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China's Power Market Reform for a High-Renewable Future: Key Drivers, Market Design, and Prospects

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Abstract

China's rapid renewable expansion coincides with deep structural reforms to its power markets. Over the past decade, reform has drawn on international market-design experience while making substantial institutional progress since 2015. Unlike developed markets adapting established frameworks to accommodate renewables, China must address high-renewable integration alongside conventional market-liberalisation challenges. High renewable penetration creates several shared analytical challenges, including revenue adequacy under near-zero marginal costs, intensified price volatility, limited participation by emerging flexible resources, incomplete markets for new system attributes, and ambiguous planning–market interactions. In China, responses to these challenges are shaped by two foundational drivers: (1) using the market as an instrument of government policy and (2) hierarchical prioritisation of end-user price stability and socio-political acceptability of reform over allocative efficiency. These drivers have produced a reform pathway characterised by strict price control, technology-specific participation rules, and planning-led adequacy coordination. Provincial pilots implement variants of this pathway iteratively, while international experience provides comparative reference points. The review concludes that power systems worldwide combine wholesale markets with broader planning and system-operator governance, although the balance and institutional form differ substantially across jurisdictions. China's reform occupies a distinct position on this continuum, warranting evaluation frameworks suited to layered market–administrative coordination and sector-coupled net-zero transitions. The principal implication is not that China will converge towards a single internationally recognised market template, but that reforms are likely to maintain structured divergence rooted in China's political economy while remaining part of the broader shift towards hybrid governance everywhere.

Keywords: China's power market reform, Deregulation, High renewable penetration, Energy policy, Electricity market design

1. Introduction

Over the last four decades, electricity-market reforms have sought to improve efficiency, attract investment, and expand consumer choice [1]. Rising renewable penetration is now reshaping established markets in Europe, North America, and Australia [2, 3, 4]. China, by contrast, is building market institutions while renewables scale rapidly. It is notable for deployment amounting to roughly half of global renewable investment and for diverse provincial experiments, while market reform is widely viewed as an enabler of carbon neutrality by 2060 [5].

China's reforms confront a *dual challenge* common to many emerging markets. First, they must address conventional liberalisation problems, including market power, stranded assets, and distribution of reform benefits [6, 7], for which experience in the European Union, the United States, and Australia provides reference points [8, 9]. Second, high renewable penetration erodes generator revenue adequacy, weakens price-based coordination of heterogeneous resources, and creates newly scarce system attributes that existing products may not compensate. These problems remain unsettled internationally, while China's political economy and reform pace limit direct transfer of foreign arrangements.

The current round of power market reforms was launched in 2015, symbolised by the high-level “Document No. 9,” which set the overall reform orientation and mandate for the power sector [10]. Later that year, the National Development and Reform Commission (NDRC) and the National Energy Adminis-

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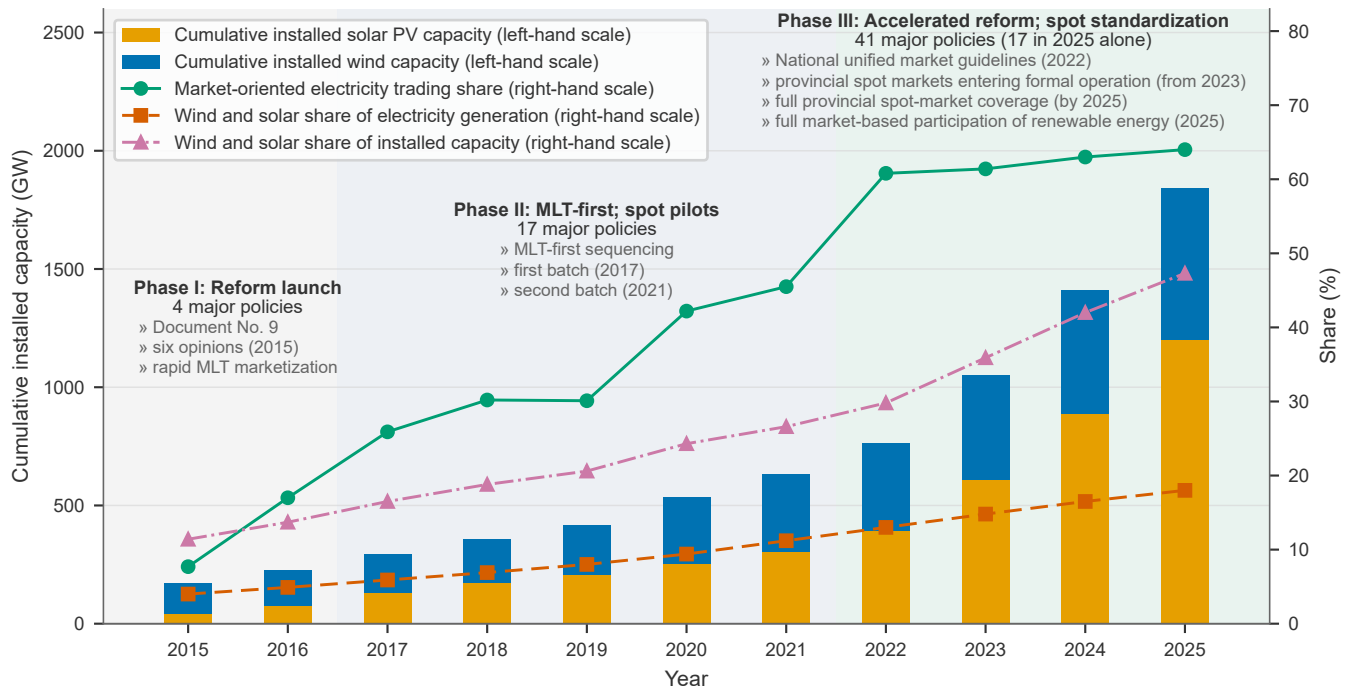


Figure 1: Evolution of China's power market reform and renewable energy integration (2015–2025). Illustrative phases (not an official periodisation): Phase I, reform launch and rapid medium- and long-term (MLT) marketisation (2015–2016); Phase II, a prolonged “MLT first, spot later” pilot era (2017–2021); and Phase III, accelerated spot standardisation (2022–2025). Shaded bands count nationally important market-policy documents per phase (chronology in Table A.3); stacked bars show cumulative wind and solar capacity (GW, left axis); lines show market-oriented electricity trading share and wind and solar shares of generation and installed capacity (% , right axis).

tration (NEA) issued a supporting notice (Fagai Jingti (2015) No. 2752) with six annexed implementation opinions spanning tariffs, market building, trading institutions, plan liberalisation, retail access, and captive plants. Medium- and long-term (MLT) marketisation then advanced rapidly: in December 2016, NDRC and NEA issued interim nationwide basic rules for MLT trading [11], while the Beijing and Guangzhou power exchange centres were inaugurated and provincial trading centres were established in succession. By around 2017, MLT trading had been rolled out nationwide, with trading arrangements operational across the system while detailed rules and coverage were still evolving; policy attention then shifted to exploring spot markets. China launched spot-market pilots from 2017, with a first batch comprising the Southern regional market (initially centred on Guangdong) and seven provincial pilots (Western Inner Mongolia, Zhejiang, Shanxi, Shandong, Fujian, Sichuan, and Gansu), followed by a second batch in 2021 (Liaoning, Shanghai, Jiangsu, Anhui, Henan, and Hubei). As those pilots expanded, MLT rules were periodically brought into alignment with spot-market development. The revised nationwide MLT Basic Rules issued in June 2020 [12] strengthened MLT–spot interfaces through contract-for-difference-style settlement and deviation settlement and thereby helped prepare the pilot phase. In 2022, NDRC and NEA further issued the Guidelines on Accelerating the Development of a National Unified Electricity Market System, setting phased targets for the development of this system: “initial establishment by 2025”

and “basic completion by 2030” [13]. Since then, China's market development has accelerated significantly, and spot market construction has entered a stage of accelerated implementation: several provincial spot markets, including Shanxi (2023.12), Guangdong (2023.12), Shandong (2024.06), Gansu (2024.09), Western Inner Mongolia (2025.02), Hubei (2025.06), and Zhejiang (2025.08), have transitioned into formal operation, and inter-provincial spot markets also entered formal operation in October 2024. Moreover, in April 2025, the NDRC and NEA issued “Document No. 394” [14], setting an end-2025 target for provincial-level full coverage of spot markets, meaning that all mainland provincial market areas would reach at least continuous-settlement trial operation or equivalent spot-market functionality. That coverage target was met by the deadline, although not all areas had entered fully formalised operation and maturity remained uneven across regions. Renewable integration has entered a new stage in parallel: wind and solar capacity and generation have grown rapidly since 2015, with major policy milestones coinciding with deployment surges. In 2025, NDRC and NEA issued Document No. 136, formally enabling full market-based participation of renewable energy [15].

Figure 1 suggests that market-rule development lagged renewable deployment for much of the post-2015 period. During launch and rapid MLT marketisation, renewables already featured in transition planning yet remained a modest system share, and much integration still relied on administrative and technical arrangements rather than trading institu-

tions. Through the prolonged pilot era, policy attention centred on spot pilots, MLT harmonisation, plan liberalisation, and coal-power pricing rather than on high-renewable-penetration design. From the early 2020s onward, especially after 2022, sharply rising wind and solar shares coincided with a marked acceleration in rulemaking on flexibility services, cross-regional coordination, and renewable market participation.

This evolution has attracted extensive study, but the literature remains divided among partly overlapping strands rather than offering an integrated account of market design under rising renewable penetration. One strand examines institutions, reform motivations, and macro trajectories: the 2015 package and its structural shortcomings [16]; international policy learning [17]; complementary state–market roles [18]; planning legacies and ideational barriers to liberalisation [19]; and wider regulatory and transition pathways [20, 21, 22].

A second strand evaluates outcomes from provincial pilots and panel studies. It covers early price, efficiency, and reliability effects [23]; industrial-tariff reductions attributable partly to regulated network charges and surcharges rather than wholesale competition alone [24, 25]; unbundling and energy-efficiency gains [26, 27]; dispatch under joint electricity and carbon reforms [28]; and stranded-asset and political-economy constraints [29, 30]. More recent work examines renewable integration [31], provincial resource differences and convergence [32], quota-allocation burdens [33], flexibility and adequacy pressures [34], and provincial reform performance [35].

The literature therefore still lacks a sufficiently current account of how market reform interacts with high renewable penetration. Agency assessments, including the International Energy Agency’s (IEA) analysis of flexibility and inter-provincial trade [36], illuminate the 2015 agenda but predate or only partly cover the post-2022 acceleration in deployment and rulemaking shown in Figure 1 and Table A.3. This review integrates the institutional, outcome-oriented, and high-renewable strands to assess China’s experimentation since 2015. The remainder of this review is organised as follows. Section 2 synthesises international market-design challenges under high renewable penetration as a comparative baseline. Section 3 identifies two foundational drivers shaping China’s reform, illustrated through sequencing and stepwise construction. Section 4 examines market-design responses under high renewable penetration, through strict price control, technology-specific participation rules for emerging resources, and planning–market relationships. Section 5 compares China’s renewable settlement, flexibility and adequacy instruments, and inter-provincial integration with international hybrid architectures and locates Chinese arrangements on a shared governance continuum. Section 6 concludes by stating the review’s contributions, noting framework limitations and reform uncertainties, and outlining future research directions.

