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Breaking through the dilemmas: pathways for natural gas distributed energy development under China's dual carbon goals

Jiehui Yuan^{1,2,*} and Zhihong Liu²

¹ Center for Western Jiangxi Regional Economic and Social Development, Yichun University, Yichun 336000, China

² Institute of Energy & Resource, Environment and Carbon Neutrality, Yichun University, Yichun 336000, China

* Correspondence author; E-mail: yuanjh_2015@tsinghua.org.cn.

Abstract: Natural gas distributed energy (NGDE), characterized by an integrated energy utilization efficiency exceeding 70%, low carbon emissions, and rapid start–stop capabilities, offers a critical pathway for achieving China's dual carbon goals. This paper establishes a unified framework through which to perform a system analysis for exploring the potential dilemmas involved in the development process of NGDE in China and investigating viable pathways to promoting the development of NGDE under China's dual carbon goals. The results show that the critical dilemmas of NGDE in China include high gas-fired electricity costs, gas supply security challenges due to high import dependence, incomplete grid integration mechanisms, and undiversified business models. Based on these findings, possible pathways for fostering the large-scale development of NGDE in China have been determined, including enhancing gas supply security, optimizing pricing mechanisms, diversifying market models, and advancing technological integration. The study argues that during the critical window of the 15th Five-Year Plan for Building a New Energy System, NGDE must move beyond a pure substitution mindset toward a synergy mindset that emphasizes deep integration with renewable energy. In this context, it should position itself as a flexible peaking support and integrated energy supply solution within the new power system, contributing to carbon neutrality efforts in countries such as China.

Keywords: dual carbon goals; natural gas distributed energy; synergy development; unified analysis framework; dilemmas; pathways.

1. Introduction

Since China explicitly proposed its dual carbon goals (i.e., carbon peaking by 2030 and carbon neutrality by 2060) in 2020, the energy structure transition has entered an accelerated



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phase. By the end of December 2025, the combined installed capacity of wind and solar power in China had reached 1,840 GW, historically surpassing thermal power to become the largest power source in the electricity system [1]. While renewable energy capacity continues to expand at an unprecedented pace, the inherent intermittency of its output poses a growing and formidable challenge to the secure and stable operation of the power system—a reality that cannot be overlooked. How to establish an energy system that is both clean, low-carbon, safe and reliable has become a core issue to be addressed during the 15th Five-Year Plan period (2026–2030).

Natural gas distributed energy (NGDE) has emerged as a promising niche energy in this context. Using natural gas as feedstock, it provides cooling, heating, electricity, steam and other energy products locally at the user end, achieving integrated energy utilization efficiency exceeding 70% [2], while offering additional advantages including low carbon emissions, short construction periods, and rapid start–stop capabilities [3]. The revised *Natural Gas Utilization Management Measures* (2024) classified NGDE as a priority category [4]. The National Energy Administration in China has explicitly stated that natural gas power generation is an important flexible peaking power source and a key component of new energy system construction. Policy support has opened unprecedented development space for NGDE in recent decades[5].

A growing body of literature has examined NGDE development in China under the dual carbon goals, broadly falling into three thematic streams. The first stream addresses overall development status and challenges. Zhou *et al.* (2024) identified key barriers including high initial investment, grid access conflicts, and uncertain returns, noting that projects remain concentrated in economically developed and gas-rich regions [6]. Regional studies have also examined variations across provinces (Li, 2026 [7]). The second stream centers on policy frameworks and economic viability [8–11]. Hou *et al.* (2019) systematically reviewed NGDE policies and economics, while others have examined gas price constraints and the impact of differentiated subsidy policies on project viability [8]. The third stream addresses technical and operational dimensions, particularly integration with renewable sources [2, 12–15]. Ren *et al.* (2022) reviewed distributed energy system optimization [2], and Wen *et al.* (2022) demonstrated that NGDE integrated with PV and heat pumps can achieve primary energy savings of 5.52% to 26.83% [12].

Despite these valuable contributions, several important gaps remain. First, most studies address NGDE challenges in isolation—focusing separately on policy, economics, or technology—without capturing the interplay among these dimensions. The simultaneous pressures of rising costs, declining subsidies, grid barriers, and business model stagnation constitute a systemic dilemma beyond single-dimension analysis. Second, few studies have examined how NGDE can reposition itself within the evolving power system as renewable penetration grows and gas-fired generation faces rising cost pressures [16]. Third, the literature lacks a synergy perspective that views NGDE as a complementary partner to renewables rather than a competitor [17], and pays limited attention to the pathway from demonstration projects to large-scale deployment [18].

