Grid connection and Electricity Market Reform under the Background of New Energy: A Case Study Based on Guangdong Province

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Abstract: Against the backdrop of China's "dual carbon" goals and structural economic transformation, the rapid growth of the renewable energy sector has posed new challenges to large-scale grid integration and market-oriented reforms. Using Guangdong Province as a case study, this research applies institutional economics, structural transformation theory, and comparative case analysis to examine the interaction between power market reform and renewable energy integration. The findings indicate that systemic barriers such as information asymmetry, state-owned enterprise monopolies, and local protectionism continue to constrain resource allocation efficiency and innovation incentives in China's electricity market. By comparing Germany's energy transition experience, the study highlights the importance of distributed generation, cross-regional power transmission, and spot market development, while proposing reform pathways tailored to China's national context. Policy recommendations include promoting the separation of grid enterprises' main and auxiliary businesses, accelerating the establishment of spot and ancillary service markets, enhancing cross-regional market coordination, and scaling up energy storage and green finance. This study contributes to the theoretical understanding of institutional reform under green transition and provides practical guidance for China's electricity market reforms.

Keywords: Renewable Energy Integration; Electricity Market Reform; Guangdong Case; Institutional Economics; Green Transition

1. Introduction

1.1 Research Background

Since the reform and opening-up policy, China's rapid economic development has seen a flourishing of various industries across China. This has been accompanied by a growing demand for electricity, and environmental issues have always been a major concern in my country. However, since the 21st century, the traditional electricity market has exhibited monopolistic characteristics in all aspects, compared to the market-based economy across various industries today. This has led to uneven resource allocation and inefficiencies, making it difficult to keep pace with my country's rapid development. Consequently, the marketization of the electricity sector ushered in a new round of institutional reforms in 2015. Within the current economic growth model, China is shifting towards high-quality development driven by innovation and sustainability, and the low-carbon transformation of its power system is accelerating. According to the 2021 Electricity Industry Development Report released by the China Electricity Council, national power generation increased from 5.74 trillion kWh in 2015 to 7.63 trillion kWh in 2020, with an average annual growth rate of 5.8%. While the proportion of market-based trading volume has increased significantly, institutional, functional, and regulatory aspects remain imperfect, and cross-regional trading barriers are severe.

After China proposed the goal of reaching carbon peak and carbon neutrality in 2020, this goal accelerated China's transformation from a traditional power system to a new power system. According to data released by the National Energy Administration, by the end of April 2025, the installed capacity of renewable energy power generation in China had exceeded 2 billion kilowatts, and the installed capacity of wind and photovoltaic power generation had exceeded 1.5 billion kilowatts, exceeding the installed capacity of thermal power; the national renewable energy power generation reached 1120.2 billion kilowatt-hours, accounting for

38%. The new energy industry (photovoltaic, wind power, electric vehicles, energy storage) has become the core carrier of structural transformation. With the increasing scale of renewable energy grid connection, new energy power generation has made the power supply more flexible and diverse, but this has brought challenges to the traditional power trading model [1]. Although traditional power trading has been reformed since 2015, its market freedom is not high, and there are problems such as increased transaction costs caused by information asymmetry. In addition, the current market is still dominated by state-owned enterprises, and local protectionism and administrative barriers are prevalent, resulting in inefficient resource allocation and limited innovation [2].

In the process of market-oriented construction of my country's power grid system, there have been problems such as the imperfect coordination mechanism between the medium- and long-term market and the auxiliary service market, which has led to disputes over electricity fee sharing; the failure to fully implement the separation of primary and secondary businesses of power grid enterprises, which will use their monopoly advantage in the transmission and distribution business to radiate fair competition in the upstream and downstream auxiliary business fields[3]; and the high rate of wind and solar power curtailment in order to achieve peak load regulation when facing grid congestion and other problems[4]. In today's industrial and economic transformation, these problems highlight the shortcomings of the development of my country's new energy industry under the current system.

As one of the earliest countries to start the energy transformation to new energy, developed countries such as Germany have achieved stable operation of a high proportion of new energy without major technological innovations [5]. Their electricity marketization, efficient management model for coordinating operators in the face of grid congestion, and distributed power generation structure are worthy of reference and learning in my country.

1.2 Problem

Currently, China's new energy grid connection and power market reform have the following prominent problems:

First, the market trading mechanism is imperfect, and information asymmetry is prominent. Under the current market system, medium- and long-term contracts still dominate, the development of the spot market is limited, and the marginal cost advantages of renewable energy are not fully reflected. Furthermore, the lack of transparency in the electricity pricing mechanism leads to information asymmetry among market participants, increasing transaction costs.