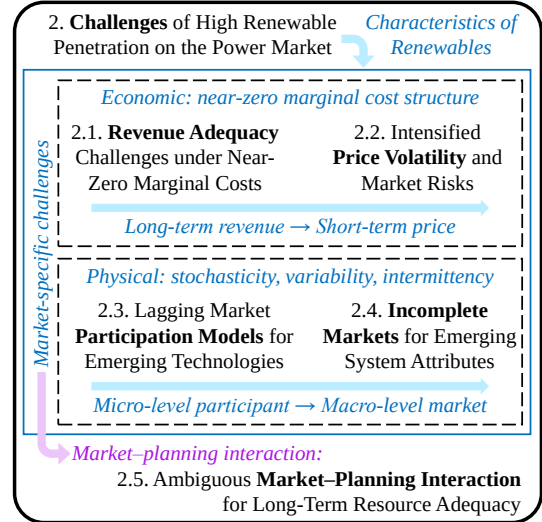


Figure 2: Five interrelated wholesale-market challenge categories under high renewable penetration.

2. Challenges of High Renewable Penetration on the Power Market

This section focuses on wholesale electricity markets, where high renewable penetration reshapes chiefly short-run prices and trading rules; pass-through to end-user bills depends on separate retail and regulatory arrangements. The challenges stem from the distinct economic and physical characteristics of renewable resources: near-zero marginal costs economically, and strong stochasticity, variability, and intermittency physically. These properties expose fundamental tensions in existing wholesale frameworks. Figure 2 schematically organises five interrelated categories reviewed below: revenue adequacy, market risks, participation of emerging technologies, incomplete market mechanisms, and planning–market interactions for long-term resource adequacy.

2.1. Revenue Adequacy Challenges under Near-Zero Marginal Costs

Renewables with near-zero marginal costs depress average wholesale prices through the merit-order effect, weakening fixed- and capital-cost recovery from energy-only trading. This intensifies the longstanding “missing money” problem and exposes limitations of marginal pricing under high renewable penetration [37, 38]. Stronger scarcity pricing can in principle improve cost recovery, but governments are often reluctant to expose consumers to prolonged high and uncertain energy prices, leaving a continuing role for long-term contracts and capacity mechanisms [38]. Reduced operating hours and compressed spreads particularly weaken investment incentives for dispatchable resources still needed for balancing and reliability [39, 40].

Many markets therefore supplement energy revenues for conventional resources. Instruments such as Reliability Must-Run contracts, out-of-market uplift payments, and targeted capacity remuneration schemes have been adopted in regions including

ERCOT, ISO-NE, and CAISO² to support the financial viability of dispatchable generators [41, 42, 43]. Such reliability and flexibility payments reflect the fact that energy-only merchant generation was rarely a durable equilibrium; capacity and reliability supplements predate high renewable penetration, which has intensified rather than created the cost-recovery shortfall [44, 45, 46, 47].

Renewable generators also face declining revenues through self-cannibalisation during periods of high availability [48, 49]. Feed-in tariffs (FiTs), contracts for difference (CfDs), and long-term power purchase agreements (PPAs) can stabilise income, but their role in market remuneration remains unsettled as renewable penetration grows because support design shapes generators' exposure to market prices and hence their bidding and dispatch incentives [38]. This differs from the more established capacity or reliability payments for conventional resources.

2.2. Intensified Price Volatility and Market Risks

High renewable penetration reshapes short-term prices in two related ways: through the merit-order effect, which depresses average wholesale prices and increases exposure to very low and negative prices; and through weather-dependent generation, which increases net-load fluctuations and can produce scarcity spikes when renewable output falls short. Measured price variability may also rise relative to legacy thermal-dominated systems in which prices were typically bounded below at zero or by regulation, so part of the apparent increase reflects a wider price distribution rather than uncertainty alone [50].

Empirical evidence confirms these dynamics in markets with significant renewable shares: high output can drive prices to very low or negative levels, while forecast errors or extreme weather can trigger sharp spikes [50, 49]. Depressed average prices combined with greater tail risk amplify financial exposure for producers and increase hedging costs for consumers and retailers, leaving traditional risk-management instruments insufficient or costly during system stress [50, 51].

2.3. Lagging Market Participation Models for Emerging Technologies

High renewable penetration increases reliance on flexibility providers, including energy storage, demand response, virtual power plants (VPPs), and hybrid or co-located resources. Their operational characteristics, ownership, and service portfolios differ from conventional generation, so legacy participation models often fit poorly [52].

²These labels are commonly used for both organisations and their corresponding organised-market footprints. The organisations are the Electric Reliability Council of Texas (ERCOT), ISO New England Inc. (ISO-NE), and the California Independent System Operator (CAISO). Other labels used below are PJM Interconnection (PJM), whose initials historically referred to the Pennsylvania–New Jersey–Maryland power pool; the Midcontinent Independent System Operator (MISO); the Southwest Power Pool (SPP); and the New York Independent System Operator (NYISO). PJM and SPP retain interconnection or power-pool names rather than literal operator titles, but both now perform regional system and market functions. Organisational, system, and market boundaries are related but need not be identical.

Two gaps matter: restrictive bid formats, aggregation limits, and operational representations within existing products [53, 54]; and unclear eligibility, aggregation, and operational responsibilities for prospective flexibility products [55]. Together they constrain product innovation and commercial viability.

Federal Energy Regulatory Commission (FERC) Orders 841 and 2222 remove formal U.S. barriers for storage and aggregated distributed resources [56, 57], yet interconnection, telemetry, and computational constraints remain. Effective access therefore requires rules for qualifying, aggregating, metering, and settling heterogeneous resources across energy, capacity, and ancillary products.

2.4. Incomplete Markets for Emerging System Attributes

High renewable penetration makes operational flexibility, inertia, and frequency stability more salient as predictable dispatchability and inherent rotational inertia decline. Thermal-dominated systems often relied on conventional ancillary markets and administrative valuation; renewable penetration can make previously ample attributes scarce, yet dedicated market responses remain partial. Researchers have explored expanding the ancillary-service portfolio, notably ramping [58, 59] and inertia [60, 61] products, but coordinated procurement frameworks and unified theories of multi-dimensional attribute pricing remain elusive, and valuation often stays fragmented and administratively driven.

A further question is whether such attributes can be efficiently valued as standalone products [62]. Their value often emerges from system-level security-constrained operational models and depends on system conditions and interactions among resources.

A major difficulty is accrediting heterogeneous, context-dependent contributions across space and time, which requires probabilistic analysis and assumptions about resource interactions [63]. Simplified metrics may miss complementarities, bias investment, and impair operations [64].

The problem therefore spans products, measurement, accreditation, and pricing, requiring closer integration of reliability assessment, techno-economic modelling, and market design.

2.5. Ambiguous Market–Planning Interaction for Long-Term Resource Adequacy

High renewable penetration complicates long-term resource adequacy by blurring the roles of markets and planning: market prices reveal operational scarcity and investment needs, while planning institutions adjust requirements when market outcomes diverge from policy or reliability objectives [65, 66].

This feedback becomes ambiguous when low-price renewable hours signal short-run abundance but scarcity spikes signal tightness, while entry and retrofit depend on expected earnings across energy, capacity, and administrative arrangements. Fragmented capacity mechanisms or misaligned planning and market timelines can support conflicting adequacy conclusions [40, 67]. Integrated resource plans, reliability mandates, and administrative procurement also often operate separately from market outcomes, weakening investment coordination [68, 69].

These challenges also sit within net-zero and sector-coupling transitions [70, 44], requiring generation and network investment to align with flexible demand, distributed resources, storage, and electrified loads. This review centres on Chinese electricity-market institutions while recognising that reform increasingly crosses this boundary.

These challenges confront systems at different points on a continuum of hybrid governance. Pure energy-only coordination is a stylised baseline, not an operational template: established markets already combine wholesale trade with capacity remuneration, reliability contracts, long-term revenue support, planning mandates, and administrative interventions on prices and adequacy.

3. Key Drivers Shaping China’s Electricity Market Reform

Unlike theoretical market design, which can pursue efficiency objectives in isolation, practical development must navigate institutional and policy context. China’s relatively cautious liberalisation reflects distinct policy priorities and governance frameworks. This section identifies the foundational drivers underpinning China’s reform and illustrates, through representative examples, how they manifest in sequencing and phased market construction; Section 4 then examines design choices more directly tied to high renewable penetration.

3.1. Foundational Drivers of Market Development in China

China’s electricity market reform is shaped by two related drivers: (1) using the market as an instrument to extend government policy, and (2) prioritising end-user price stability and socio-political acceptability of reform over allocative efficiency [71]. These drivers are not unique to China, but their weights and implementation logic place Chinese reform towards the administratively coordinated end of the hybrid governance continuum observed across Europe, North America, and Australia.

The Market as an Instrumental Extension of Government Policy. Wholesale markets elsewhere were never fully autonomous: governments retain boundaries, reliability mandates, and retail safeguards, while layered instruments mediate investment and revenue alongside energy markets [45, 68, 65]. China makes that layered role explicit: the market functions as an instrumental extension of government policy [71], not as a substitute for administrative planning. Market mechanisms serve as an optimisation layer where planning-based approaches face inherent limitations [72], such as allocating massive heterogeneous resources and discovering scarcity value. The market thus bridges rigid administrative targets and the growing complexity of a modern power system.

Hierarchical Prioritisation: End-User Price Stability and Socio-Political Acceptability of Reform. Market-design literature commonly balances efficiency, reliability, affordability, and distributional equity [73]. Chinese policy gives particular weight to *end-user price stability*, meaning administratively acceptable retail tariffs, and the *socio-political acceptability of reform*, meaning limits on disruptive price and income shocks during incremental opening [74, 75, 76]. At the 2015 launch,

policy emphasised reducing commercial and industrial electricity costs, partly in response to the documented pre-reform gap between Chinese and U.S. industrial tariffs [77]. Institutional development on the generation side was likewise framed around benefits to end users, while retail opening initially covered larger commercial and industrial consumers and protected residential and agricultural tariffs [74, 78]. For much of the following period, policy communication stressed cost reduction more than upward price flexibility. Only the October 2021 coal-power pricing reform formally allowed tariffs to move both upward and downward, relaxing the earlier downward-oriented constraint that would otherwise impede further spot-market development [79, 80]. Wholesale competition therefore operates within retail, contract, and spot safeguards intended to keep outcomes within distributional tolerance and an acceptable reform pace.

