ISSN: xxxx-xxxx

The Dual Trajectory: Navigating China's Energy Transition Through Traditional and New Energy Technologies

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Abstract

This paper provides a detailed, expert-level analysis of the technological development trends within China's traditional and new energy sectors. By synthesizing recent data and policy announcements, it examines the complex, dual-track nature of China's energy strategy: a continued reliance on fossil fuels for energy security and grid stability, coupled with an unprecedented, globally dominant expansion of renewable energy capacity. The report details technological advancements in clean coal, offshore oil recovery, high-efficiency solar and wind, and advanced energy storage systems. It highlights the strategic and economic drivers behind these trends, including national policy, massive investment, and domestic manufacturing leadership. The analysis concludes that China's energy transition is not a simple, linear phase-out but a nuanced and often contradictory process driven by the twin imperatives of climate action and energy security. The report identifies key challenges, such as grid integration and policy misalignment, and projects future pathways that will have profound implications for both China and the global energy landscape.

Keywords: China, Energy Transition,Traditional Energy,New Energy

1. Introduction: Setting the Stage for a Global Energy Transformation

China's energy sector stands at a critical juncture, navigating the complex intersection of rapid economic development, escalating energy demand, and ambitious national climate commitments. As the world's largest energy consumer, China's energy policies are of paramount global significance, with its power demand accounting for a third of the global total in 2024.[1] In response to this immense consumption and its status as the world's largest greenhouse gas emitter, China has committed to reaching carbon peaking by 2030 and achieving carbon neutrality before 2060.[2] These commitments, enshrined in key national planning documents such as the 14th Five-Year Plan, frame a transformative agenda for the nation's energy future.[4]

However, the pathway to these goals is not a simple linear progression from fossil fuels to renewables. Instead, China's energy transition is characterized by a "dual trajectory," where the nation simultaneously modernizes and expands both traditional and new energy technologies. This report moves beyond simplistic narratives to provide a nuanced, data-driven analysis of this complex process. It examines the technological advancements, policy decisions, and economic drivers that underpin China's strategy. By synthesizing data from official government reports, academic papers, and industry analyses, this paper aims to provide a comprehensive and authoritative reference on the current state and future trends of

ISSN: xxxx-xxxx

China's energy sector. The subsequent sections will detail the evolving roles of traditional and new energy sources, the critical enabling infrastructure, and the policy landscape shaping this multifaceted transition.

2. The Enduring Role and Technological Evolution of Traditional Energy

While China's renewable energy sector is expanding at an unprecedented pace, traditional energy sources, particularly coal, continue to play a foundational role in the country's energy strategy. This is not a simple matter of legacy reliance; rather, it is a calculated rebalancing of priorities driven by the twin imperatives of economic development and national energy security. This section analyzes the paradoxical data that reflects this dual approach and details the technological innovations aimed at making traditional energy more efficient and flexible.

2.1. Coal's Strategic Rebalancing: From Primary Fuel to Flexible Support

The data on China's electricity generation reveals a striking and often misunderstood paradox. In 2024, fossil fuels provided 62% of China's total electricity generation, with coal alone accounting for 59% of the mix.[1] This high share persists despite the fact that zero-emissions capacity already accounts for 57% of China's total installed power capacity.[5] This divergence between installed capacity and actual generation highlights a fundamental challenge: the intermittency of renewable energy and the need for a stable, dispatchable power source to ensure grid reliability.

In response to this challenge, China has not embarked on a linear phase-out of coal. Instead, the country is navigating a complex and seemingly contradictory path. In the first half of 2025, new and revived coal projects reached a decade-high of 75 GW, with construction starts equivalent to the entire coal power capacity of South Korea.[6] This surge in activity follows a period in 2022-2023 when more than 100 GW of new coal power was approved each year.[6] At a superficial level, this trend might appear to be a direct contradiction of China's climate pledges. However, a deeper analysis reveals a more strategic rationale. The country's explosive growth in clean energy is already meeting all new electricity demand growth.[6] The new and technologically advanced coal plants are therefore not being built to serve as a primary source of new baseload power.