Second, state-owned enterprises (SOEs) still harbor monopolies and local protectionism. The dominant position of power grid companies in their core business of transmission and distribution makes it easy for them to create competitive barriers as they expand into upstream and downstream markets, stifling the vitality of private enterprises and innovative entities. Furthermore, some regions, driven by fiscal and employment considerations, tend to protect local energy projects, hindering the effective flow of cross-regional markets.

Third, renewable energy grid integration technology and grid flexibility are insufficient. With the rapid growth of renewable energy installed capacity, the power system faces greater challenges with frequency fluctuations and voltage stability. While coastal regions like Guangdong have some energy storage and pumped hydropower facilities, they remain insufficient compared to the rapid scale of renewable energy development. Furthermore, the failure to fully resolve cross-regional transmission bottlenecks has limited the absorption rate of renewable energy.

Fourth, the regulatory and legal systems are still imperfect. The existing laws and regulations such as the Electricity Law fail to fully cover the new problems brought about by the development of new energy [6]. For example, the market status and trading rules of emerging entities such as virtual power plants and vehicle-to-grid (V2G) are still unclear, and the regulatory system lacks independence and systematisms.

Against this backdrop, this study raises the following core questions:

What institutional barriers exist in China's new energy grid connection process?

How can market-oriented reforms interact with green transformation goals to promote the development of the new energy industry?

What implications does international experience (such as the German model) have for China's electricity market reform?

How to design a path for electricity market

reform that suits China's national conditions?

1.3 Research Significance

1.3.1 Theoretical significance

First, by introducing institutional economics, structural transformation theory, and national innovation system theory, this study deepens our understanding of the interactive relationship between institutional reform and energy transformation in the context of green transformation. While existing research has often focused on technical aspects or macro-institutional design, this study emphasizes how institutional barriers specifically constrain renewable energy grid integration and market-oriented reforms, providing a new theoretical perspective for renewable energy research.

Secondly, in the comparative case study, this study compares China, a typical "state-led economy", with developed countries such as Germany, summarizing the differences and commonalities in market-oriented reform paths, thereby expanding the academic boundaries of comparative research on energy governance models.

1.3.2 Practical significance

At the policy and practical level, this study can help inform targeted solutions for China's electricity market reform. By identifying key bottlenecks in the current system, it proposes pathways for promoting the separation of primary and secondary businesses among power grid companies, improving cross-regional market mechanisms, and promoting energy storage and green finance. These initiatives provide a reference for the government to formulate actionable policy measures.

This research also has direct practical value in achieving the "dual carbon goals," increasing the uptake of new energy, and stimulating private sector investment. Particularly in Guangdong Province, a region with high electricity load, this case study can provide valuable lessons for other regions across China.

Finally, this research has international significance. Against the backdrop of global energy transition and climate governance, China, as the largest developing country, can leverage its experience in power market reform and renewable energy grid integration to serve as a reference for other emerging economies and promote cooperation and exchange on green and low-carbon transitions worldwide.

2. Literature Review

Existing research on renewable energy grid integration primarily focuses on grid operation and technology. Scholars generally focus on the volatility of wind and solar power generation and its impact on system stability, proposing ways to enhance flexibility through energy storage, smart grids, and optimized dispatch (Xue Yuan et al., 2025). While these studies offer methodological contributions to addressing the engineering challenges of renewable energy integration, they also exhibit a pronounced "technology-centric" orientation and lack in-depth analysis of institutional arrangements and market mechanisms. In contrast, literature on electricity market reforms focuses more on market efficiency and resource allocation. For example, empirical research demonstrates that market-based electricity pricing can improve energy efficiency (Gang & Shu-Ra, 2020), but it also reveals structural obstacles such as state-owned enterprise monopolies and local protectionism (Munkhsaikhan & Kamal, 2024). While this type of research has yielded results in optimizing market mechanisms, it lacks relevance to the practical challenges of renewable energy grid integration.

International experience, such as that of Germany and the United Kingdom, demonstrates the crucial role of institutional and market design in managing the volatility of renewable energy. Germany ensures the stable operation of a high proportion of renewable energy through the development of spot and ancillary service markets (Gui Xiaolu, 2024), while the United Kingdom and the United States rely on independent regulatory mechanisms to enhance market transparency and competitive efficiency (Xie Jingdong et al., 2022). These experiences demonstrate that technological advancement alone is insufficient to address the challenges of renewable energy consumption; institutional innovation and market mechanisms are equally important. However, existing domestic research remains deficient in three areas: First, most studies lack a systematic integration of the gap between technology and institutions; second, while international experience offers valuable insights, China's state-led governance structure dictates the unique nature of its reform path; and third, regional case studies are insufficient, failing to fully illuminate the specific contradictions in the interaction between

renewable energy grid integration and market-oriented reforms in high-load regions such as Guangdong. Based on these findings, this article, using Guangdong Province as a case study and drawing on international comparisons, proposes a reform analysis framework that combines local adaptability with institutional innovation.