The rest of this paper is organized as follows. Section 2 elaborates the concept and strategic value of NGDE and establishes a synergy mindset framework that reconceptualizes NGDE as an enabler of multi-energy complementarity. Section 3 reviews the current development status and identifies the key dilemmas constraining NGDE deployment across four interconnected dimensions. Section 4 proposes corresponding breakthrough pathways across these four dimensions. Section 5 discusses the interrelationships among these pathways, the theoretical and practical implications of the synergy mindset framework, and the limitations of this study. Section 6 concludes the paper and offers policy implications.

2. Conceptual foundation and the synergy mindset framework

2.1. Definition and system characteristics

Natural gas distributed energy (NGDE) refers to a distributed energy supply system that uses natural gas as the primary energy source, drives generators through gas turbines, gas engines, or other prime movers, and utilizes waste heat recovery devices to provide energy service such as heating and cooling [2]. Its typical configuration is the combined cooling, heating and power (CCHP) system—simultaneously outputting electricity, heat (steam or hot water), and cooling (via lithium bromide absorption chillers) within the same system, achieving cascade utilization of energy [17, 19].

Compared with traditional centralized energy supply, NGDE exhibits four distinctive features: (1) Proximity to load—energy production and consumption are highly co-located, significantly reducing transmission and distribution losses; (2) Multi-energy cogeneration—a single system simultaneously meets multiple energy demands including electricity, heating, cooling, steam and other energy products; (3) Operational flexibility — rapid start-stop capability enables both base-load and peaking operations[9,14]; and (4) Low carbon emissions — compared with coal combustion, emissions of carbon dioxide and sulfur dioxide are significantly reduced [20].

2.2. The synergy mindset framework: Repositioning NGDE in the new power system

Within the new power system, the strategic value of NGDE manifests primarily in three dimensions, which collectively inform the synergy mindset framework proposed in this study, as showed in Figure 1. First, compensating for renewable energy intermittency. Wind and solar power outputs exhibit pronounced intermittency and uncertainty, while NGDE, with its flexible start-stop and rapid response characteristics, can serve as an important flexible peaking power source for the new power system [14, 21]. As the share of renewable energy continues to rise, the peaking value of gas-fired power will become increasingly prominent [16, 22]. Second, enhancing integrated energy utilization efficiency. Traditional thermal power plants generally achieve efficiency levels of approximately 40%, whereas NGDE, through CCHP cascade utilization, can achieve integrated energy utilization efficiencies exceeding 70% [2, 17], with some projects reaching over 80%. This model, in which one unit of energy produces multiple outputs, aligns strongly with the pursuit of

maximum energy efficiency under the dual carbon goals [20]. Third, supporting low-carbon transformation of end-use energy consumption. In scenarios such as industrial parks, large commercial complexes, data centers, and hospitals, NGDE can serve as the anchor of integrated, multi-energy complementary supply systems, locally meet users' multiple energy demands, replacing dispersed coal-fired boilers and inefficient air conditioning systems [14, 19]. By coupling NGDE with renewable sources such as solar PV, wind, and geothermal heat pumps, these NGDE-based multi-energy complementary systems can maximize overall energy efficiency and facilitate the deeper integration of renewables. Compared with coal-fired power generation, NGDE demonstrates significant advantages in abiotic resource depletion and other environmental impact categories [13, 23].