Together, these drivers produce a gradual, sequential reform pathway in which the market serves as an instrumental component within broader governance and is not expected to deliver comprehensive liberalisation from the outset. Reforms since 2015 also operate within a concentrated industry structure inherited from earlier restructuring [81]: the State Grid and China Southern Power Grid as regional network and system operators, and generation capacity largely with five central state-owned groups (China Energy, Huaneng, Datang, Huadian, and the State Power Investment Corporation (SPIC)). That structure conditions reform alongside the instrumental market role and welfare priorities outlined above, but primarily as a contextual constraint shaping institutional sequencing illustrated in the following examples.

3.2. Illustrative Examples of Key Drivers in China’s Electricity Market Reform

The discussion centres on two patterns: mandatory MLT marketisation prior to the formal operation of spot markets, and phased implementation under central guidance. The first illustrates the instrumental role of markets within a planning-led system; the second, together with administratively guided tariffs, cross-subsidies, bounded MLT and spot arrangements, and gradual retail opening, illustrates how welfare priorities and reform pacing are built into practice [74, 78, 82].

3.2.1. Medium- and Long-Term Contracts Before Spot Markets

In much of the market-design literature, short-run spot clearing establishes dispatch prices first, after which voluntary forward and hedge contracts form around those outcomes. Australia’s National Electricity Market (NEM)³ illustrates this pattern: a gross-pool, energy-only spot market preceded the later formalisation of extensive forward contracting [83, 51].

China’s “MLT first, spot later” pattern refers primarily to mandatory institutional sequencing under the current reform

³The Australian Energy Market Operator (AEMO) operates both the NEM in eastern and south-eastern Australia and the geographically separate Wholesale Electricity Market (WEM) in Western Australia. Where a compact operator–market label is useful, this article therefore uses “AEMO NEM” or “AEMO WEM” rather than treating AEMO itself as a single market region.

round. Following the 2015 launch, nationwide rules required large-scale MLT trading shaped by administrative benchmarks, guided ranges, and centralised matching; spot pilots began only in 2017, and the first provincial markets entered formal operation in December 2023. During this interval, long-term positions formed through rule-bound MLT arrangements rather than optional contracts around an established spot reference.

This sequencing reflects both foundational drivers. MLT contracts, with fewer transactions, lower trading frequency, and clearer contractual boundaries, are easier to oversee administratively than spot markets [84, 85]. Introducing MLT trading brought market allocation into the system while retaining control over aggregate outcomes and limiting abrupt changes in dispatch and income [86], thereby containing distributional risk during the transition.

The “MLT first, spot later” sequencing entails clear trade-offs. Institutional continuity reduces implementation complexity and resistance, which remained substantial even under gradual reform [30]. The trade-off is weaker marginal price signals and lower operational efficiency than under stylised spot-first sequencing [87], leaving early outcomes closer to the pre-reform benchmark. Pairing revenue stability with wholesale competition has precedents elsewhere: U.S. competitive transition charges [6] compensated generators for early spot exposure relative to cost-of-service regulation, and UK retail opening proceeded gradually so as to limit households’ immediate wholesale-price exposure. Other large emerging systems likewise followed “MLT first, spot later” sequencing: India, with long-term PPAs preceding fuller short-term integration [88]; Brazil, with centralised long-term auctions and contracts before short-term pricing took a fuller role [89]; and Russia, with regulated vesting contracts covering much wholesale trade until day-ahead liberalisation [90]. In China’s reform, the “MLT first, spot later” sequencing chiefly reflects nationwide mandatory scale, sustained administrative guidance of contract volumes and prices, and embedding in planning-led coordination, rather than the sequencing label alone.

3.2.2. Stepwise Reform for Adaptive Market Development

China’s stepwise reform uses regulatory oversight to phase in and adapt market mechanisms [85, 87]. Beyond MLT-before-spot sequencing, gradualism covers transaction types, batches of provincial pilots, participant eligibility, and the later inclusion of renewable technologies.

California’s restructuring ahead of the 2000–01 electricity crisis illustrated how expanding competition with thin long-term contracting and heavy spot exposure for many loads could destabilise reform [91, 92]. China’s mandatory MLT marketisation before formal spot clearing also emphasises hedging alongside competition, but through administratively guided contracts rather than voluntary bilateral forwards. More broadly, the stepwise path reflects lessons from documented reform failures abroad, not only from successful templates.

Given this dual challenge and the welfare and instrumental priorities above, gradualism is a *deliberate* strategy, not an interim deviation from a complete blueprint. First, in the absence

of prior experience, it helps contain the risk that market outcomes deviate from government oversight. Second, it provides a means to incrementally pursue policy objectives, such as social acceptance, without implying that the approach is inherently optimal. Third, it limits the risk that abrupt changes to revenue arrangements disrupt investment, which China has had to sustain at an unusually rapid pace throughout the reform period [93].

These benefits carry corresponding trade-offs: interim MLT arrangements stabilised revenues and enabled smoother implementation while limiting the influence of spot outcomes on contract benchmarks. Prolonged reliance may complicate later harmonisation of MLT, spot, and capacity rules; strict price limits and weak short-run convergence are one manifestation. Figure 3 is consistent with limited short-run convergence across provinces at varying renewable penetration, though the price-only comparison is illustrative and does not identify causality.

By contrast, a *coordinated-package* path jointly analyses, consults on, and specifies interacting policy modules before near-simultaneous implementation. The United Kingdom illustrates this pattern in two settings. The 2013 Electricity Market Reform (EMR), enacted through the Energy Act 2013 [94], was not a full-sector blueprint but a legislated bundle in a mature market: CfDs for low-carbon investment, a capacity market for reliability, and complementary carbon-price and emissions standards were layered onto an existing wholesale market after substantive debate over how the instruments would fit together. The post-2021 Review of Electricity Market Arrangements (REMA; Appendix B) was likewise launched as a wide-ranging package review after the 2021–23 energy crisis, revisiting locational pricing and high-renewable operational issues within the EMR framework already in place. EU crisis responses show that broad option menus often narrow as acute stress eases [95]; REMA similarly illustrates how existing contracts and settlement arrangements, together with the need to reassure past and present investors, make established rules difficult to revise.

High-level mandate clusters, including Document No. 9 and its supporting implementation opinions in 2015, can look package-like at first glance; yet they chiefly establish direction rather than a co-specified, jointly implemented rule package at the market-design level. Operational rules have instead been revised as pilots progress, including successive nationwide updates to MLT trading rules to align contracting and settlement with advancing spot-market pilots, rather than through a single ex ante design implemented as one block. Mandatory MLT trade, provincial spot pilots, administratively bounded prices, and follow-on instruments have correspondingly unfolded in sequence, with imperfect coupling across modules only gradually addressed. China differs from the UK package pattern chiefly in its sequencing. REMA nonetheless offers a related lesson about path dependence: pilot-era MLT, spot, and price rules may become entrenched before national interfaces are fully aligned, particularly as private and market-exposed investment expands. Rising wind and solar shares also pose an emerging, general design question for wholesale market rules accommodating intermittent output, helping to explain both

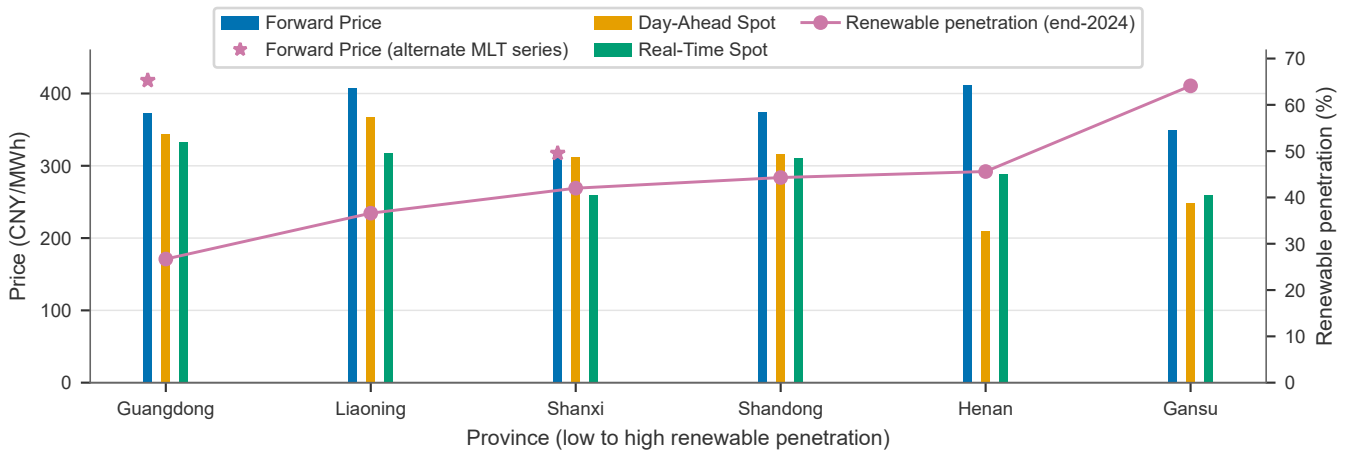


Figure 3: Provincial average MLT and spot prices in 2024 (CNY/MWh). Provinces are ordered by year-end wind and solar installed-capacity share (line, right axis). Bars show weighted-average MLT, day-ahead spot, and real-time spot prices; asterisks mark an alternate published MLT average where reported (Shanxi: renewable MLT; Guangdong: monthly-cycle MLT). For Liaoning and Henan, where spot markets were not yet formal, MLT uses market-transaction averages and spot bars reflect November and May 2024 trial operations. Source: 2024 provincial power trading centre reports. The comparison is confined to published average prices; consistent, cross-province statistics on MLT versus spot volume shares, or on MLT volumes and prices by contract horizon (annual, quarterly, monthly, and intra-month), would further clarify the MLT–spot interface but are not available in these disclosures.

China’s successive pilot-era revisions and high-renewable items on agendas such as REMA.

4. China’s Pathway for Power Market Reform under High Renewable Penetration

Building on the drivers and sequencing patterns above, this section examines three market-design responses under high renewable penetration: strict price control, technology-specific participation rules for emerging flexible resources, and planning-led adequacy coordination.

4.1. Strict Price Control under Extreme Risk Aversion

High renewable penetration intensifies price volatility and market risks. China’s response reflects pronounced aversion to extreme outcomes: policymakers have imposed strict controls on both MLT contracting and provincial spot markets to stabilise expectations and maintain public confidence. Those controls limit extreme fluctuations but weaken short-run price signals and the ability of wholesale prices to reflect underlying supply–demand conditions.

Administrative guidance over MLT contracting is one principal channel. Contract volumes and prices remain relatively rigid: generators and consumers face administratively guided minimum contracting requirements as a condition for participation (for example, coal-fired generators must secure at least 80% of the previous year’s actual generation in annual contracts, with cumulative requirements reaching 90% when monthly and intra-month cycles are included [96]), and prices are commonly linked to benchmark coal-fired tariffs within a $\pm 20\%$ band [79].