2.1 Theoretical Framework

The issues of renewable energy grid integration and electricity market reform involve both the technical logic of energy system operation and the economic logic of institutional design and market mechanisms. For a systematic analysis, this study mainly draws on the following three types of theories:

2.1.1 Structural transformation theory

Structural transformation theory emphasizes that the reallocation of resources across different industries and sectors during economic development is the fundamental driving force behind improved economic efficiency and technological progress. The rise of the new energy industry is a key manifestation of China's economic transition from a traditional, high-carbon energy system to a low-carbon, green one. In the electricity market, the integration and absorption of new energy sources not only represent a shift in energy supply methods but also a reshaping of institutional and market structures.

Within this framework, this study regards the integration of renewable energy into the grid as a core link in structural transformation and explores how institutional constraints affect the effective flow of resources between different energy sectors.

Specifically, the structural transformation theory helps explain why, despite the gradual decline in the cost of new energy, its large-scale grid connection is still subject to institutional barriers (such as grid monopoly and local protectionism) [7].

2.1.2 Institutional economics

Institutional economics focuses on how institutional arrangements influence resource allocation efficiency and economic performance. In the electricity market, institutional barriers (information asymmetry, market access restrictions, and regulatory deficiencies) are often more decisive than technical issues.

According to institutional economics, the essence of market-oriented reform is to reduce transaction costs, reduce monopoly and rent-seeking behavior through institutional innovation, and thus improve market efficiency.

In the context of new energy, institutional economics can explain why the current grid structure and market rules are insufficient to support a high proportion of new energy access, and how to improve this situation through institutional design (such as separation of primary and auxiliary grids and construction of spot markets).

2.1.3 National innovation system theory

The theory of national innovation systems emphasizes that innovation relies not only on enterprises and markets but also on support from institutions, policies, and national governance structures. In the new energy industry, innovation encompasses both technological breakthroughs (e.g., energy storage, smart grids, and vehicle-grid interaction) and institutional innovation (e.g., market mechanism design and regulatory reforms).

With the help of this theory, this study analyzes the role of the state in the market reform of the power industry, especially how to stimulate the vitality of market players while maintaining energy security and macro-control.

By comparing the governance models of different countries, we can further understand the boundaries of the state's role in the marketization of new energy and the effectiveness of policy design.

In summary, this study applies structural transformation theory to explain the macro-background of new energy grid integration, uses institutional economics to analyze the mechanism logic of market-oriented reforms, and combines national innovation system theory to discuss the role of government in institutional design, thereby constructing a multi-dimensional analytical framework.

2.2 Research Methods

In order to deeply explore the interactive mechanism between renewable energy grid integration and electricity market reform, this study will adopt the following research methods:

2.2.1 Literature review method

By systematically combing through relevant research at home and abroad, summarizing existing achievements and shortcomings, we provide a theoretical basis and entry point for research.

Categorize and organize topics, such as: power

grid system and new energy grid connection, power market reform, and reference to international experience.

Comparing scholars' perspectives and identifying the contributions and controversies of different studies

ensures that the research builds on existing literature, avoids duplication, and accurately identifies research gaps.

2.2.2 Comparative case study method

Germany was selected as the core international case and Guangdong Province as a typical domestic case for cross-national and regional comparisons.

German Case: Sorting out the market-oriented reform paths in Germany's energy transition (distributed generation, direct current transmission, and the construction of spot and ancillary service markets), and analyzing their achievements and shortcomings.

Guangdong Case: Focuses on the prominent contradictions in Guangdong in the integration of new energy grids and power market reforms, such as the contradiction between high electricity demand and new energy consumption, grid transmission bottlenecks, and limited coverage of the spot market.

Through comparison, we summarize the reform logic and applicability under different institutional backgrounds and propose a localized reform path for China.

2.2.3 PESTEL analysis

PESTEL analysis systematically evaluates the feasibility of market-oriented reforms from six dimensions: politics (P), economy (E), society (S), technology (T), environment (E), and law (L).

Political dimension: Analyze the game and coordination between the central and local governments in the electricity market reform.