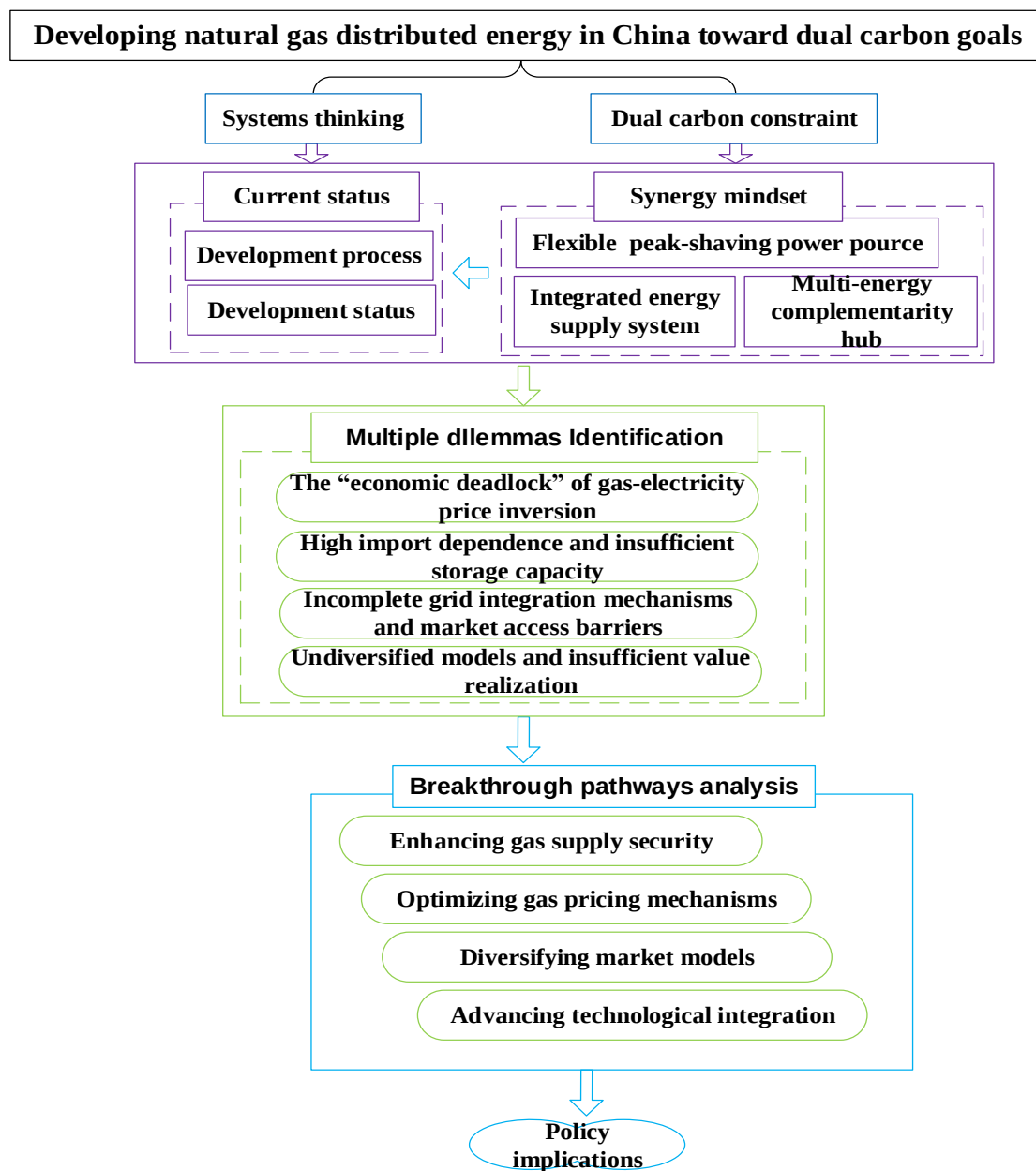


Figure 1. A framework for exploring pathways to the high-quality development of natural gas distributed energy in China toward dual carbon goals. (Source: the figure is drawn by the author).

These three dimensions—flexibility, efficiency, and low-carbon end-use support — collectively point to a fundamental rethinking of NGDE’s role. Rather than viewing NGDE as a standalone energy source competing with renewables for market share [16, 22], the synergy mindset framework positions NGDE as an enabler of multi-energy complementarity [2, 12]: a flexible partner that can compensate for renewable intermittency, a high-efficiency converter that maximizes the value of natural gas, and an integrated service provider that meets diversified end-use demands. This framework challenges the conventional substitution mindset that has dominated NGDE policy and investment decisions [6, 8], and calls for a more nuanced understanding of NGDE’s distinctive role within the evolving new energy system [5, 24].

3. Development status of NGDE in China

3.1. Continuous improvement of the policy framework

In recent years, policy support for NGDE has steadily increased, as listed in Table 1. In 2024, the state revised and issued the Natural Gas Utilization Management Measures, classifying NGDE as a priority category [4]. The 15th Five-Year Plan proposal adopted by the Fourth Plenary Session of the 20th Central Committee of the Communist Party in 2025 explicitly called for developing distributed energy and building zero-carbon factories and parks. In November 2025, the National Energy Administration issued the Guiding Opinions on Promoting the Integrated Development of New Energy, calling for promoting multi-field integrated development of distributed new energy. In 2026, the National Energy Administration further clarified support for natural gas power generation projects to engage in joint operations [18]. The Guiding Opinions on Enhancing Peak-Shaving, Energy Storage, and Intelligent Dispatching Capacity Building issued by the National Development and Reform Commission and the National Energy Administration proposed moderately deploying a number of peak-shaving gas power projects in regions with guaranteed gas supply, affordable gas prices, and significant peak-shaving demand, fully leveraging the rapid start-stop advantages of gas-fired units to enhance the system’s short-term peak and deep regulation capabilities [21, 22].

Table 1. Major policies supporting NGDE (2016–2025). (Source: the table is tabulated by the author).