Spot markets are similarly bounded as shown in Figure 4. Foreign ceilings remain materially higher than typical Chinese

provincial limits in nominal USD terms, even where complementary mechanisms constrain extreme scarcity prices. Examples include NEM’s wide ordinary band and its 600 AUD/MWh administered cap after a cumulative threshold breach, and the wider Single Day-Ahead Coupling (SDAC) band in Europe. Purchasing power and input-cost differences nevertheless preclude direct welfare comparisons. The salient contrast is therefore the width of caps and the complementary governance applied when prices move. Hybrid architectures elsewhere typically combine relatively wide scarcity-price bands with bid validation, cost verification, market-power surveillance, competition enforcement, and penalties for violations, so large price movements are possible in principle but policed *ex ante* and *ex post* [97]. China sits further towards the administrative-stabilisation end of that continuum: it combines guided MLT trade with the narrowly bounded provincial bid price limits in Figure 4 to suppress many extreme wholesale market outcomes at the design stage. Price-spike concerns are universal, but systems with stronger disclosure, surveillance, and competition enforcement can rely more on *ex post* oversight (for example, Australia’s NEM); others place greater weight on *ex ante* constraints (for example, China). NEA and its regional offices supervise market order, registration, and disclosure under the revised *Measures for Supervision of the Electricity Market* and related rules; the State Administration for Market Regulation applies general antitrust and fair-competition law to undertakings in marketised segments. Rules have strengthened since 2024 [98], but provincial disclosure, surveillance, and visible competition casework still lag mature organised markets, leaving narrow caps and guided MLT prices as important complements.

Wholesale controls sit within a broader stabilisation architecture: residential, agricultural, and public-welfare loads re-

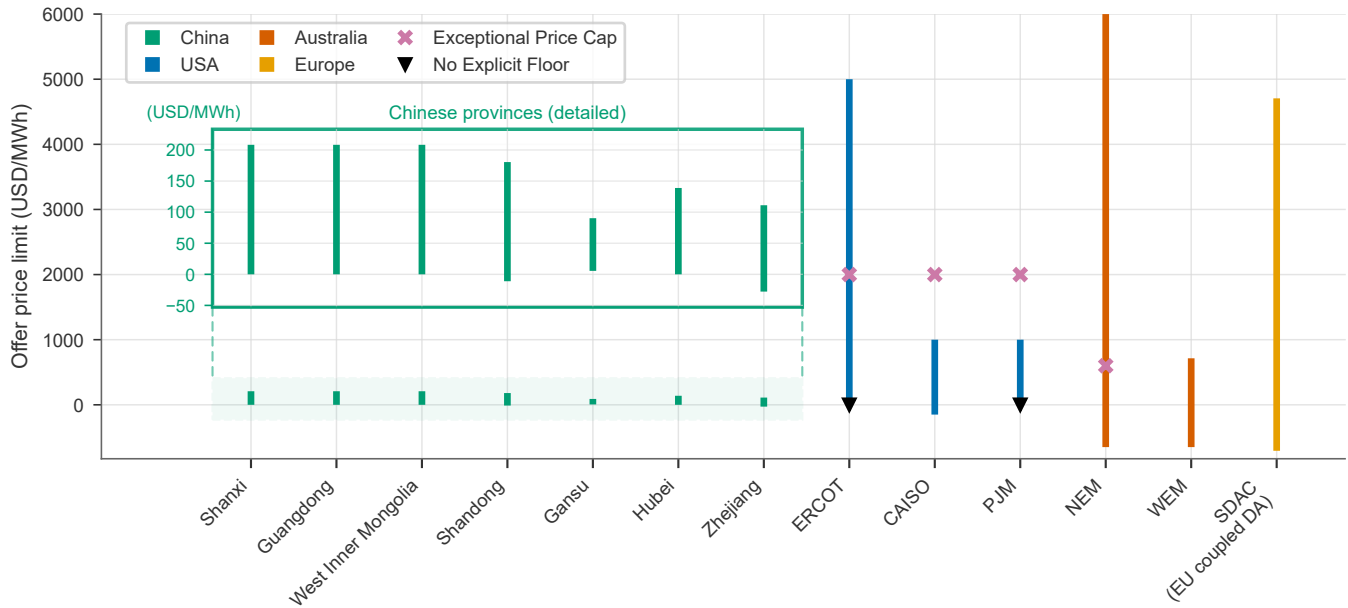


Figure 4: Wholesale energy bid price limits in Chinese provincial and selected international markets (USD/MWh), converted at approximate average exchange rates (CNY:USD=7.2:1, AUD:USD=1.54:1, EUR:USD=0.85:1). The bars refer to wholesale energy products only: provincial spot energy in China, day-ahead and real-time energy in North America and Australia, and coupled energy under the Single Day-Ahead Coupling (SDAC). Many wholesale market rules distinguish bid limits from clearing limits; in some markets the two bands differ numerically, though usually only modestly (e.g. Shandong bid limits -80 to 1,300 CNY/MWh versus clearing limits -100 to 1,500 CNY/MWh). The figure focuses on bid-side limits as the primary comparison metric. The main vertical axis is truncated at 6,000 USD/MWh; NEM's nominal market price cap after conversion ($\approx 13,200$ USD/MWh) is marked above the truncated bar. Chinese provincial limits are shown in an inset magnifying the lower band on a linear USD/MWh scale; for most North American and Australian energy markets, day-ahead and real-time bid limits coincide on the plotted values, and PJM and ERCOT have no explicit bid floor (0 USD/MWh is shown for illustration). The European comparator is the Single Day-Ahead Coupling (SDAC): the SDAC bar reports harmonised maximum and minimum clearing prices (HMMCP); although defined as clearing limits, the same band governs admissible day-ahead bids in participating bidding zones such as France, Germany, Spain, Italy, and the Nordic markets. Chinese provincial spot bids are generally capped at no more than 1.5 CNY/kWh (approximately 208 USD/MWh), with floors typically at zero; for inter-provincial spot trade, the bid floor is zero and the ceiling is twice the exporting province's upper limit (not shown). Crosses labelled "Exceptional Price Cap" denote jurisdiction-specific limits that apply conditionally or after validation and differ from the ordinary bid band, as detailed below. Most North American and Australian markets allow substantially wider bid ranges, usually alongside additional mechanisms to manage extreme outcomes:

ERCOT: When the Peaker Net Margin (PNM) exceeds three times the Cost of New Entry (CONE), the System-Wide Offer Cap (SWCAP) is lowered to \$2,000/MWh to limit extreme shortage pricing;

CAISO: Standard energy bid limits are \$1,000/MWh (upper) and \$-150/MWh (lower) for both day-ahead and real-time markets; bids above \$1,000/MWh are subject to cost verification, with a hard cap at \$2,000/MWh;

PJM: Bids exceeding \$1,000/MWh require validation; unverified bids are automatically capped at \$1,000/MWh;

NEM: Under normal operation the market allows a wide offer band (market price cap on the order of 20,300 AUD/MWh before USD conversion); if spot prices over a rolling period cumulatively exceed the cumulative price threshold, the market enters an administered pricing period in which the administered price cap applies at 600 AUD/MWh until the period ends.

main largely on government catalogue tariffs, while mandatory MLT contracts cover most volume at guided prices and spot markets chiefly clear residual imbalances. Short-lived wholesale spikes therefore need not move most end-user tariffs. Uneven transparency over provincial clearing outcomes nevertheless obscures the wholesale-retail linkage in published data, and narrow caps do not eliminate market-power concerns where generation remains concentrated and enforcement is still developing.

Taken together, China's approach has limited extreme volatility and insulated most end-user tariffs, at the cost of weaker allocative price signals. Pure energy-only markets are rare in practice; the more relevant contrast is with hybrid architectures that tolerate wider wholesale bands while relying on capacity, contract, and enforcement layers to manage tail risk. China places greater weight on ex ante administrative stabilisation.

Recent policy developments nevertheless indicate a gradual shift towards relaxing administrative constraints and enhancing market-based price formation. For 2026 MLT contract signing, a notice issued in December 2025 relaxes mandatory contracting ratios for generators and consumers to a 70–80% baseline across trading cycles, down from the 90% cumulative levels applied under earlier guidance, with provisions for seasonal adjustment [99]. National MLT basic rules require prices to be formed by market participants without third-party intervention [100], while retaining authority to set bid and clearing limits and easing, without repealing, the nationally mandated benchmark-linked $\pm 20\%$ band. These changes suggest an evolving balance between risk control and market vitality as China's power market matures, though provincial rules for 2026 trading in Guangdong [101], Shanxi [102], Jiangsu [103], Shaanxi [104], Ningxia [105], and Guangxi [106] indicate substantial near-term continuity in benchmark-linked bands and re-

lated arrangements.

4.2. *Technology-Specific versus Product-Based Participation Rules*

Energy storage, demand response, and VPPs face lagging or unclear participation models under high renewable penetration. This subsection contrasts *product-based* access, where participation follows deliverable requirements for energy, ancillary-service, capacity, or demand-response products, with *resource-category* access, where rules are organised first around entity types such as storage enterprises or VPP operators.

China's national guidance grants equal standing to new-type entities, including storage and VPP operators [109, 110], but provincial implementation remains predominantly resource-category-first. Capability, settlement, and market access therefore hinge primarily on entity registration and certification rather than on qualification against a unified flexibility product. Provincial rulebooks typically establish separate participation chapters for storage, VPPs, and other emerging resources, reflecting a governance logic centred on identifiable resource categories.

This differs from many organised wholesale markets, where participation is more commonly defined through products or participation models. FERC Orders 841 and 2222 illustrate product-oriented access for storage and aggregated distributed resources, while remaining barriers arise chiefly from bid formats, qualification requirements, and settlement arrangements within those frameworks [52, 54, 55]. Great Britain (GB) offers a single-jurisdiction comparator: Ofgem clarified in 2020 that electricity storage is licensed under the generation licence rather than through separate storage-specific market rulebooks [108]; wholesale and balancing participation then follows Balancing and Settlement Code (BSC) roles and product or settlement arrangements rather than parallel entity-type chapters. EU-level rules likewise frame storage and aggregation within a product-oriented Internal Electricity Market architecture [115, 116], but national transposition and access detail differ widely across member states; we therefore do not expand those country-specific arrangements here. As shown in Table 1, the contrast is not whether emerging resources participate, but whether participation is organised primarily around products or around resource categories.

The resource-category-first approach is administratively tractable: regulators can introduce storage and VPP rules without first harmonising cross-technology products and can adapt requirements to uneven metering, unit-based spot pilots, and provincial objectives. It also assigns renewable integration, demand response, peak shaving, and deployment targets to identifiable entity classes.

The structural trade-off is that targeted deployment incentives may weaken technology neutrality, reinforce provincial differences, and delay integrated flexibility products as resources become more heterogeneous. Although national guidelines broaden participation [117], the near-term pathway remains category-based; fuller neutrality requires more harmonised attribute- or flexibility-based rules.

4.3. *Planning–Market Disconnection: “Conceived by Government, Nurtured by Market”*

Managing the planning–market relationship under high renewable penetration is a common challenge across hybrid architectures. Long-run adequacy has always drawn on a mix of wholesale market outcomes, capacity arrangements, and planning mandates; high renewable penetration makes it harder to align these instruments and timelines.