Economic dimension: evaluate electricity trading efficiency, return on investment, and industrial competitiveness.

Social dimension: Investigate the public and businesses' acceptance of and perception of fairness regarding renewable energy power.

Technical dimension: Examining the supporting role of technologies such as energy storage, smart grids, and blockchain transactions in marketization.

Environmental dimension: measures the effect of reforms on carbon emission reduction and the improvement of new energy consumption rate.

Legal dimension: Examining the adaptability and room for improvement of the existing legal system in the reform.

Through this method, the feasibility of reform paths can be evaluated from multiple perspectives, avoiding the one-sidedness of a single technical or economic perspective.

3. Case Analysis

China's regional practices, represented by Guangdong Province, reveal the real contradiction between the integration of new energy grids and market-oriented reforms. On the one hand, as the province with the highest electricity load, Guangdong's new energy installed capacity continues to expand, gradually becoming an important component of power supply; on the other hand, insufficient energy storage, limited cross-regional transmission, lagging market mechanisms and regulatory defects make it difficult for new energy to effectively play its marginal cost advantage, and the problem of wind and solar power curtailment still exists. Although Guangdong has explored spot market pilots, energy storage construction and vehicle-grid interaction, its institutional reforms and market innovations are still insufficient compared to the huge demand [8].

In contrast, Germany has achieved stable operation of a high proportion of renewable energy by relying on spot and ancillary service markets, distributed generation and cross-border interconnection; the United States has built a "capacity + spot + ancillary service" system through regional markets such as PJM and CAISO, and California has promoted the popularization of distributed photovoltaics and energy storage; Europe has accumulated experience in cross-border market coupling and virtual power plant mechanisms. However, these countries also face price fluctuations and unstable corporate profits caused by excessive marketization [9]. Overall, the experience of Europe and the United States shows that the high proportion of renewable energy grid connection depends on multi-level market mechanisms and cross-regional cooperation, while China's particularity lies in the need to balance market efficiency and stable returns under the "state-led" framework and explore institutional paths that are in line with local national conditions [2].

4. Analysis and Discussion

The Guangdong case shows that the core

bottleneck of China's new energy grid connection and market-oriented reforms is not technology, but institutional constraints: market mechanism defects, state-owned enterprise monopoly and local protectionism, insufficient transmission and storage, and lagging supervision [10]. These problems make it difficult for new energy to enter the market competition fairly, and the marginal cost advantage cannot be fully realized [10].

Combining institutional economics with structural transformation theory reveals that market-oriented reforms are a key driver of green transformation by reducing transaction costs and optimizing price signals and incentive mechanisms. This goal, in turn, drives institutional innovation, forcing the government to accelerate reforms in the power grid system, cross-regional collaboration, and regulatory mechanisms. Compared to the experiences of Germany, Europe, and the United States, China's reforms are unique in their dual nature of "state-led + market-driven": maintaining energy security while gradually introducing competition and flexibility mechanisms. This necessitates a gradual approach to reform, striking a balance between local pilot projects and nationwide rollout.

In summary, integrating new energy into the grid presents not only a technological challenge but also a matter of institutional innovation. Only through the interaction of technological progress and institutional reform can China truly achieve the dual goals of large-scale integration of new energy and green transformation.

5. Policy Recommendations

5.1. Grid System Reform: Promoting the Separation of Primary and Auxiliary Power Systems and Cross-Regional Coordination

5.1.1 Promote the separation of primary and secondary businesses of power grid companies

Currently, power grid companies continue to expand into upstream and downstream sectors, leveraging their monopoly advantage in transmission and distribution to create competitive barriers. We should draw on international experience to further promote the separation of primary and secondary businesses of power grid companies:

Clarify the boundaries of the core business of power transmission and distribution. Grid companies should focus on infrastructure construction and safe grid operation, and should not use their dominant market position to participate in competitive sectors.

Separate auxiliary industries, gradually divest grid companies of their monopoly influence in secondary businesses such as integrated energy, energy storage, and electricity sales, and introduce diversified market players;

Establish an independent trading platform to ensure the neutrality and transparency of the electricity trading market.

5.2.2 Strengthen cross-provincial and cross-regional market coordination. While loads are concentrated in coastal areas such as Guangdong, new energy resources are mainly distributed in the southwest and northwest. Cross Regional power trading barriers have severely restricted the consumption of new energy. Suggestions:

Establish a unified national electricity market coordination mechanism to reduce hidden barriers set up by local governments for taxation and job protection;

Promote the construction of inter-regional power transmission channels, such as accelerating the progress of ±1100kV UHVDC transmission projects [11];

Introduce a cross-regional capacity compensation mechanism to ensure that the exporting and importing areas share benefits in electricity trading.