Policy document	Year	Issuing authority	Key content & Impact on NGDE
Strategic plan for energy production and consumption revolution (2016–2030)	2016	NDRC, NEA	Set 2030 gas share target of ~15%; provided long-term strategic guidance for NGDE
Cogeneration management measures	2016	NDRC	Set NGDE efficiency threshold at $\geq 70\%$; established industry access standard
Opinions on accelerating the utilization of natural gas	2017	NDRC <i>et al.</i>	Identified gas as a main energy source; encouraged NGDE development
Several opinions on promoting the coordinated and stable development of natural gas	2018	State Council	Promoted domestic gas exploration and supply security; laid foundation for NGDE gas supply
Action plan for carbon peaking by 2030	2021	State Council	Promoted efficient gas utilization across industry, transport, and power sectors
"14th Five-Year Plan" modern energy system plan	2022	NDRC, NEA	Set 2025 gas production target of 230 bcm; positioned NGDE as key pathway for modern energy system
Opinions on improving institutional mechanisms and policy measures for green and low-carbon energy transition	2022	NDRC, NEA	Encouraged enterprises to develop distributed energy on self-owned land; promoted multi-energy integrated supply systems
Natural gas utilization management measures (Revised)	2024	NDRC	Classified NGDE as "Priority Category" – the most direct favorable policy for NGDE in recent years
Energy law of the People's Republic of China	2024	NPC Standing Committee	First energy law; clarified legal status of distributed energy; provided legal protection for NGDE
"15th Five-Year Plan" proposal	2025	CPC Central Committee	Explicitly called for developing distributed energy and zero-carbon factories/parks; designated NGDE as a priority pathway
Guiding opinions on enhancing peak-shaving, energy storage, and intelligent dispatching capacity building	2025	NDRC, NEA	Supported gas-fired peaking projects; enabled NGDE participation in power peak-shaving
Clarified support for natural gas power generation projects to engage in joint operations	2026	NEA	Broadened NGDE market access and business models

3.2. Steady progress in project implementation

Driven by policy incentives, a number of NGDE projects have been successively implemented. The Shantou Chenghai Yixin NGDE Project in Guangdong Province plans to

construct two 75 MW gas–steam combined cycle generating units in its first phase, with an estimated annual power generation of approximately 750 GWh and annual heat supply of approximately 1.2 million tons. The Qingyuan Shijiao NGDE Project has completed two 100 MW–class gas–steam combined cycle cogeneration units, with annual power generation of 1.1 TWh and annual heat supply of 2.03 million GJ [10]. The Guangxi Huaneng Nanning Jiangnan Distributed Energy Station is designed for annual power generation of 660 GWh and annual steam supply of 300,000 tons, achieving energy utilization efficiency exceeding 80%. The Phase I project of Chengdu Tianfu International Bio-city NGDE has commenced operation, providing stable steam, cooling, heating, and electricity services to biopharmaceutical enterprises in the park. Upon full completion, it is expected to generate annual sales of 1.5 TWh of electricity, 1.63 million tons of steam, and 5.45 million GJ of cooling [24].

In addition to these large-scale projects, several innovative NGDE applications have emerged. In November 2025, the PipeChina Group officially put into operation China's first high-pressure natural gas long-distance pipeline residual pressure power generation project in Nantong, Jiangsu, expected to generate 3 GWh of electricity annually and reduce carbon emissions by over 2,000 tons [21]. In December 2025, PipeChina further launched the country's first pressure energy zero-carbon data center in Shaoxing, Zhejiang, establishing an integrated synergistic operation system that links pressure energy, electricity, cold energy, and computing power. The Chengdu Gas Group built the city's first multi-energy complementary gas-fired power project at the Siemens Industrial Park, using four 1,200 kW gas generator sets with a daily power generation capacity of 40,000 kWh [24]. The Datang Rugao NGDE Project, a national energy administration first batch gas turbine innovation development demonstration project with a total installed capacity of 91.4 MW, uses the first China Aero-Engine AGT–25 domestic gas turbine; in September 2025, units 2 and 4 were officially transferred to commercial operation[10]. The Chongqing Huafeng NGDE Project, with an installed capacity of 100 MW, achieves an annual comprehensive energy efficiency of 86.7%—far exceeding the “not less than 70%” requirement stipulated in the Cogeneration Management Measures.

3.3. The significant gap between scale and targets

Despite steady project implementation, a notable gap remains between overall industrial scale and policy expectations. By the end of 2025, China's NGDE installed capacity had reached approximately 60 GW, accounting for over 5% of the national total installed capacity [2, 14]. However, a 2025 report by the China City Gas Association indicated that the number of NGDE projects remained significantly distant from the target of constructing approximately 1,000 NGDE projects set in the 12th Five-Year Plan primarily due to high operating costs [9, 18]. Global NGDE installed capacity is projected to exceed 250 GW by 2025, with China contributing over 30% of incremental capacity—yet this increment manifests more in absolute numerical growth than in share of the power mix [8, 15]. In 2026, the national new natural gas power generation installed capacity reached 18.7 GW, of which over 63% were

park-level distributed projects—yet 41 signed natural gas power generation projects were forced to suspend or delay due to early-stage pitfalls [7, 10]. The level of industrial standardization and professionalization still requires significant improvement [9, 23].

