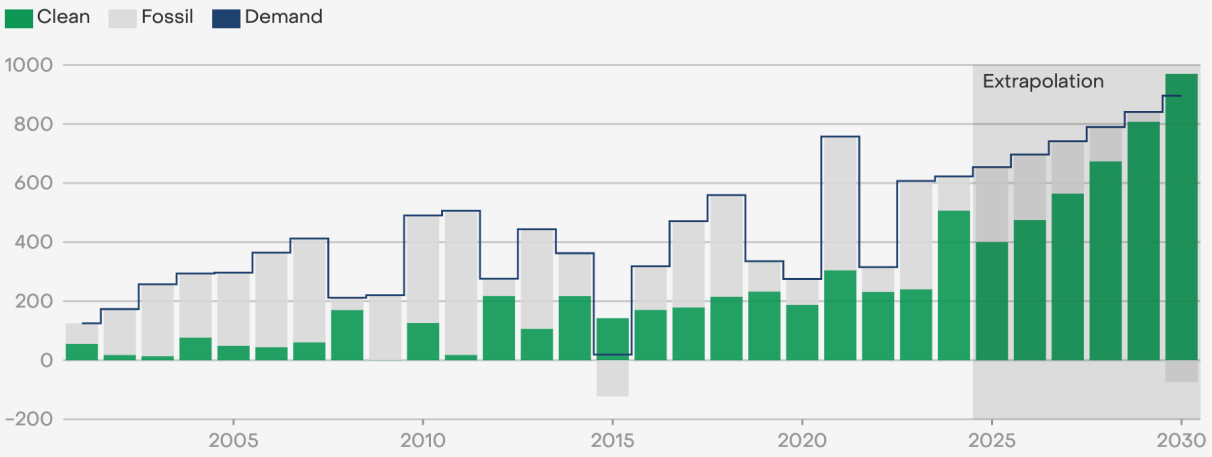
Meanwhile, the share of coal generation has decreased steadily, from nearly 80% in the mid-2000s, to around 70% in the mid-2010s, and further to 54.8% in 2024. This relative decline is accelerating. From 1991 to 2000, clean electricity met only 16% of the increase in demand. This share rose to about 22% between 2001 and 2010, and to around 45% from 2011 to 2020. In 2024, clean electricity generation surged by 15.4% year-on-year. Despite rapid growth in electricity demand (6.8% compared to 2023), clean electricity met almost all (84.2%) additional demand.

Even under conservative assumptions, coal generation in China could soon peak and enter structural decline. If clean electricity — including hydro, wind, and nuclear — maintains its average annual growth rate from 2021 to 2024 while solar power expands at a moderate 25% annually, clean electricity would meet even high demand growth of 6.5% annually before 2030. Ember analysis indicates that if not for unusual weather conditions in 2024, clean generation would have already met 97% of demand growth in that year.

Even with conservative assumptions, clean power would cover all of China's demand growth before 2030

Annual change in electricity generation and demand (TWh)



Source: Yearly electricity data, Ember
Extrapolation assumes high demand growth of 6.5% annually. Clean sources excluding solar maintain 2021–2024 annual growth rates. For solar, a conservative 25% annual growth rate is applied to account for near-term grid constraints. This rate broadly aligns with the IEA's Announced Pledges Scenario in its World Energy Outlook (2024).