Instead, the role of coal is shifting. These new plants, along with retrofitted existing units, are being designed to act as flexible, supporting resources for an increasingly renewable-heavy grid.[6] The primary technological focus is on enhancing the "peak shaving" capabilities of coal-fired power plants, allowing them to rapidly ramp up and down to back up intermittent solar and wind power.[8] Research into these "clean coal technologies" (CCTs) is extensive and includes innovations like ultra-supercritical coal-fired plants and advanced coal conversion and pollution control systems.[9] One particularly notable technological advancement involves the integration of coal-fired power plants with molten salt thermal energy storage (TES) systems.[10] This coordinated charging configuration, which utilizes steam from the plant for thermal storage, can reduce the plant's minimum stable operating load from 30% to 0%, thereby achieving a thermal efficiency of 39.87%.[10] Such technologies are critical for ensuring grid stability and reliable electricity supply during periods of low renewable output.

This strategic rebalancing highlights a fundamental national trade-off. For policymakers, ensuring energy security and grid stability in the short-to-medium term is a prerequisite for the long-term, high-stakes

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commitment to carbon neutrality. The ongoing expansion of coal capacity, while seemingly paradoxical, is thus a calculated response to the systemic challenge of integrating variable renewable energy sources. This phenomenon is rooted in a "structural inertia" and a "policy disconnect," where top-down climate goals clash with local and provincial mandates to maintain a secure and reliable power supply.[6] The future of coal in China is therefore not about growth in generation but about its ability to act as a technological tool that enables the clean energy transition.

	Installed Capacity (GW)	**Share of Total Capacity (%)**	**Generation (TWh)**	**Share of Total Generation (%)**
Thermal	1,438	43%	6,171	62%
- Coal	1,139	34%	5,871	59%
- Gas & Other	299	9%	300	3%
Hydro	436	13%	1,600	16%
Wind	521	16%	989	10%
Solar	887	26%	853	9%
Nuclear	60.83	2%	450.85	5%
Total	3,349	100%	9,936	100%

Table 1: China's Electricity Capacity and Generation Mix (2024)

Note: Data derived and aggregated from multiple sources including NEA, Ember, and official reports.[5] Capacity figures reflect cumulative installed capacity by the end of 2024.

2.2. Strengthening Energy Security: Advancements in Oil and Gas Exploration

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Beyond coal, China's traditional energy strategy also includes a strong focus on bolstering domestic oil and gas production to enhance energy security. The 14th Five-Year Plan explicitly reasserts the goal of boosting national natural gas production and maintaining a stable level of crude oil output.[2] This strategic emphasis is a direct response to global geopolitical tensions and the need to reduce reliance on imported fuels.[12]

A key aspect of this effort involves technological advancements in difficult and previously inaccessible resource extraction. A recent breakthrough by China National Offshore Oil Corp (CNOOC) demonstrates this commitment. The company announced a world-first in achieving large-scale thermal recovery of offshore heavy oil.[13] This technology unlocks access to proven reserves exceeding 600 million tons, which account for approximately 20% of China's total heavy oil reserves.[13] The large-scale development of heavy oil thermal recovery is considered a "world-class problem" due to the technical and economic challenges involved in extracting the high-viscosity, high-density crude from offshore platforms.[13]

The successful deployment of this technology at projects like the Kenli 10-2 oilfield in Bohai Bay not only strengthens China's domestic production capabilities but also positions the country as a potential exporter of this specialized technology to other nations with significant heavy oil resources.[13] This pattern of leveraging a massive domestic market as a testbed for advanced energy technologies and then exporting the proven solutions is a recurring theme in China's energy strategy. It transforms the nation from a consumer of global energy technologies into a provider of specialized, high-value energy solutions, thereby building a new form of economic influence in the international energy landscape.

3. The Ascendancy of New Energy: A Revolution in Power Generation

The most defining characteristic of China's energy landscape is the explosive and globally dominant growth of its new energy sector. This growth is driven by a combination of aggressive national policy, immense investment, and a near-monopoly on the entire clean energy supply chain. The scale and speed of this transformation are unprecedented, reshaping not only China's energy mix but the global energy transition as a whole.