4. Multiple dilemmas of NGDE in China

4.1. Cost dilemma: The “economic deadlock” of gas–electricity price inversion

Gas-fired integrated costs substantially exceed those of mainstream power sources. This constitutes the most fundamental obstacle constraining NGDE development. China’s integrated gas-fired electricity costs range from approximately 0.059–0.072 USD/kWh (0.59–0.72 RMB/kWh), far exceeding those of coal-fired power (approximately 0.030–0.040 USD/kWh), hydro, wind, and solar power [8, 15]. In the context of deepening electricity market liberalization, gas-fired power finds itself at a distinct disadvantage in competitive bidding [16, 22].

Rising gas prices have continued to squeeze profit margins. In 2026, the LNG long-term contract pricing mechanism shifted to the Japan Korea Marker (JKM) plus a 1.8 USD/MMBtu premium, while domestic pipeline transmission fees were also raised [9, 25]. These changes pushed the benchmark gas price from 2.8 RMB/Nm³ to 3.45 RMB/Nm³. Meanwhile, 12 provinces including Guangdong and Zhejiang have adopted a dual-track pricing system consisting of capacity payments and energy charges; under which distributed generation projects that have not obtained peak-load regulation capacity certification in advance are ineligible for the capacity compensation component [18]. Major turbine models such as Siemens SGT-800 and GE 6F.04 now mandate major overhauls every 4,000 operating hours under 2026 maintenance agreements, an 18% reduction from 2022 standards, pushing full lifecycle operations and maintenance costs up by 23% [10, 11].

Long payback periods and insufficient capital attraction remain key financial barriers. A case study of an industrial park energy supply project shows a static payback period of 6.02 years [9, 14]. When unit costs drop to 7,000 RMB/kW, regions including Jiangsu, Chongqing, Shanghai, and Guangdong can be prioritized for deployment. However, against the backdrop of an immature carbon market and incomplete gas–price linkage mechanisms, the long-term returns of projects face considerable uncertainty [12, 23]. Notably, a study on natural gas distributed coupled new energy projects shows that in a comprehensive scenario balancing cost minimization and carbon emission minimization, the daily operating cost increases by only 4.6% compared with the pure cost-minimization scenario, while carbon emissions decrease by 10.9% [7, 26].

4.2. Gas supply dilemma: High import dependence and insufficient storage capacity

Natural gas import dependence remains persistently high. China is characterized by a resource endowment of poor oil and scarce gas. The high import dependence on natural gas exposes supply to international market dynamics, geopolitical factors, and various unforeseen events [15, 20], as illustrated in Figure 2. The 14th Five-Year Plan for Modern

Energy System Development set a target of domestic natural gas production reaching 230 billion cubic meters or more by 2025 — yet this level still cannot meet domestic demand [18].

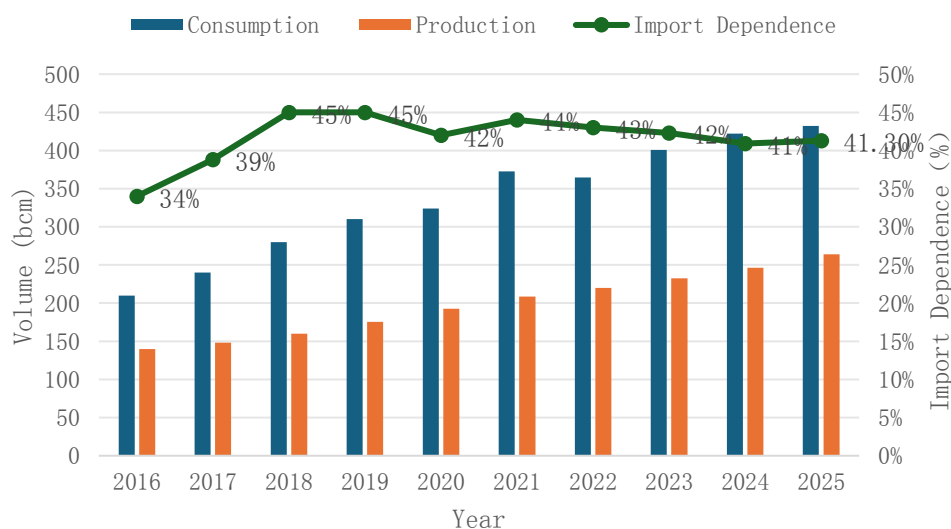


Figure 2. Consumption, production & import dependence of natural gas in China (2016-2025). (Source: the figure is drawn by the author).

Insufficient gas storage capacity constrains peaking capability. China’s gas storage facility construction lags behind, with insufficient storage capacity to effectively respond to seasonal gas consumption fluctuations and sudden supply disruptions [9, 14]. This directly constrains NGDE’s ability to function as a peaking power source—during periods of gas supply shortage, distributed energy projects may face the predicament of “no gas to burn” [21, 22].