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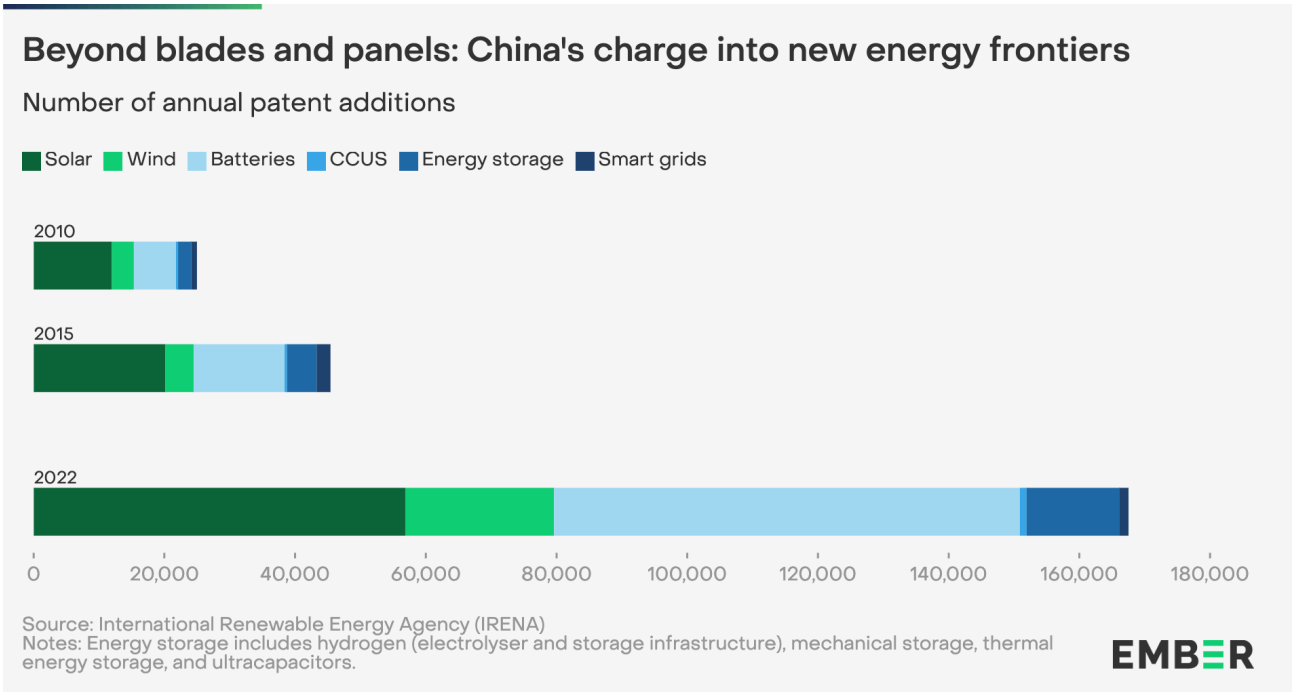
Beyond today's technologies: Critical for a deeper transition

Scaling established technologies — such as wind, solar, and battery storage — remains vital, but the next phase of China's clean electricity transition demands breakthroughs in emerging fields. The International Energy Agency (IEA) emphasises that while existing market-ready solutions can deliver most emissions cuts needed by 2030, achieving net zero by 2050 will significantly depend on technologies still in development.

As mature technologies like solar and EVs achieve commercial viability — and ensuring a sound market environment grows increasingly critical to their sustained success — China is already pivoting towards the next-generation frontiers, including innovative energy storage solutions, smart grids, industrial electrification systems, and negative-emissions technologies.

According to the International Renewable Energy Agency (IRENA), China's annual patent filings for emerging clean energy technologies — including batteries, carbon capture, utilisation and storage (CCUS), energy storage, and smart grids — surged nearly tenfold between 2010 and 2022. This growth was led by breakthroughs in battery technologies and other storage solutions, such as hydrogen, thermal, and mechanical storage systems.