5.2 Market Mechanism Construction: Improving the Spot and Ancillary Service Markets

5.2.1 Accelerate the promotion of the spot market

The spot market is key to realizing the marginal cost advantage of new energy. Pilot regions such as Guangdong should take the lead in achieving full operation of the spot market, and then gradually promote it nationwide.

Expand market coverage: Incorporate new energy power stations and energy storage companies into the spot market;

Optimize electricity pricing mechanisms: Introduce time-of-use electricity pricing and dynamic electricity pricing to enhance the guiding role of price signals on flexible resources;

Promote the capacity market: Ensure long-term returns on new energy investments through capacity compensation mechanisms and reduce market uncertainty.

5.2.2 Improve the ancillary services market.

Under conditions with a high proportion of renewable energy, the system requires more peak shaving, frequency regulation and backup services.

Establish a unified national ancillary services market and clarify the market position of flexible entities such as energy storage and virtual power plants [12];

Reasonable compensation mechanisms for entities that provide flexibility services, such as dynamic frequency regulation incentives;

Encourage the participation of market-oriented regulatory resources, such as vehicle-to-grid (V2G) and demand-side response.

5.3 Technology and Infrastructure Support: Energy Storage and Smart Grid

5.3.1. Vigorously develop the energy storage industry

Energy storage is the key to solving the volatility problem of new energy. Suggestions:

Scale up the construction of new energy storage systems: Prioritize support for the construction of electrochemical energy storage and pumped hydropower storage, and expedite the approval and grid connection processes;

Promote the application of electric vehicle energy storage: Encourage new energy vehicles to participate in electricity market regulation through vehicle-to-grid (V2G) interaction;

Improve the energy storage business model: Increase the returns of energy storage projects through capacity leasing, ancillary service compensation, green financial instruments, etc.

5.3.2 Promoting smart grids and distributed energy

Build an intelligent dispatching platform: achieve unified management and control of different renewable energy power stations and improve the flexibility of grid dispatching;

Promote distributed generation and microgrids: In load-center areas such as Guangdong, encourage the construction of distributed photovoltaics, industrial and commercial energy storage, and microgrids;

Develop digital trading platforms: Utilize blockchain and cloud computing technologies to enhance the transparency and security of electricity transactions.

5.4 Supervision and Guarantee Mechanisms: Independence, Transparency, and Policy Coordination

5.4.1 Establish an independent regulatory agency

Drawing on Germany's experience, China should explore the establishment of a relatively independent power market regulatory agency to avoid excessive dependence of regulatory power on the government or power grid companies. The functions of this agency include:

Market rule formulation and enforcement supervision;

Third-party market monitoring and information disclosure;

Dispute arbitration and fair competition protection.

5.4.2 Improve the legal and policy system

On the basis of the Electricity Law, further refine the status of new energy market players and trading mechanisms;

Promote the integration of the Energy Law and the Renewable Energy Law to establish a complete legal framework for green energy;

Incorporate the "dual carbon goals" into hard constraints at the legal level to form long-term policy stability.

5.4.3 Coordination of fiscal and financial support

Establish a green finance mechanism to support new energy and energy storage companies in financing through green bonds and carbon markets;

Establish a central and local fiscal compensation fund to alleviate short-term conflicts of interest arising from power reform;

Tax incentives and subsidy policies for qualified new energy and energy storage projects to lower the entry threshold.

6. Conclusion

Driven by the "dual carbon goals," China's renewable energy sector is developing rapidly, but its large-scale grid integration and power market reforms remain constrained by deep-seated institutional barriers. The case of Guangdong Province reveals that the core bottleneck is not technology, but rather flawed market mechanisms, state-owned enterprise monopolies and local protectionism, insufficient cross-regional transmission, and inadequate supervision. These issues hinder the realization of the marginal cost advantages of renewable energy, limiting both consumption and investment incentives.

Research shows that market-oriented reforms are a key driver of efficiency and green transformation, while green transformation goals,

in turn, drive institutional innovation. International experience suggests that the development of spot and ancillary service markets, the promotion of distributed generation, cross-regional collaboration, and independent regulation are the core systems for achieving a high proportion of renewable energy grid integration. China's reforms must explore a gradual path of "state-led + market-driven" within a state-led system. This article's contribution lies in revealing the interactive logic between renewable energy grid integration and market-oriented reforms, proposing a localized reform direction for institutional innovation, and providing valuable experience for other developing countries.

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