Gas costs are difficult to pass through effectively. Under the current electricity market framework, gas-fired electricity feed-in tariffs remain tightly regulated, while gas prices fluctuate with international markets—this gas-electricity price inversion keeps NGDE projects in the unfavorable position of rigid costs and elastic revenues [8, 15]. Even in provinces that have adopted dual-track pricing, such as Jiangsu’s Datang Rugao project with an electricity price of 0.532 RMB/kWh and capacity price of 45 RMB/kW month, the electricity price remains far below the gas-fired integrated cost range of 0.59–0.72 RMB/kWh [10].

4.3. Institutional dilemma: Incomplete grid integration mechanisms and market access barriers

Grid integration mechanisms present institutional obstacles. NGDE projects face considerable uncertainties in the grid integration process. Grid integration faces numerous restrictions, including grid technical conditions, precise metering and control methods, modifications to existing grid design procedures, and lack of necessary infrastructure [3, 19]. Currently, China has yet to issue grid integration standards specifically for distributed power sources such as natural gas CCHP systems [8, 15], making grid integration conflicts particularly acute. The 2026 version of the Southern Power Grid Distributed Power Source Grid Integration Technical

Specification mandates island detection response time ≤ 0.2 seconds and independent dual-plane access for the dispatch data network [18].

Complex project approval processes and hidden high thresholds stem from the 2026 environmental regulations. In 2026, new environmental regulations require all gas turbine exhaust outlets to install online NMHC monitors with data transmitted directly to provincial ecological cloud platforms; the factory boundary ozone precursor concentration limit has been tightened to 0.06 ppm; and noise control has tightened the standard by adding a clause specifying that nighttime noise peaks must not exceed 55 dB [9, 10]. Environmental impact assessment preparation units must hold the gas power generation special qualification issued by the Ministry of Ecology and Environment in 2025. One Suzhou industrial park project was halted by resident complaints because the fugitive NMHC emission prediction value exceeded the new standard by 0.3 mg/m³ [7, 24]. Furthermore, the 2026 Distributed Energy Project Approval Work Guidelines require land use to be industrial land or new industry land with distributed projects on ecological green spaces rejected from 2026 [18, 25].

Insufficient cross-departmental coordination and policy implementation bottlenecks are pervasive challenges. NGDE involves approval and oversight from multiple departments including energy, housing and urban-rural development, environmental protection, and land resources [5, 18]. A project in Foshan had all equipment delivered on-site but got stuck at grid connection acceptance because it had not conducted reverse verification of grid-related protection settings, resulting in 112 days of construction delay [10].

4.4. Business model dilemma: Undiversified models and insufficient value realization

Over-reliance on the single CCHP model remains a significant barrier. Currently, most NGDE projects remain confined to the traditional CCHP model, with revenue sources primarily dependent on electricity, heating, and cooling fees [14, 19]. Business models are transitioning from standalone equipment sales toward integrated offerings of energy services and carbon-trading mechanisms. However, despite energy performance contracting projects now accounting for a notable share, most have yet to fully capitalize on diversified revenue streams [7, 27].

Neither the peaking value nor the carbon reduction value has been fully monetized. NGDE's flexible start-stop characteristics endow it with inherent peaking advantages, yet in the current electricity ancillary services market, the peaking value of distributed gas-fired power has yet to receive full recognition and reasonable compensation. China's power ancillary services fees account for only approximately 1.9% of on-grid electricity fees [16, 22]. Regarding carbon reduction, the CCER market restarted in 2023; by 2025, the first batch of 9 projects completed emission reduction registrations totaling 9.48 million tons [13, 20]. However, whether NGDE projects can be incorporated into the CCER system remains uncertain [12, 23].

The industry inertia of prioritizing construction over operation remains a prominent issue. Research on a data center NGDE project in Zhejiang Province shows that project economic benefits and carbon emission levels are positively correlated, but the growth rate

of carbon emissions far exceeds that of economic benefits [7, 26]. The extensive nature of operation and maintenance management further deteriorates project economics.

5. Breakthrough pathways for NGDE development in China

5.1. Enhancing gas supply security

Expanding domestic gas sources and reducing import dependence are critical priorities. This entails increasing domestic natural gas exploration and development efforts and promoting the large-scale development of unconventional natural gas such as shale gas and coalbed methane. The 14th Five-Year Plan for Modern Energy System set a target of domestic natural gas production reaching 230 billion cubic meters or more by 2025. Unconventional gas production capacity should be further accelerated to establish a diversified supply pattern of conventional gas, unconventional gas, imported pipeline gas, and LNG [3, 9].

To strengthen gas storage facilities and enhance peaking and supply security capacity, China is accelerating the construction of underground gas storage and LNG receiving terminals to increase reserve capacity. A multi-level natural gas reserve system is being established. Beyond national strategic reserves, local governments and enterprises are being encouraged to develop commercial storage facilities to strengthen the ability to respond to supply fluctuations and seasonal imbalances.