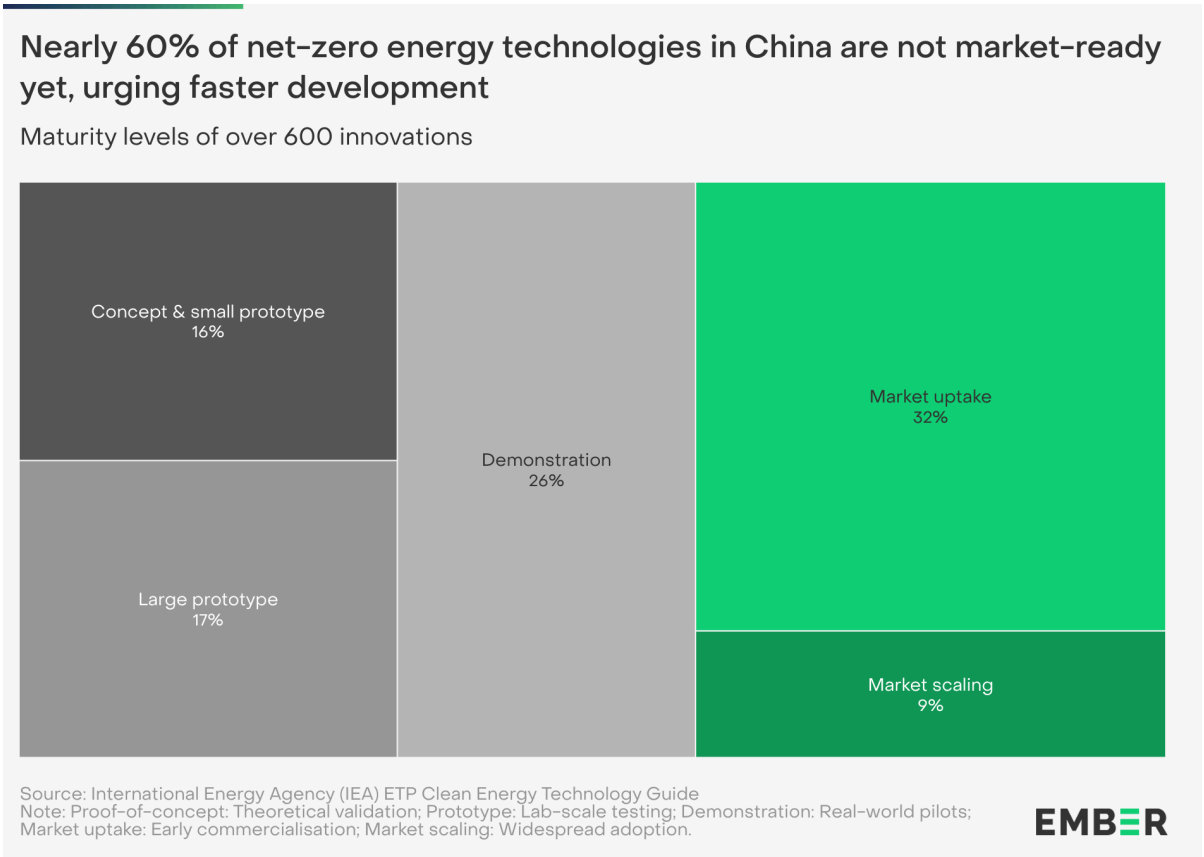


These innovations are critical for building a resilient and reliable clean electricity future — particularly in managing long-duration variability in renewable generation, electrifying harder-to-abate sectors like steelmaking and shipping, and addressing residual emissions.

A recent modelling study by the Energy Research Institute of the Chinese Academy of Macroeconomic Research — a top think tank affiliated with China's macro-planner, the National Development and Reform Commission (NDRC) — highlights two pillars for achieving carbon neutrality before 2060: renewable-powered grids and widespread electrification.

Beyond expanding wind and solar capacity, the first pillar hinges on digitalisation and advanced energy storage technologies to build a flexible, adaptive grid that can reliably distribute clean electricity when and where it's most needed. Furthermore, deep electrification and decarbonisation in heavy industry, central to the second pillar, depend on progress in innovative solutions such as renewable-based hydrogen production, hydrogen-based steelmaking and chemical manufacturing, CCUS, and industrial carbon recycling.