In China's reform, long-run resource adequacy remains anchored primarily in government-led capacity planning and project approval, while wholesale and retail markets chiefly operationalise dispatch and cost recovery for capacity already in the system, with limited feedback from wholesale market outcomes into approval and investment decisions. Chinese industry commentary summarises this division as “conceived by government, nurtured by market” [118]: capacity is conceived through planning and approval, while generators must operate in markets to recover costs and earn returns. The same broad logic, whereby long-lived capacity is fixed through upfront authorisation while operational layers recover costs through market or regulated settlement, is familiar across much public infrastructure; in China's electricity sector it is combined with planning-led coordination, concentrated state ownership, and still-developing wholesale institutions.

Many OECD electricity systems exhibit a related separation, in which energy and ancillary-service markets primarily coordinate short-run operation and limited entry while long-run generation mix, network investment, and reliability continue to rely on planning, regulated procurement, and system-operator governance [65]. California load-serving entities, for example, must meet resource adequacy showings through advance contracting and compliance processes [119, 120] within an integrated resource planning framework that shapes regulated procurement portfolios, while actual capacity additions remain decentralised investment decisions by predominantly private generators. China's wholesale and retail markets play a broadly analogous operational role, dispatching and settling capacity largely approved elsewhere, but administrative planning and approval remain more decisive for entry and siting; both cases rely on hybrid coordination, with China placing greater weight on upfront administrative approval and state-owned investment channels and established systems often combining planning mandates with stronger wholesale and contract signals for locational and technology choices. California nevertheless lies towards the more administratively coordinated end of the U.S. spectrum: ERCOT relies more heavily on scarcity pricing for adequacy, while capacity-market jurisdictions retain competitive procurement within their reliability frameworks [40, 65].

Structural concentration and state-owned enterprise (SOE) consolidation underpin this pattern. Since the early-2000s round of state-sector reform, official guidance has stressed reorganising and strengthening existing state capital rather than breaking up large incumbents in pillar industries [121, 122]. Recent official commentary similarly stresses accelerating strategic restructuring and specialised integration among state-owned enterprises [123]. Electricity supply illustrates this

Table 1: Product-oriented versus resource-category-first access logic (illustrative). Organised wholesale markets typically treat the market product or participation model as the primary rulebook axis; the Chinese provincial samples instead organise access around entity categories. Columns A–C code ✓ for features explicit in primary rules or official interpretation and ◦ for partial or non-dominant features; rows are illustrative and not directly comparable cell-for-cell. Column A marks whether deliverable products or participation models primarily define access; column B marks parallel rule chapters keyed to entity types; column C marks category-based registration or certification as a market-access gate. International rows draw on Federal Energy Regulatory Commission (FERC) Order 841 implementations (CAISO, PJM), ERCOT energy-storage-resource protocols, Australian Energy Market Operator (AEMO) NEM integrated-resource-provider registration [107], and Great Britain (GB) generation-licence clarification for storage [108]. National Chinese rows reflect NEA/NDRC guidance on new-type entities and MLT trading [109, 100, 110]; provincial rows reflect Shandong 2026 market rules with parallel storage and VPP registration chapters [111], Gansu rules classifying power-, load-, and mixed-type operators [112], Shanxi rules distinguishing market-type from response-type VPPs [113], and Zhejiang VPP rules [114]. The national row marks ◦ for all three columns because unified product pathways remain limited at the central level; provincial implementation is richer in columns B and C for the sample provinces.

Jurisdiction	Dominant access axis	A. Access via product or participation model	B. Parallel entity-type rule chapters	C. Category-based registration gate
<i>International (illustrative)</i>				
CAISO (FERC Order 841)	Product-oriented	✓	◦	◦
PJM (FERC Order 841)	Product-oriented	✓	◦	◦
ERCOT (storage protocols)	Product-oriented	✓	◦	◦
AEMO NEM	Product-oriented	✓	◦	◦
GB (generation licence)	Product-oriented	✓	◦	◦
<i>China</i>				
National (93, 357, 1656)	Resource-category-first	◦	◦	◦
Shandong 2026 market rules	Resource-category-first	◦	✓	✓
Gansu VPP rules	Resource-category-first	◦	✓	✓
Shanxi VPP rules	Resource-category-first	◦	✓	✓
Zhejiang VPP rules	Resource-category-first	◦	✓	✓

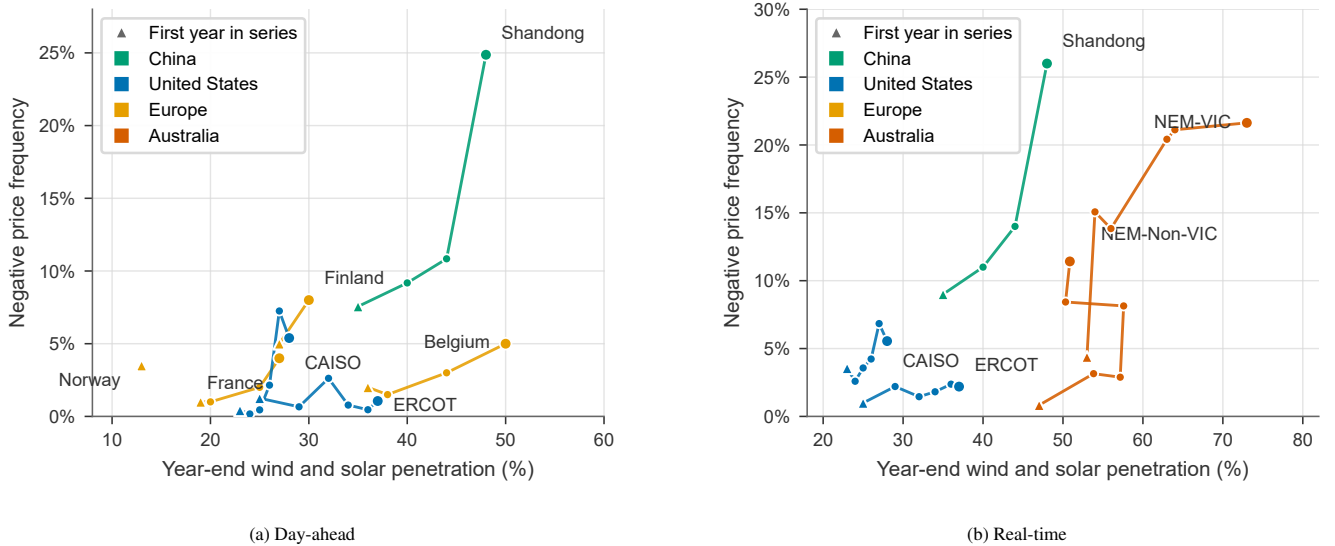


Figure 5: Negative price frequency versus year-end wind and solar penetration (2020–2025). Each point is one calendar year; lines connect consecutive years within each region, with a triangle marking the first year. Start years differ by market according to data availability (from 2020 for CAISO, ERCOT, and NEM; 2022 for Shandong; and 2020–2024 for European day-ahead markets in panel (a)). Where 2025 appears, the observation covers January–June only. Panel (a) covers day-ahead markets for Finland, Norway, Belgium, France, Shandong, CAISO, and ERCOT; panel (b) covers real-time markets for NEM (Victoria and non-Victoria), Shandong, CAISO, and ERCOT. Direct cross-market comparison is illustrative: the panels mix zonal day-ahead, nodal, and provincial uniform spot prices, differ in market size and interconnection, and use non-comparable price aggregates. Colors follow the regional grouping in Figure 4.

tendency at the provincial level, where generation ownership remains highly concentrated. In Zhejiang, for example, thermal capacity owned by Zhejiang Provincial Energy Group Company Ltd. accounts for roughly 50% of total provincial thermal capacity, while the four largest thermal generators exceed 80% combined; all are SOEs under central or provincial ownership. Through state asset supervision and enterprise hierarchies, authorities can translate planning and approval decisions into capacity outcomes with relatively high certainty even

when wholesale signals are weak. A related systemic risk is overbuilding under state direction: when approval pathways and state-owned investment can add capacity with limited reliance on wholesale scarcity signals, expansion may run ahead of demand growth, grid accommodation, and market institutions needed to coordinate dispatch and revenues, a tension that intensifies when overlapping national and provincial build targets for renewables, coal, and storage proceed in parallel.

Planning-led coordination can align deployment targets, ap-

provals, grid accommodation, and preferential finance while wholesale investment signals play a secondary role. This approach, supported by state-owned investment, enabled China to reach its 2030 target of 1,200 GW of wind and solar by July 2024, well ahead of the original schedule.

The limitations remain visible despite this success in scale. In Shanxi and Shandong, among the first formal provincial spot markets, misalignment has appeared in frequent negative or near-zero prices. Even after accounting for renewable revenue support, limited pass-through of spot prices to demand-side tariffs, and other influences on negative-price formation, recurring negative prices still suggest that incremental renewable output is exceeding local willingness-to-pay and flexibility at the margin. Figure 5 shows wide variation in negative-price incidence across markets, though direct comparison remains illustrative for the reasons noted in the caption. Even so, recurring negative prices indicate local marginal surplus. Planning-led expansion and stabilised mechanism-price revenues weakly transmit these spot signals into approval and investment, allowing renewable deployment programmes to continue while national deployment priorities remain unchanged.

5. Discussion: Convergent Challenges, Divergent Institutions

This section synthesises the institutional narrative above against the international challenge baseline, asking where Chinese arrangements echo global hybrid responses and where they occupy a distinct position on the shared governance continuum. Table 2 provides an illustrative summary map across six design dimensions; the subsections that follow examine the revenue, flexibility/adequacy, and seam themes in more detail.

Three themes organise the discussion that follows: long-term revenue arrangements, emerging system attributes, and market seams.

5.1. Design of Long-Term Contracts for Renewable Energy

Recovering fixed and capital costs through energy-only market revenues undermines revenue adequacy and long-term investment incentives for both conventional and renewable generators. In principle, addressing this issue may require a fundamental rethinking of market paradigms built on marginal pricing [128]. In practice, however, most jurisdictions have so far relied on incremental, add-on mechanisms that supplement or repair existing market frameworks rather than replacing them entirely. For conventional generators, revenue adequacy concerns have been widely addressed through capacity payments, capacity markets, reliability options, and other forms of revenue support. China also outlined a national-level policy framework for the coal-fired generation capacity price mechanism in late 2023, leaving detailed design and implementation to provincial markets under central guidance [129]. Yet revenue adequacy challenges increasingly affect renewable generators themselves, which is the focus of this subsection.

In China, concerns over renewable revenue adequacy have emerged alongside the gradual withdrawal of policy subsidies.