To strengthen the market-oriented pricing mechanism for natural gas, the upstream-downstream gas price linkage should be improved so that gas prices can reflect supply-demand changes in a timely manner. A gas-electricity price linkage mechanism should be explored for NGDE projects, under which feed-in tariffs or integrated energy prices would adjust upward when gas prices rise. The dual-track system consisting of capacity payments and energy charges, which has been piloted in 12 provinces, should be expanded nationwide, with peak-load regulation capacity certification processes streamlined accordingly [18, 22].

5.2. Optimizing gas pricing mechanisms

Localization of core equipment is essential to reduce initial investment. In July 2025, Harbin Electric Corporation successfully completed full-load test runs of its independently developed 16 MW HGT16 gas turbine—China's first 16 MW-class turbine with full independent intellectual property rights. In December 2025, the first domestically produced 16 MW-class prototype achieved ignition. The upstream localization rate has reached 72%, although high-end bearings still rely on imports. Strengthened R&D and industrialization efforts remain necessary.

Raising the self-consumption ratio maximizes local consumption benefits. Case analyses indicate that projects with self-consumption ratios above 65% yield significantly higher returns than those primarily exporting surplus power to the grid. Industrial parks and data centers are the largest application segments, accounting for 43% and 28% of the Chinese market respectively [7, 27].

Diversified policy support is critical for wider NGDE deployment. In June 2025, the Shanghai Municipal Development and Reform Commission released the *Shanghai 2025 First Half Natural Gas Distributed Energy Supply System Development Special Fund Allocation Plan (Draft)*, demonstrating sustained government support. As unit costs fall to 7,000 RMB/kW, regions such as Jiangsu, Chongqing, Shanghai, and Guangdong could be prioritized for accelerated deployment.

5.3. Diversifying market models

Approval processes should be streamlined to reduce institutional transaction costs. The 41 gas-fired power projects forced to suspend or delay due to early-stage pitfalls underline the urgent need for clearer and more predictable approval pathways [9, 10]. For small-scale renovations without new emissions, simplified approval procedures could shorten timelines, while broadening the pool of qualified EIA institutions could ease bottlenecks.

Grid integration mechanisms need improvement to ensure fair access. Dedicated grid integration standards for distributed sources such as gas CCHP systems should be issued without further delay. Unified access implementation rules should be established to eliminate regional inconsistencies. The 2026 Southern Power Grid Technical Specification could serve as a national model, provided that a sufficiently long transition period is allowed for project developers to adapt.

Cross-departmental coordination mechanisms should be strengthened. Joint approval and coordination mechanisms among energy, housing, urban-rural development, environmental protection, and land resources departments should be established to facilitate information sharing and standard unification. The ongoing electricity reform, which repositions the grid from a buy-sell margin-earning entity to a public utility charging only network fees, may further alleviate the conflict of interest between NGDE and the grid.

5.4. Advancing technological integration

The paradigm should shift from standalone operation toward multi-energy complementarity. The greatest opportunity for NGDE lies not in replacing others, but in coordinating with them. Research shows that hybrid systems combining gas turbines with renewables capture the wide load-regulation range and high efficiency of gas-based distributed energy, while also enabling the local consumption of renewable power [12]. This approach is exemplified by the Chengdu Gas Group's project at the Siemens Industrial Park, where optimizing for both cost and carbon emissions yields a 4.6% increase in daily operating cost against a 10.9% reduction in carbon emissions [26].

The peaking value of NGDE should be unlocked through participation in electricity ancillary services markets. Distributed gas-fired power should be incorporated into these markets, allowing its peaking value to be fairly compensated. *The Guiding Opinions on Enhancing Peak-Shaving, Energy Storage, and Intelligent Dispatching Capacity Building* explicitly propose the moderate deployment of peak-shaving gas power projects in regions with secure gas supplies and acute peaking needs.

Carbon asset value should be activated to build diversified revenue models. The development of carbon trading markets should be accelerated to include NGDE carbon reductions in emissions trading systems. The CCER restart confirms the viability of carbon credit trading: the first 9 projects completed emission reduction registrations of 9.48 million tons, with initial transactions of 748,800 tons at 80.45 RMB/ton [23]. Standardized mechanisms for carbon asset rights and benefit sharing should be established, making carbon revenues a meaningful contributor to project returns. New business models—including energy performance contracting and carbon asset management—warrant further exploration.

New scenarios such as data centers and emerging energy demands should be embraced. Data centers have become China's second largest NGDE application segment, with a 28% market share [27]. PipeChina's pressure-energy zero-carbon data center in Shaoxing has pioneered an integrated system linking pressure energy, electricity, cold energy, and computing power. This emerging application is expected to become a significant growth driver for NGDE.