IEA tracks over 600 energy technologies and components critical to achieving net-zero emissions, each categorised by maturity: proof-of-concept, prototype, demonstration, market uptake, and market-scaling. Roughly 60% of these innovations are not yet commercially mature. The challenge extends beyond sheer numbers: many of the high-impact solutions for hard-to-abate sectors like steel, aviation, and shipping, such as green hydrogen-based steelmaking or ammonia-fuelled vessels, are still in early development. Accelerating their scale-up is critical to achieve deep decarbonisation.



Bridging the gap between lab-scale prototypes to commercially viable solutions — a phase often termed the "innovation valley of death" — is fraught with substantial challenges: validating technical feasibility, overcoming scalability hurdles, and securing market acceptance.

In such circumstances, capital naturally gravitates towards proven technologies. In 2024, global energy transition investments surpassed $2 trillion, with China alone accounting for nearly 40% of this total — a 20% increase from 2023. Yet over 90% of these investments flowed to mature sectors like EVs and solar, while emerging solutions saw a 23% drop in investment.

For China, addressing this gap is now urgent. Its clean energy transition has entered a transformative phase in which enabling technologies — such as grid-scale energy storage and smart infrastructure — are critical to unlocking further progress. Meeting this urgency demands accelerated R&D efforts, rapid scaling of pilot projects, and stronger policy frameworks — all essential steps for sustaining China's momentum towards a clean electricity future.

Scaling clean innovations to power China's high-quality growth

Breakthroughs in emerging clean energy technologies will unlock new frontiers for high-value industries, catalysing China's economic restructuring towards high-quality growth.

For decades, China's rapid expansion was fuelled by traditional engines like real estate investments and local government spending. But these pillars are now losing momentum. In 2024, property sector investment shrank by 10.6%, while debt-laden local governments can no longer rely on land sales to prop up growth.

The old playbook is exhausted. In its place, China is pursuing a sweeping economic restructuring, centred on high-tech and clean industries — a strategy encapsulated by the concept of "New Quality Productive Forces". At its core, this transformation aims to promote innovation-driven industries such as advanced manufacturing and clean energy, while modernising traditional sectors through digitalisation and decarbonisation.

The early results are encouraging. As traditional industries struggle, the clean tech industry — particularly the "new three" sectors of solar panels, batteries, and EVs — is booming. In 2024, it expanded at three times the rate of the overall economy, contributing roughly 13.6 trillion RMB ($1.9 trillion) to the country's economic output — an amount roughly equivalent to the annual GDP of countries like Australia.

According to China's National Bureau of Statistics, the value-added of the "new economy" sectors – encompassing high-tech and clean energy — exceeded 18% of the country's GDP in 2024, up from 17.25% in 2021.

Yet, despite these positive trends, challenges remain. Last year, China narrowly met its GDP growth target of 5%, even as clean tech sectors expanded at double-digit rates. This highlights the pressing need to scale up the new economy even further.

To achieve this, the country must look beyond established sectors like wind and solar. These sectors, already the world's largest, now face significant challenges like "involution", a term describing intense internal competition. Geopolitical tensions and growing trade protectionism further dampen export demand. Together, these factors suggest that the growth potential of these mature sectors may be nearing its peak.

Fostering a virtuous cycle for future prosperity

The path forward lies in deepening the clean electricity transition — a strategy poised to unlock substantial demand for emerging technologies like green hydrogen, smart grids, and advanced heating systems.

This technological leap will spur investment and innovation, driving breakthroughs that lower costs, fuel industrial growth, and create high-quality employment. These benefits, in turn, will build confidence and garner broad-based support for an even faster transition. The result? A self-reinforcing virtuous cycle that fosters the patience and persistence essential for long-term success.

The clean electricity transition is not a sprint but a marathon — one that demands unwavering commitment to transform today's prototypes into tomorrow's engines of growth. Securing such a commitment is especially critical as China's transition enters a deeper, more complex phase, where sustained effort will be key to achieving lasting impact.

Supporting information

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