3.1. Solar and Wind: Leading the Renewable Charge

China's renewable energy deployment is occurring at a staggering pace. In 2024, the country contributed more than half of the global increase in both solar and wind generation.[1] This single-year expansion was immense: wind and solar capacity additions combined reached 356.5 GW, accounting for 83% of all new capacity added to the grid.[5] According to the International Renewable Energy Agency (IRENA), China was responsible for 63.8% of the world's total renewable capacity additions in 2024, and it now hosts more than 50% of the world's operational solar power capacity.[14]

This leadership extends beyond sheer volume to technological innovation. China is rapidly shifting its manufacturing dominance from older solar cell technologies to next-generation, high-efficiency designs. While Mono PERC (Passivated Emitter and Rear Cell) technology remains a widely used "workhorse" with approximately 22% efficiency, the focus is now on more advanced cells.[15] TOPCon (Tunnel Oxide Passivated Contact) technology, with efficiencies reaching 23-24%, is seen as a compelling and cost-effective upgrade from PERC lines.[15] Even more advanced is Heterojunction Technology (HJT), which

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offers the highest efficiency potential at 24-26% and superior temperature performance, though it requires new manufacturing lines.[15] Looking to the future, Chinese companies like Trinasolar are pioneering the commercialization of perovskite tandem cells, which combine thin-film perovskite with a silicon base to push efficiency past 30% in a lab setting.[17]

The same pattern of rapid development is evident in the wind sector. Chinese engineers have developed a prototype floating wind turbine capable of generating 17 MW of clean electricity, a record for this type of technology.[18] This innovation is designed to withstand extreme conditions, including typhoon-speed winds and waves over 78 feet high.[18] This is a game-changing development because it unlocks a vast, previously untapped resource: 80% of the world's offshore wind potential lies in waters deeper than 50 meters, a depth unsuitable for traditional fixed-bottom turbines.[18] The commercialization of floating wind technology could make wind energy a viable major source of power for countries with deep territorial waters, such as Japan.[18]

China's dominance in clean energy manufacturing is not a coincidence; it is a strategic maneuver that makes renewables the most economically viable energy choice globally. The massive investment in clean energy—more than double that of any other country in 2024—has given China a near-monopoly on the clean energy supply chain and a commanding 55% global market share in new solar additions.[20] The sheer scale of this production has created manufacturing overcapacity, which in turn has driven down solar component prices to record lows.[20] This has made clean energy cheaper than new coal or gas in almost every market, demonstrating that renewables are now a "market-driven choice—not just a subsidized one".[23] By providing the most cost-effective solutions for decarbonization, China is accelerating the global energy transition on its own terms, positioning itself as the undisputed leader in this critical industrial and technological revolution.[19]

	Mono PERC	**TOPCon**	**HJT**	**Perovskite Tandem**
Efficiency Range	~ 22%	23%-24%	24%-26%	28%+, Lab: 30%+
Manufacturing Cost	Low (Established Infrastructure)	Moderate (Line Upgrades)	High (New Lines Required)	Very High (Early Stage)
Key Advantages	Well-established, low production cost	Higher efficiency, lower degradation, better bifacial gains	Highest efficiency potential, superior temperature	Extremely high efficiency potential, leverages existing silicon

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			performance, excellent bifacial gains	infrastructure
Key Challenges	Becoming outdated, less efficient in high heat	Higher defect rates, moderate upgrade costs	High silver consumption, new manufacturing lines required	Still in early commercialization, R&D phase

Table 2: Comparison of Next-Generation Solar Cell Technologies

Note: Data derived from industry publications and expert analysis.[15]

3.2. Hydropower and Nuclear: The Baseload Backbone

While solar and wind are at the forefront of the new energy revolution, older clean energy technologies like hydropower and nuclear continue to form a critical part of China's energy backbone. Hydropower remains China's largest source of clean electricity, contributing 13% of the total in 2024.[1] In a single year, China's hydropower fleet grew by 14.4 GW, which accounted for a whopping 93% of the global total increase.[14] In 2023, China completed the world's largest hydro-solar power plant in Sichuan, demonstrating a strategic approach to using the consistency of hydropower to offset the variability of solar power.[24]

Nuclear power is also expanding at a rapid clip. As of December 2024, China had 58 nuclear power plants in operation and ranked first globally with 27 additional plants under construction for the 18th consecutive year.[11] The country's installed nuclear power capacity is projected to surpass that of France in 2025, and China General Nuclear Power Group has articulated a long-term goal of reaching 200 GW by 2035.[11] This expansion is underpinned by a policy of maximizing self-reliance in reactor technology manufacturing and design, with advanced pressurized water reactors like the Hualong One now being exported to other countries.[11] The country's participation in the ITER nuclear fusion project and its research into the thorium fuel cycle further underscore its commitment to technological leadership in this sector.[11]