6. Conclusion and policy implications

6.1. Conclusion

Driven by both the dual carbon goals and the 15th Five-Year Plan for Building a New Energy System, NGDE is currently at a critical stage of transitioning from policy-driven to market-oriented development. Policy dividends continue to be released — the Natural Gas Utilization Management Measures classify it as a priority category and policy directives explicitly call for developing distributed energy. Multiple dilemmas — high gas-fired electricity costs, gas supply security challenges, incomplete grid integration mechanisms, and undiversified business models—are intertwined, keeping this niche energy lingering outside the threshold of large-scale development.

The breakthrough for NGDE cannot rely on any single policy intervention, but requires coordinated efforts across four dimensions: enhancing gas supply security, optimizing pricing mechanisms, diversifying market models, and advancing technological integration. More importantly, NGDE must move beyond a pure substitution mindset — it is not meant to replace coal-fired power, nor compete with wind and solar—but rather to shift toward a synergy mindset of deep integration with renewable energy. Within the new energy system, NGDE's differentiated positioning lies in: serving as a flexible peaking power source to compensate for renewable energy intermittency, as an integrated energy supply system to enhance end-use energy efficiency, and as a multi-energy complementarity hub to achieve synergistic optimization across multiple energy sources.

From policy experimentation to industrial mainstream, NGDE requires not only policy support, but also institutional adaptation and market rule refinement. Only thus can this energy form — combining low-carbon cleanliness with flexible efficiency—truly contribute to the energy transformation in future.

6.2. Policy implications

The findings of this study carry several practical implications for policymakers, regulators, and industry stakeholders. Articulating these implications is essential to bridge the gap between theoretical analysis and actionable governance, ensuring that the identified breakthrough pathways can be effectively translated into concrete measures that accelerate NGDE deployment and contribute to China's dual carbon goals. These implications are presented below from three interconnected levels—national policy, provincial regulation, and industry practice—given that effective NGDE development requires coordinated action across all three.

For national-level policymakers: First, an integrated policy framework should be developed that treats NGDE not as a competitor to renewables but as a complementary partner. This requires moving beyond sectoral approaches that design gas and renewable policies separately. The synergy mindset framework advanced in this paper suggests that policy coordination across gas, electricity, and carbon markets is essential. Second, the CCER methodology should be expanded to explicitly include NGDE projects, particularly those that replace coal-fired boilers or integrate with renewable energy systems. The CCER market restart has demonstrated viability, but the eligibility of NGDE projects remains uncertain; clarifying this would unlock significant carbon revenue streams for project developers. Third, the national grid integration standards for distributed power sources should be issued without further delay, with reasonable transition periods that allow project developers to adapt to new technical requirements.

For provincial and local regulators: First, the dual-track system consisting of capacity payments and energy charges piloted in 12 provinces should be expanded nationwide, with peak-shaving capacity certification processes streamlined to ensure distributed projects can access capacity compensation. Second, local governments should streamline project approval processes by establishing one-stop service windows that eliminate redundant cross-departmental submissions. The current system, where projects require approvals from energy, housing and urban-rural development, environmental protection, and land resources departments with inconsistent standards, creates excessive delays. Third, targeted financial support should be provided to priority regions where NGDE unit costs have dropped to competitive levels, including Jiangsu, Chongqing, Shanghai, and Guangdong, to catalyze market takeoff.

For grid operators and project developers: First, grid operators should proactively develop unified access protection implementation rules that eliminate regional standard inconsistencies. The *2026 Southern Power Grid Distributed Power Source Grid Integration Technical Specification* provides a useful reference, but consistent application across regions is needed. Second, project developers should prioritize high-load, stable-demand users such as industrial parks and data centers — which together account for over 70% of the Chinese market — and design systems with self-consumption ratios exceeding 65% to maximize returns. Third, developers should actively explore business model diversification, including

energy performance contracting and carbon asset management, to move beyond the single CCHP revenue model.

The successful cases of PipeChina's pressure energy zero-carbon data center and the Datang Rugao project's use of indigenously developed AGT-25 gas turbines demonstrate that innovation in both technology and business models can unlock new value. With the implementation of these policy recommendations, NGDE can transition from policy experimentation to industrial mainstream, making a meaningful contribution to China's dual carbon goals.

Declaration of Generative AI and AI-assisted Technologies

During the preparation of this manuscript, the authors used generative AI tools only to improve language and readability. The authors take full responsibility for the content of the manuscript.

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Conflicts of interests

The authors declare that there are no potential conflicts of interest.

Authors' contribution

Conceptualization, Z.L.; methodology, Z.L. and J.Y.; investigation, Z.L.; resources, J.Y.; writing—original draft preparation, Z.L. and J.Y.; writing—review and editing, Z.L. and J.Y.; visualization, Z.L.; supervision, J.Y. All authors have read and agreed to the published version of the manuscript.

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