Under earlier policy regimes, renewable revenues were largely guaranteed through administratively determined payments, and profitability was rarely in question. As market reforms have deepened, such subsidies have been increasingly viewed as distortionary to price formation, and policy direction has shifted towards requiring renewable generators to rely more on market-based revenues. A critical turning point occurred in January 2025, when NDRC and NEA issued Document No. 136, mandating the full participation of renewable generation in electricity markets. China therefore introduced the Renewable Energy Sustainable Development Price Settlement Mechanism, built around “mechanism electricity volumes” and “mechanism prices”, to support sustainable renewable development as subsidies are phased down and market participation expands. Under this framework, eligible renewable projects may designate a share of their expected generation as mechanism electricity, which is settled at an administratively defined mechanism price [15]. Functionally, this arrangement resembles a CfD scheme: when market prices fall below the mechanism price, the revenue gap is ultimately allocated among commercial and industrial consumers; when market prices exceed the mechanism price, projects are settled at the mechanism price or are required to share excess revenues, which are similarly redistributed to commercial and industrial consumers in accordance with policy rules.

Comparable approaches can be observed internationally. The United Kingdom has long relied on CfD to support renewable deployment, and its CfD framework includes a Negative Pricing Suspension Mechanism to prevent unreasonable payments during periods of extreme negative prices. More broadly, integrating renewable generators into capacity adequacy mechanisms has been explored as a means of stabilising revenues, potentially offering a more technology-neutral and competitively balanced solution.

China’s mechanism electricity and mechanism price arrangements represent a transitional response to subsidy phase-out and deeper market liberalisation, in line with the gradualist reform logic outlined above. While initially conceived as a bridging mechanism, such arrangements may evolve into a more enduring component of China’s electricity market architecture as renewable penetration continues to rise.

5.2. Flexibility and Reliability Assessments: Addressing the Incomplete Market

Maintaining system reliability and operational flexibility has become increasingly critical under high renewable penetration. Globally, how to systematically identify, classify, and quantify emerging system attributes and translate them into well-defined market products remains an open question in electricity market design.

Resource adequacy (RA) constitutes one important dimension of power-system reliability. Hybrid architectures elsewhere pursue adequacy through capacity markets, resource-adequacy obligations, or reliability options layered onto energy markets. In China, the scale and location of new capacity remain set primarily through top-down planning and state-owned

Table 2: Illustrative comparison of selected wholesale-market design features under high renewable penetration. Entries are stylised summaries of the mechanisms discussed in the text, not exhaustive rule inventories; variation within the United States and European Union (EU) is compressed. “AEMO NEM” denotes the National Electricity Market operated by the Australian Energy Market Operator. Great Britain (GB) is shown separately because it ceased participating in the Single Day-Ahead Coupling (SDAC) and Single Intraday Coupling (SIDC) after the Brexit transition period [124]. The comparison draws on the jurisdiction-specific sources cited in Sections 4–5 and official European and Australian rules [125, 126, 127].

Dimension	China	GB	EU coupling	U.S. organised markets (illustrative)	AEMO NEM
Reform sequencing	Mandatory MLT contracting before provincial spot pilots	2001/2005 wholesale reforms before the 2013 CfD and Capacity Market package	National markets before progressive day-ahead and intraday coupling	Organised spot markets before later adequacy overlays in some regions	Gross-pool spot clearing before extensive financial contracting matured
Wholesale price boundaries	Narrow provincial caps; guided MLT bands	Exchange and balancing-market limits; outside SDAC/SIDC	Common SDAC/SIDC limits across participating zones	Generally wider caps; operator-specific mitigation	High ordinary cap; administered cap after cumulative threshold
Resource adequacy / capacity	Planning-led entry; regulated capacity prices; no competitive capacity market	National Capacity Market	National adequacy arrangements alongside coupled energy trading	Capacity markets, resource-adequacy obligations, including flexible requirements, or energy-only scarcity pricing	Energy-only spot design plus reliability and investment settings
Renewable long-term revenue	Mechanism electricity/prices; FiT and subsidy phase-down	CfDs and related support	National support alongside coupled trading	PPAs, state programmes, and certificates	Certificates and contracts alongside spot exposure
Flexibility / attribute products	Limited pilots; category-based storage and VPP access	Balancing and stability products; storage licensed as generation	EU product framework; national access rules	Ramping products; federal storage and aggregation models	Frequency-control services; technology-specific registration
Cross-border / seam coordination	Unified-market agenda; incomplete inter-provincial coordination	Border-specific interconnector arrangements outside SDAC/SIDC	SDAC/SIDC link zones while national institutions remain	Separate markets with eastern seam and western market coordination	Five interconnected price regions under one NEM framework

investment. Complementary to this planning-led adequacy, policymakers have introduced regulated capacity compensation before competitive capacity markets. The national coal-fired capacity price mechanism outlined above [129] is an administratively guided revenue instrument for existing coal units rather than a market auction for new entry. More recent State Council implementation opinions call for further improving regulated capacity-price mechanisms for coal, pumped hydro, and storage, support eligible regions in exploring competitively determined capacity prices, and envisage exploring a capacity market “when conditions are mature” [130]. Several provinces are studying capacity-market or capacity-pricing arrangements in line with this guidance, but none has yet implemented a full competitive capacity market comparable to PJM or ISO-NE.

Beyond long-term adequacy mechanisms, international markets have also pursued exploratory approaches to operational flexibility and other scarcity attributes required for reliable real-time system balancing. Representative examples include CAISO’s Flexible Ramping Product and MISO’s Ramp Capability Product; inertia and stability mechanisms such as the Stability Market operated by the UK National Grid Electricity System Operator (ESO); and fast frequency response in ERCOT and the Australian NEM. China has also begun to explore similar mechanisms, albeit to a more limited extent; one notable example is Shandong Province, where ramping ancillary services have been introduced and subsequently incorporated into the joint clearing framework of the provincial spot market.

Currently, mechanisms that explicitly value operational flexibility and other scarcity attributes remain a lower priority in China, as evidenced by the relatively small number of pilots and attribute-specific products. Regulatory effort has centred on expanding market coverage, improving end-user price pass-through, and advancing national market unification, leaving limited institutional space for systematic attribute valuation. Yet balancing pressures under high renewable penetration are already material. Flexibility and reliability are practical system needs, not abstract future concerns, and China’s still-evolving institutions may offer an opportunity to integrate attribute valuation earlier rather than rely solely on successive add-ons.

5.3. Expanding and Integrating Markets: Toward a National Unified Electricity Market

Under high renewable penetration, efficient coordination across market seams, namely provincial boundaries, regional operating zones, and interfaces between grid operating models, matters increasingly for balancing and resource sharing. Mature systems confront similar seam problems; in practice, market-based seam coordination remains incomplete almost everywhere, so the comparison turns on institutional form and degree of progress.

Many mature markets face a similar tension between local autonomy and regional coordination, often through cross-border or multi-state market coupling rather than nationwide administrative unification. In Europe, the Single Day-Ahead

Coupling (SDAC) and Single Intraday Coupling (SIDC) allocate cross-zonal capacity through common coupling arrangements while national bidding zones and institutions remain in place [131]. In the United States, strong state authority and local protectionism have impeded formal cross-state market mergers, leaving seven organised markets (PJM, MISO, ERCOT, CAISO, SPP, NYISO, and ISO-NE) largely separate [132]. Coordination has instead developed through partial, seam-specific arrangements. At major eastern interfaces, markets rely on bilateral joint operating agreements (JOAs) and market-to-market (M2M) coordination; an optional PJM–MISO Coordinated Transaction Scheduling (CTS) interchange product saw persistently low use and is now slated for retirement [133, 134]. Western seams have pursued a related path of functional integration without full regional transmission organization (RTO) consolidation, notably CAISO’s Western Energy Imbalance Market (WEIM) and Extended Day-Ahead Market (EDAM) and SPP’s Markets+ [135, 136, 137]. Across these European and U.S. cases, wider geographic coordination can improve balancing and resource sharing, but the comparison indicates that enlarging a dispatch footprint is not equivalent to achieving fully integrated governance or settlement.

For China, the policy push towards a national unified market likewise points to wider area coordination, but the binding constraint is whether inter-provincial integration will impose comparable market discipline or remain largely procedural. China’s national market has made substantial progress towards unification, yet integration across provincial boundaries remains challenging. Inter-provincial barriers largely stem from provincial-level operating entities responsible for planning, dispatch, and balancing within administrative boundaries; provincial governments retain substantial autonomy in constructing local markets despite top-level guidance. Additional tensions exist between the two major grid operators: China Southern Power Grid employs a “Joint Clearance and Operation” model, whereas the State Grid follows a “Layered and Tiered Operation” approach. While the two grids have achieved a degree of coordination through negotiated rule alignment [138], this coordination remains limited in scope and primarily procedural, with substantial barriers still constraining deep, efficient market integration.

The international arrangements above are instructive but do not constitute a benchmark of complete institutional integration: European coupling retains national bidding zones and institutions, while U.S. organised markets remain separate outside specific western platforms and eastern seam arrangements. China’s inter-provincial integration faces analogous limits in practice: provincial planning and dispatch autonomy, dual-grid operating models, and coordination that is still largely procedural rather than competitively market-disciplined. National rhetoric towards a unified market nonetheless continues to outpace market-based cross-provincial coordination on the ground. The open question is not whether China lags a fully integrated benchmark, which scarcely exists abroad, but whether procedural unification will evolve into the competitive settlement and price exposure that western coupling models also require to deliver efficiency gains. These constraints partly reflect reform sequencing: China has prioritised workable provincial and re-

gional markets first, while treating deeper cross-seam harmonisation as a longer-run goal.

5.4. Implications for Power-Market Reform in Developing Countries

The comparison also offers broader implications for developing countries that are building wholesale institutions while expanding electricity access and renewable supply. China’s experience shows that reform sequencing is shaped jointly by inherited physical systems, governance arrangements, and system scale. Against this background, the discussion below identifies considerations for diagnosing feasible and durable reform paths under different national and regional conditions.

First, physical conditions delimit what a market can credibly coordinate. Although infrastructure has not been treated above as a separate design theme, it underlies much of the analysis. U.S. seam coordination, for example, remains constrained by insufficient transfer capability and congestion [139]. In China, extensive long-distance transmission means that physical transfer capability does not emerge from this review as the principal obstacle to wider integration; the analysis consequently focuses more on provincial planning, dispatch, and settlement coordination. The balance between physical and institutional constraints will differ across systems. In many developing systems, reliable networks, dispatch, communications, metering, and settlement remain prior conditions for deeper short-term trading or differentiated scarcity and flexibility products. These prerequisites are especially salient in Sub-Saharan Africa [140].

Second, reform durability depends on whether institutions remain workable as system conditions and policy priorities evolve. The evolving interfaces among energy trading, adequacy, network coordination, and policy objectives in both the Chinese and international cases make durability difficult to infer from formal adoption or institutional form alone. A practical assessment should therefore ask whether rules are executable, payment chains credible, investment commitments financeable, and responsibilities sufficiently clear in practice. The allocation of affordability, reliability, cost recovery, and investment risk among governments, firms, and consumers also shapes feasible reform sequencing. In developing systems, considerations shaping this choice can include limited familiarity with hedging instruments, uncertainty about the effectiveness of market-power mitigation, and the political difficulty of exposing consumers to volatile prices; together, these factors may lead policymakers to favour more tightly bounded and gradual reforms while institutional capability and confidence develop. The broader implication is to align market architecture with objectives, administrative capability, and institutional continuity, while recognising that a durable balance cannot be specified in advance or assumed to follow a predetermined sequence [141].