The emphasis on these centralized, high-volume, and predictable clean energy sources—hydropower and nuclear—highlights a fundamental aspect of China's energy strategy. The country is blending these massive, centralized power sources with a burgeoning decentralized system of distributed solar and energy storage. This is a pragmatic response to the significant geographical mismatch between major renewable resources (hydropower in the southwest, solar in the west) and the industrial load centers in the east.[25] The strategy involves building large-scale, high-volume power plants in resource-rich regions while simultaneously deploying distributed solar on rooftops in land-constrained eastern coastal areas to meet local demand.[24] The success of this hybrid model, however, is entirely dependent on the grid's ability to manage this highly complex mix of centralized and decentralized assets, a challenge that is being addressed through aggressive investment in grid modernization and energy storage.

4. Enabling Technologies and Infrastructure for a New Power System

The rapid expansion of intermittent new energy sources necessitates a fundamental transformation of the country's grid infrastructure and the deployment of advanced enabling technologies. Without a flexible and resilient power system, the full potential of solar and wind energy cannot be realized. China's strategic response involves massive investment in grid modernization and an explosive build-out of energy storage capacity.

4.1. Grid Modernization and Energy Storage: The Linchpin of Intermittency

In 2024, China invested a massive RMB608 billion (US$84.7 billion) in grid transmission expansion and modernization projects, representing a 15% year-on-year increase.[5] This investment is designed to facilitate the connection of a record-breaking 429 GW of new capacity to the grid and to double or triple ultra-high voltage transmission lines to transport power from resource-rich regions to demand centers.[5]

The most crucial enabling technology for managing the new power system is energy storage. The New Energy Storage (NES) sector in China is growing at an explosive rate. By the end of 2024, China's cumulative NES capacity reached 73.76 GW / 168 GWh, an increase of over 130% year-on-year and accounting for more than 40% of the global total.[27] While lithium-ion batteries remain the dominant technology, accounting for 96.4% of total installed capacity, the country is actively piloting alternative technologies like compressed air storage, vanadium flow batteries, and gravity-based systems.[27]

The purpose of this massive build-out goes beyond simply storing energy. It is a strategic effort to transform previously "wasted" or curtailed renewable energy into a valuable, marketable product.[29] Historically, grids have preferred high-speed transmission from steady sources like coal.[22] Energy storage is a direct response to this preference. It allows for the "smoothing" of renewable energy output, provides demand support during peak hours, and can even postpone costly grid upgrades.[31] The plummeting cost of battery cells—with an average price of US$66.3 per kWh in a major 2024 auction—makes this not just a technical solution but an economically compelling one.[32] By turning intermittent power into a reliable, dispatchable asset, energy storage makes renewables more attractive to grid operators and investors,

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thereby accelerating the financial viability of the entire clean energy system.

Project Name	**Location**	**Capacity**	**Technology Type**	**Strategic Purpose**
Huadian Xinjiang Kashgar	Xinjiang Autonomous Region	500 MW/2 GWh (Phase 1)	Lithium Iron Phosphate (Li-ion)	Standalone, grid-forming and grid-following support, peak shaving
Xinhua Wushi	Inner Mongolia Autonomous Region	500 MW/2 GWh (Phase 1)	Hybrid Li-ion and Vanadium Flow	Largest hybrid energy storage installation, provides grid-forming capabilities
Ulanqab Facility	Inner Mongolia Autonomous Region	1 GW/6 GWh	Lithium Iron Phosphate (Li-ion)	World's largest power generation-side electrochemical storage, co-located with generation assets
Iron-Chromium Flow Battery Project	Inner Mongolia Autonomous Region	Megawatt-level	Iron-Chromium Flow Battery	Pilot project for low-cost, high-performance battery technology charged by renewables
Pumped Hydro Storage (PHS)	Various regions	58.7 GW (2024)	Pumped Hydro Storage	Grid firming and flexible power supply

Table 3: Key New Energy Storage Projects in China

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Note: Data compiled from various news and industry reports.[5]

4.2. Carbon Capture, Utilization, and Storage (CCUS): A Bridge for Hard-to-Abate Sectors

Carbon Capture, Utilization, and Storage (CCUS) is identified as a vital component of China's long-term decarbonization strategy. A report commissioned by the Ministry of Science and Technology found that CCUS will be an "essential tool" for China to achieve carbon neutrality by 2060, providing between 1.5 and 2.7 Gt of annual emissions reductions by 2050.[33] The technology involves capturing carbon dioxide (