Third, the relevance of a standard market-design template does not imply a uniform implementation pathway: reform still needs to be adapted to local conditions. China’s experience shows that widely recognised reform elements, including those identified in established templates [142, 93], can be pursued through different sequences and institutional arrangements. Market integration illustrates this distinction. A smaller

country may begin with a nationally covering market and encounter its most consequential seam at an international border; a large federal or administratively segmented system may first confront domestic seams. Cross-border trade requires transmission, compatible operating and settlement rules, payment security, and durable coordination, while also raising questions of sovereignty and security of supply [143, 144, 145]. European coupling provides one possible reference: cross-border allocation has deepened while national institutions remain, although each region must resolve the underlying conditions in its own setting. The potential gains from integration may be general; the relevant geographic scale, institutional route, and coordination of market outcomes with planning and reliability requirements remain matters for case-by-case diagnosis.

The resulting implication is disciplined differentiation. Market depth, reform sequence, and performance criteria should be matched to binding physical constraints and to the governance arrangements needed to make a selected path durable. Access, reliability, cost recovery, investment mobilisation, and enforceable exchange may therefore be as informative as price convergence or trading volume when assessing progress.

6. Conclusions and Future Directions

6.1. Contributions

Existing studies have examined the 2015 reform package, institutional change, reform progress, and individual spot pilots from different perspectives [16, 18, 20, 85, 87]. Building on that literature, this review's contribution is an integrative account of how market design is being shaped by the dual challenge of institutional reform and high renewable penetration, including developments after 2022. It establishes a shared international challenge baseline, identifies two foundational Chinese drivers—the instrumental use of markets and the priority given to end-user price stability and reform acceptability—and traces three design responses: strict wholesale price control, resource-category-first participation rules for emerging flexibility providers, and planning-led adequacy summarised as “conceived by government, nurtured by market”.

6.2. Implications

Comparative discussion then locates China on a hybrid governance continuum without assuming convergence on a single internationally recognised wholesale template. The principal implication is continued structured divergence: reform is likely to combine planning-led adequacy, administrative revenue bridges, provincial pilots, and selectively deepened spot and contract institutions. These layers may use success criteria that differ from efficiency-centric norms, yet they resemble capacity, contract, and planning supplements already common abroad. Analytical tools should therefore evaluate renewable integration, reliability, and cost allocation across hybrid architectures, including whether price control and guided contracting can support more credible wholesale signals, whether category-based access can evolve towards clearer flexibility products, and whether inter-provincial coordination can progress from

procedural unification to competitive settlement and price exposure. Low-carbon systems also require stronger coordination of variable supply and demand through more responsive pricing, deeper quantity coordination, or a workable combination of the two. For developing systems, the broader lesson is to match market depth, reform sequencing, and integration strategies to physical prerequisites, institutional capacity, and local governance conditions.

6.3. Limitations and reform uncertainties

These claims should be read within clear framework limitations. The review is an institutional and design synthesis, not a causal evaluation: it cannot identify treatment effects of specific provincial rules on prices, curtailment, or investment. A national narrative necessarily compresses heterogeneous provincial implementations and still-evolving local rulebooks. Evidence is drawn chiefly from public policy documents, trading-centre disclosures, and secondary literature, so gaps in comparable volume, contract-horizon, and seam-performance statistics constrain what can be asserted. International comparisons are used to position arrangements on a shared continuum, not as full institutional audits of every comparator market. Finally, the scope centres on wholesale institutions and planning–market interfaces; retail tariff detail, carbon-market coupling, and broader sector coupling enter only where they shape those interfaces.

Future reform trajectories remain uncertain even where policy states a direction of travel. Key uncertainties concern how far mandatory MLT ratios and narrow provincial price bounds will be relaxed; how provincial implementations of mechanism electricity and mechanism prices under Document No. 136 will evolve; whether the national unified-market agenda will produce more market-based inter-provincial settlement; and whether regulated capacity prices and limited flexibility pilots will develop into more explicit adequacy and attribute products. These are reform uncertainties, not predictions: outcomes will depend on subsequent national rules, provincial implementation, distributional priorities, and the performance of existing pilots.

6.4. Future research directions

Future research should examine how hybrid power-market arrangements perform when price formation, contracting, resource adequacy, and investment remain jointly shaped by market and administrative coordination. China provides a distinctive setting because provincial spot markets operate alongside guided MLT contracting, planning-led adequacy, regulated capacity prices, and renewable revenue-stabilisation mechanisms, while inter-provincial market integration remains incomplete.

Several priorities follow from the analysis. First, causal evidence is needed on how planning–market interfaces and bounded spot prices affect dispatch, curtailment, price formation, and investment across provinces with different resource mixes and stages of market development. Second, national market unification should be evaluated against operational outcomes using comparable measures of cross-provincial transfers, transmission utilisation, price convergence, and settlement

exposure, rather than rule alignment alone. Third, the welfare, investment, and risk-allocation effects of mechanism electricity and mechanism prices under Document No. 136 require systematic ex post evaluation as implementation develops. Further work should also assess whether category-based access for storage, demand response, and virtual power plants evolves into clearer product-based valuation of flexibility. Comparative analysis across provinces can help distinguish formal rule adoption from operational effects and clarify which findings reflect China's institutional setting and which travel more broadly across hybrid market architectures.

Appendix A. Major Policy Documents of China's Power Market Reform (2015–2026)

This appendix summarises the key high-level policy documents issued by the Chinese central government and national ministries. These policies constitute the regulatory framework for the transition towards a national unified electricity market and a high-renewable power system. The chronology is current through February 2026.

Selection criteria for Table A.3: (i) *National scope*: top-level central documents only; (ii) *Market focus*: instruments governing market structure, trading, and pricing; (iii) *Completeness*: compiled from publicly available sources and may omit some instruments; (iv) *Policy titles*: most are author translations, consistent with the main text, as many instruments lack widely used official English titles.

Table A.3: Comprehensive Chronology of National-level Power Market Reform Policies (2015–2026)

Date	Policy Title and Source No.	Key Objectives and Impacts
2015-03	Several Opinions on Further Deepening the Reform of the Electric Power System (Zhongfa (2015) No. 9)	Sets overall reform orientation; the usual marker for the launch of the current reform round.
2015-11	Notice on Issuing Supporting Documents for Power Sector Reform (Fagai Jingti (2015) No. 2752)	A joint NDRC–NEA notice with six annexes: (1) transmission and distribution tariff reform; (2) power market construction; (3) trading institutions; (4) orderly generation/consumption plan release; (5) retail-side reform; (6) captive coal plants (guidance). These are implementation opinions/guidance that elaborate the 2015 orientation rather than detailed market rules.
2016-10	Notice on Issuing Measures for Retail Company Access and Exit and Measures for Incremental Distribution Reform (Fagai Jingti (2016) No. 2120)	Standardised market entry/exit for retail companies and incremental distribution reforms.
2016-12	Notice on Issuing the Interim Basic Rules for Power Medium- and Long-term Trading (Fagai Nengyuan (2016) No. 2784)	Established a national framework for medium- and long-term electricity trading (interim rules), laying the foundation for market-based power trading.
2017-04	Notice on Orderly Liberalising Generation and Consumption Plans (Fagai Yunxing (2017) No. 294)	Progressively reduced planned electricity volumes and expanded the scope of market-based trading.
2017-08	Notice on Launching Electricity Spot Market Construction Pilot Work (Fagai Ban Nengyuan (2017) No. 1453)	Launched the first batch of eight provincial electricity spot market pilots.
2017-11	Notice on Piloting Market-based Trading for Distributed Generation (Fagai Nengyuan (2017) No. 1901)	Launched pilots allowing distributed generation to trade directly or through grid-facilitated arrangements.
2017-11	Notice on Issuing the Work Plan to Improve Compensation (Market) Mechanisms for Electricity Ancillary Services (Guoneng Fa Jianguan (2017) No. 67)	Set a three-stage national roadmap for broader service coverage and more competitive ancillary-service procurement.
2018-07	Notice on Actively Promoting Improvements to Electricity Market Trading (Fagai Yunxing (2018) No. 1027)	Expanded market-based trading and standardised MLT and user entry procedures.
2019-05	Notice on Establishing a Renewable Energy Electricity Consumption Guarantee Mechanism (Fagai Nengyuan (2019) No. 807)	Established provincial renewable-electricity consumption responsibility weights and associated assessment arrangements.
2019-06	Notice on Fully Liberalising Generation and Consumption Plans for Commercial Operating Power Users (Fagai Yunxing (2019) No. 1105)	Principles for fully liberalising generation/consumption plans for commercial and industrial users.
2019-08	Opinions on Deepening Electricity Spot Market Pilot Development (Fagai Ban Nengyuan Gui (2019) No. 828)	Deepened the first pilots and strengthened coordination between medium- and long-term and spot markets.
2019-10	Guidance on Deepening the Market-oriented Pricing Mechanism for Coal-fired On-grid Tariffs (Fagai Jiage (2019) No. 1658)	Established a market-oriented pricing mechanism for coal-fired power based on a benchmark price with floating bands.
2020-06	Notice on Issuing the Basic Rules for Power Medium- and Long-term Trading (Fagai Nengyuan Gui (2020) No. 889)	Unified the national standards and operational processes for MLT power trading.
2021-05	Opinions on Further Improving the Pricing Mechanism for Pumped-storage Hydropower (Fagai Jiage (2021) No. 633)	Retained and refined two-part pricing while strengthening pumped storage's connection to electricity markets.
2021-06	Notice on the 2021 On-grid Tariff Policy for New Energy (Fagai Jiage (2021) No. 833)	Ended central subsidies for specified new wind and solar projects, applied local coal-power benchmark prices, and allowed voluntary market trading.
2021-09	Reply on the Green Electricity Trading Pilot Work Plan (Fagai Tigai (2021) No. 1260)	Launched green-power trading pilots and enabled the environmental value of renewable electricity to be reflected separately in transactions.
2021-09	Notice on Issuing the Measures for Supervising Fair and Open Access to Power Grids (Guoneng Fa Jianguan Gui (2021) No. 49)	Strengthened non-discriminatory grid access and supervision of grid-opening conduct.
2021-10	Notice on Further Deepening the Market-oriented Reform of On-grid Tariffs for Coal-fired Power (Fagai Jiage (2021) No. 1439)	Mandated all coal-fired power into the market and liberalised commercial and industrial procurement.
2021-10	Notice on Organising Grid Enterprise Agency Power Purchase (Fagai Ban Jiage (2021) No. 809)	Established a transitional mechanism for grid enterprises to purchase power on behalf of users.
2021-11	Notice on Issuing the Measures for Retail Electricity Companies (Fagai Tigai Gui (2021) No. 1595)	Replaced the 2016 access-and-exit measures and updated registration, operation, credit, and exit requirements for retail companies.

Date	Policy Title and Source No.	Key Objectives and Impacts
2022-01	Guiding Opinions on Accelerating the Development of a National Unified Electricity Market System (Fagai Tigai (2022) No. 118)	Defined the “two-step” roadmap (2025/2030) for a national unified electricity market system.
2022-05	Notice Forwarding the Implementation Plan for High-quality Development of New Energy in the New Era (Guoban Han (2022) No. 39)	Set out 21 measures covering renewable development, market participation, and green-power and certificate mechanisms.
2022-06	Notice on Further Promoting Participation of New Energy Storage in Electricity Markets and Dispatch Operation (Fagai Ban Yunxing (2022) No. 475)	Clarified participation of new energy storage in spot and ancillary service markets.
2022-11	Notice on Further Advancing Electricity Spot Market Pilot Work (Fagai Ban Tigai (2022) No. 1609)	Expanded spot pilots and standardised cross-regional trial operation mechanisms.
2023-01	Notice on Accelerating the Construction of a New Power Load Management System (Fagai Yunxing (2023) No. 31)	Strengthened the technical basis for demand-side resources to participate in markets.
2023-05	Notice on Transmission and Distribution Tariffs for the Third Regulatory Cycle (Fagai Jiage (2023) No. 520)	Approved new transmission and distribution tariffs for the third regulatory cycle.
2023-08	Notice on Full Coverage of Green Electricity Certificates for Renewable Energy (Fagai Nengyuan (2023) No. 1044)	Implemented full green electricity certificate coverage to support renewable energy consumption and trading.
2023-09	Notice on Issuing the Trial Basic Rules for Electricity Spot Markets (Fagai Nengyuan Gui (2023) No. 1217)	Issued the first foundational national rule for unified spot market operations.
2023-09	Notice on Issuing the Measures for Electricity Demand-side Management (2023 Edition) (Fagai Yunxing Gui (2023) No. 1283)	Clarified the roles of demand response, load aggregators, and virtual power plants in system regulation and market trading.
2023-10	Notice on Further Accelerating Electricity Spot Market Construction (Fagai Ban Tigai (2023) No. 813)	Accelerated the transition of spot markets from pilots to formal operations.
2023-11	Notice on Establishing the Capacity Price Mechanism for Coal-fired Power (Fagai Jiage (2023) No. 1501)	Established the capacity price mechanism to ensure long-term generation adequacy.
2024-01	Notice on Issuing the Basic Rules for Electricity Market Information Disclosure (Guoneng Fa Jianguan (2024) No. 9)	Unified information disclosure standards to enhance market transparency.
2024-02	Notice on Improving Pricing for Electricity Ancillary Service Markets (Fagai Jiage (2024) No. 196)	Perfected the price formation and compensation for electricity ancillary services.
2024-03	Guiding Opinions on High-quality Development of Distribution Networks (Fagai Nengyuan (2024) No. 187)	Guided distribution-network development and integration of distributed resources.
2024-03	Measures for Full Guaranteed Purchase of Renewable Power (NDRC Order No. 15)	Clarified boundaries between guaranteed purchase and marketised consumption for renewables.
2024-04	Measures for Supervision of the Electricity Market (NDRC Order No. 18)	Provided the legal basis and procedures for comprehensive power market supervision.
2024-05	Basic Rules for Operation of the Electricity Market (NDRC Order No. 20)	The overarching “1+6” system rule for national power market operation.
2024-06	Notice on Further Improving the Time-of-use Pricing Mechanism (Fagai Jiage (2024) No. 731)	Strengthened time-of-use price signals to guide peak-shaving and demand response.
2024-07	Action Plan for New Power System Construction (2024–2027) (Fagai Nengyuan (2024) No. 1128)	Detailed the roadmap for constructing a new power system (2024–2027).
2024-08	Notice on Issuing the Green Electricity Trading Chapter of the Basic Rules for Medium- and Long-term Electricity Trading (Fagai Nengyuan (2024) No. 1123)	Unified the definition, organisation, pricing, and certificate-transfer rules for green-power trading.
2024-08	Notice on Issuing the Rules for Renewable Energy Green Electricity Certificate Issuance and Trading (Guoneng Fa Xinneng Gui (2024) No. 67)	Unified the issuance, trading, and retirement of green electricity certificates.
2024-09	Notice on Issuing the Basic Rules for Electricity Market Registration (Guoneng Fa Jianguan Gui (2024) No. 76)	Unified the standards for market participant registration, entry, and exit.
2024-11	Notice on Further Standardising Matters Related to Electricity Market Trading Conduct (Guoneng Zongtong Jianguan (2024) No. 148)	Standardised quotation and trading conduct to prevent collusive bidding and market manipulation.
2024-11	Guiding Opinions on Supporting Innovative Development of New Electricity-sector Market Entities (Guoneng Fa Fagai (2024) No. 93)	Defined the market positioning and participation of emerging entities such as virtual power plants and smart microgrids.
2025-01	Notice on Issuing Measures for Distributed Photovoltaic Grid Connection and Operation (Guoneng Fa Xinneng Gui (2025) No. 7)	Regulated the development, grid connection, and market trading of distributed photovoltaic generation.
2025-02	Notice on Deepening the Market-oriented Reform of On-grid Tariffs for New Energy and Promoting High-quality Development of New Energy (Fagai Jiage (2025) No. 136)	Promoted full market participation of renewable generation and introduced mechanism electricity and mechanism prices.
2025-03	Opinions on Promoting High-quality Development of the Renewable Energy Green Electricity Certificate Market (Fagai Nengyuan (2025) No. 262)	Strengthened certificate pricing, trading, and consumption certification and promoted coordination among electricity, certificate, and carbon markets.
2025-04	Guidelines on Promoting Virtual Power Plant Development (Fagai Nengyuan (2025) No. 357)	Defined the status and regulatory role of VPPs in market participation.
2025-04	Notice on Promoting Private Investment in the Energy Sector (Guoneng Fa Fagai (2025) No. 40)	Lowered market entry barriers for private enterprises in the power sector.
2025-04	Notice on Issuing the Basic Rules for Electricity Ancillary Service Markets (Fagai Nengyuan Gui (2025) No. 411)	Standardised ancillary service market rules as part of the “1+6” framework.
2025-04	Notice on Comprehensively Accelerating the Construction of the Electricity Spot Market (Fagai Ban Tigai (2025) No. 394)	Transitioned spot markets to full national coverage and continuous operation.

Date	Policy Title and Source No.	Key Objectives and Impacts
2025-05	Notice on Promoting Green Power Direct Supply Development (Fagai Nengyuan (2025) No. 650)	Supported direct trading and supply between renewable generators and end-users.
2025-07	Reply on the Program for Normalisation of Power Trading Mechanisms Across Grid Operating Areas (Fagai Tigai (2025) No. 915)	Supported normalisation of cross-grid-area trading and resource optimisation.
2025-08	Notice on Issuing the Basic Rules for Electricity Market Metering and Settlement (Fagai Nengyuan Gui (2025) No. 976)	Unified the national standards for power metering and financial settlement.
2025-09	Notice on Issuing Guidance for Organising Electricity Spot Markets under Continuous Operation (Fagai Nengyuan (2025) No. 1171)	Provided guidance for organising markets in regions with continuous spot operations.
2025-09	Notice on Using Price Mechanisms to Promote Renewable Consumption and Reduce Subsidy Pressure (Fagai Jiage (2025) No. 1192)	Used price signals to encourage the local consumption of renewable energy.
2025-09	Notice on Issuing Measures for Cross-provincial Emergency Dispatching (Fagai Yunxing Gui (2025) No. 1193)	Standardised emergency dispatching to bridge market operation and supply security.
2025-11	Guiding Opinions on Promoting New Energy Consumption and System Control (Fagai Nengyuan (2025) No. 1360)	Set out a multi-level framework for renewable-energy consumption, dispatch, and control.
2025-12	Basic Rules for Power Medium- and Long-term Trading (Fagai Nengyuan Gui (2025) No. 1656)	The final “1+6” component, unifying national MLT trading regulations.
2025-12	Guiding Opinions on Building the Evaluation System for the National Unified Electricity Market (Fagai Nengyuan Gui (2025) No. 1657)	Established an official evaluation and supervision system for national unified electricity market system performance.
2025-12	Notice on Ensuring the Signing and Fulfillment of Power Medium- and Long-term Contracts in 2026 (Fagai Yunxing (2025) No. 1502)	Regulated the annual MLT contract signing and supervision for the 2026 cycle.
2026-01	Notice on Improving the Generation-side Capacity Pricing Mechanism (Fagai Jiage (2026) No. 114)	Refined capacity pricing for coal, gas, pumped storage, and new storage and provided for reliable-capacity compensation mechanisms.
2026-02	Implementation Opinions on Improving the National Unified Electricity Market System (Guoban Fa (2026) No. 4)	State Council implementation opinions on improving the national unified electricity market system.

Note: NDRC = National Development and Reform Commission; NEA = National Energy Administration. “Document No. 9” in the main text refers to Zhongfa [2015] No. 9. Dates indicate public release, rather than document-signing or issuance, dates; where no official release was available, the first reliable public report is used.

Appendix B. Illustrative Timeline of the United Kingdom’s REMA

Supplementary chronology of the UK’s post-2021 REMA process, which revisits locational and high-renewable design issues within the earlier 2013 EMR framework; not used as a comparator for China’s reform sequencing and not part of China’s policy record.

Table B.5: Key milestones in the UK's Review of Electricity Market Arrangements (REMA).

Time	Milestone	Key Development
2022.04	Energy Security Strategy	UK Government announces plans to reform the electricity market, later termed REMA, aiming to structurally reduce the linkage between whole-sale electricity and gas prices.
2022.07	First Consultation Launch	The Department for Business, Energy and Industrial Strategy launches a comprehensive consultation with over 60 reform options, including locational marginal pricing (LMP, also known as Nodal Pricing).
2023.03	Consultation Summary	The Department for Energy Security and Net Zero publishes the consultation response, confirming structural decoupling from gas prices as a priority; design options remain under review.
2023.10	LMP Debate Intensifies	Significant industry and stakeholder pushback emerges against LMP due to concerns over investment uncertainty, grid complexity, and regional inequity.
2024.03	Second Consultation	Scope is narrowed significantly; LMP officially ruled out, while zonal and national pricing options continue under consideration.
2024.07	General Election & Policy Shift	Labour Party wins general election; new government refocuses REMA on investor confidence, affordability, and decarbonisation.
2025.07	Summer Update Report	Major policy pivot: zonal pricing ruled out; national uniform pricing retained to support market stability and investment.
2025.12–2030+	Final Policy Design and Implementation	Policy design, legislation, and phased system testing proceed under national pricing framework; full implementation expected by 2030.

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