CO_2) from power plants and industrial facilities and either using it in products or storing it underground.[33] China possesses immense geological storage potential, with one study finding more than 2,300 Gt of deep geologic storage capacity onshore.[33]

While CCUS holds significant promise, its current impact is negligible, accounting for only 0.02% of China's carbon emissions in late 2021.[33] The national roadmap, however, is ambitious, envisaging an operating capacity of 100 million tonnes by 2035 and 300 million tonnes by 2040.[33] Notable projects include the Sinopec Qilu Petrochemical Company's facility, which captures 1 million tonnes of

CO_2 annually and transports it for enhanced oil recovery (EOR).[33]

The pursuit of CCUS technology reveals a strategic preference for "decarbonization" over a full "defossilization." While some experts debate the feasibility of a 100% renewable energy system, CCUS offers a pragmatic pathway for China to reduce emissions from hard-to-abate industrial sectors like steel and cement and from its large fleet of coal-fired power plants.[33] This approach allows China to maintain critical fossil fuel-intensive industries while still meeting its climate commitments. It serves as a political and economic hedge, a middle path that reconciles continued reliance on fossil fuels—driven by energy security and economic stability—with the long-term goal of carbon neutrality.

5. Policy and Economic Drivers: Shaping the Transition

The rapid technological advancements and massive infrastructure build-out in China's energy sector are not occurring in a vacuum. They are the direct result of a highly centralized and evolving policy framework, underpinned by unprecedented levels of public and private investment.

5.1. The Evolution of Policy and its Impact

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Since the enactment of the Renewable Energy Law in 2006, China's policy mix has shifted dramatically. It has moved from a government-led, subsidy-heavy model to a more market-based approach.[29] While nationwide feed-in tariffs have been phased out, localized subsidy programs and incentives remain in place.[37] These include corporate income tax reductions of up to 15% for approved renewable energy projects and preferential land use policies from local governments.[37] The 14th Five-Year Plan sets concrete targets, such as increasing the proportion of non-fossil energy consumption to about 20% by 2025 and seeing carbon emissions peak by 2030.[2]

5.2. Investment and Supply Chains: The Economic Engine

Investment is the primary engine of China's energy transition. In 2024, China led the world in energy transition investment, accounting for two-thirds of the $2.1 trillion spent globally.[21] This massive investment has cemented China's dominance in the clean energy supply chain, with the country accounting for 81% of global supply chain investment in 2024.[21] The report from BloombergNEF highlights that China's energy transition spending—at 4.5% of its GDP—far exceeds that of other major economies.[21] This investment is heavily focused on the "new three" strategic industries: solar cells, lithium batteries, and electric vehicles, which saw a 30% jump in exports in 2023.[21] This demonstrates that China's energy strategy is not only about meeting domestic demand but also about establishing a powerful new economic engine for growth and export.

6. Conclusion and Future Outlook

China's energy sector is defined by a complex and dynamic "dual trajectory," a simultaneous commitment to two seemingly contradictory paths. On one hand, the country is leading a global revolution in new energy, with an explosive build-out of solar, wind, and energy storage capacity that is unmatched in scale and speed. On the other hand, it maintains a strategic reliance on traditional energy sources, particularly coal, which are being technologically upgraded to provide a critical safety net for grid stability and energy security. This nuanced approach, driven by massive state-backed investment and a focus on domestic technological innovation, has positioned China as the undisputed leader in the global clean energy race.

Looking ahead, China faces significant challenges in navigating this dual path. The "policy disconnect" between national climate goals and provincial-level energy security concerns remains a key obstacle that must be resolved to align incentives and accelerate the transition.[6] The massive build-out of intermittent renewables necessitates a continued and exponential investment in grid infrastructure and energy storage to prevent curtailment and ensure grid reliability.[22] Technologies like CCUS, while promising, must move

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from rhetoric to large-scale, cost-effective reality to meaningfully abate emissions from hard-to-abate sectors.[33]

Ultimately, China's energy strategy is a critical case study for the world. Its success or failure in reconciling the twin imperatives of energy security and climate action will not only determine its own economic and environmental future but will also have a profound and lasting impact on the global energy landscape for decades to come. By driving down the cost of clean energy technologies and pioneering large-scale deployment, China is providing a viable and economically attractive pathway for the global energy transition, even as its internal contradictions serve as a cautionary tale of the complexities involved.

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