

Research on the Path and Performance of Green Transformation of Power Enterprises Under the "Dual Carbon" Goals

-- A Case of Shanghai Electric Power

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Abstract: The dual carbon strategy has reshaped China's industrial development logic, rendering green transformation an inevitable choice for energy-intensive firms pursuing high-quality sustainable growth. Given China's ongoing industrialization, large-scale legacy power assets and rising electricity demand, radical carbon reduction models adopted by Western economies are infeasible; a progressive categorized transition approach is more suitable. Taking Shanghai Electric Power as a representative integrated energy enterprise, this paper draws on transaction cost, categorized governance and triple bottom line theories. It distinguishes internal and external transformation drivers, constructs an integrated system covering unit retrofits, renewable energy expansion, industrial chain extension, digital low-carbon innovation and market-based support, and establishes a three-dimensional performance framework encompassing finance, environment and society. Empirical analysis based on the firm's long-term operational data reveals that policy-market constraints and internal operational upgrades jointly fuel low-carbon reform. While heavy capital outlays trigger short-term profit pressures, transformation optimizes business portfolios, cuts environmental costs and boosts corporate value in the long run. Relevant findings offer practical references for the low-carbon upgrading of peer thermal power enterprises.

Keywords: Dual Carbon Target; Green Transformation; Transformation Motivation; Transformation Path; Three-dimensional Performance.

1. Introduction

China delivered its commitment to carbon peaking and carbon neutrality to the global community in 2020, marking the formal launch of substantial progress in nationwide comprehensive green transformation starting from 2021. Energy production and consumption account for over 70% of China's total greenhouse gas emissions, among which the thermal power sector acts as the core subject of emission reduction [1]. Unlike European and American economies that have completed industrialization and transferred high-carbon industries overseas, China's industrial and digital sectors are expanding simultaneously with rigid growth in electricity demand. Coal-fired power plants still serve as the bottom guarantee for energy supply in the short term. Hasty and blanket shutdown of thermal power units will trigger cascading contradictions including asset stranding, regional economic recession and power shortage.

The thermal power industry is a typical heavy-asset sector with highly specialized generating units. Coupled with the normalized constraints of carbon trading market and Environmental Protection Tax Law, the extensive traditional business model is no longer viable. Located in the core Yangtze River Delta region, Shanghai Electric Power operates diversified businesses covering conventional coal power, wind and solar energy, comprehensive energy supply and solid waste recycling. Its operation scale and industrial positioning are consistent with most regional listed thermal power enterprises, with complete transformation practices and accessible long-term operational data, which endows it strong representativeness as a research case. This paper conducts a full-case study on Shanghai Electric Power,

forming a complete logical chain of transformation motivation, implementation path and comprehensive performance. Breaking the limitation of single financial indicator evaluation, this research integrates environmental benefits and long-term social value, and forms replicable practical paradigms for homogeneous comprehensive energy enterprises.

2. Compound Motivations of Corporate Green Transformation

2.1. External Motivations

External driving forces stem from institutional constraints and market pressure. In terms of policies, the Environmental Protection Tax Law, national carbon emission trading market and dual control targets of energy consumption and carbon intensity have formed a full-range rigid regulatory system. Thermal power enterprises are subject to direct economic costs for pollutant discharge and excessive carbon emissions, and may face production suspension and fines in case of violations [2]. Meanwhile, carbon border adjustment mechanisms in Western countries have raised export costs for high-carbon products, forcing the whole industrial chain to carry out low-carbon renovation. Regulators mandate listed power firms to disclose ESG information, and environmental negative events will directly trigger stock price volatility and institutional divestment, pushing enterprises to mitigate environmental risks proactively.

From the market perspective, industrial parks and data centers have strong demand for long-term green power procurement that brings stable electricity premiums. Capital markets favor low-carbon entities, with green loans and

carbon-neutral bonds carrying lower financing costs than ordinary credit products. Major power groups have accelerated investment in wind and solar storage sectors, whose steady returns continuously squeeze the living space of conventional coal power. The gradual improvement of capacity price and peak shaving auxiliary service markets has created extra revenue streams for flexible retrofitted units, further strengthening external transformation incentives. From the perspective of transaction cost economics, high specialization of power equipment and frequent policy adjustments increase investment uncertainty, slowing enterprises' willingness to allocate green capital.

2.2. Internal Motivations

Internal incentives center on operational risk control, profit expansion and long-term sustainable growth. First, coal prices fluctuate cyclically and easily lead to annual losses for thermal power businesses, while wind and photovoltaic projects incur almost no fuel costs after completion. Deploying renewable assets can smooth profit volatility and reduce operational risks. Second, energy-saving retrofits, waste heat recovery, co-combustion of sludge and CCUS recycling projects can cut resource consumption and create additional revenue from solid waste disposal and carbon utilization, diversifying profit sources to offset shrinking coal power earnings [3].

In the long run, the growth ceiling of pure thermal power business has appeared, while wind, solar and hydrogen energy industries are prioritized by national industrial policies. Developing green businesses helps enterprises build a second growth curve and break path dependence on high-carbon production. Moreover, sound low-carbon layout and improved ESG ratings help establish responsible corporate image, strengthen government and client cooperation, and form soft competitive advantages in comprehensive energy project bidding, supporting long-term corporate development.

3. Integrated Green Transformation Paths Under the Dual Carbon Goal

3.1. Basic Path: Clean Renovation of Existing Coal-fired Units

Renovating in-service generating units for energy saving, pollution reduction and flexibility is the primary short-term measure for enterprises. Full sets of ultra-low emission equipment including desulfurization, denitrification and dust removal are installed, together with fully enclosed coal yards and graded wastewater circulation systems to cut pollutant discharge at the source. Technical upgrades such as turbine flow passage optimization and boiler low-temperature economizer & flue waste heat recovery are carried out to reduce standard coal consumption per kWh. The synchronous renovation of energy saving, heating and flexibility (three-in-one reform) widens the load adjustment range of units, enabling enterprises to obtain auxiliary service income from peak shaving and capacity pricing to compensate declining power generation revenue. In the medium and long term, CCUS demonstration projects are deployed. The Changxing Island CCUS project of Shanghai Electric Power has realized commercial operation, capturing coal-fired CO₂ for industrial raw materials and forming a replicable near-zero emission mode for coal power.

3.2. Growth Path: Scaled Development of New Energy

Large-scale exploitation of wind and solar power forms the core profit sector for long-term development. The company develops onshore large-scale wind-solar bases and offshore wind farms in eastern coastal areas, equipped with independent and shared energy storage to stabilize volatile output. Distributed photovoltaic and source-grid-load-storage microgrids are constructed in industrial parks to provide customized green power supply for industrial clients. Shanghai Electric Power deploys domestic Yangtze River Delta projects and overseas wind-solar assets in Hungary and Turkey to disperse resource risks across regions. A virtual power plant platform is built to integrate distributed adjustable loads and improve local renewable energy absorption capacity, realizing environmental value monetization through green certificates and green power trading. Biomass and gas-fired peaking units are matched to build a multi-energy complementary supply system [4].

3.3. Extension Path of Full Industrial Chain and Comprehensive Energy Service

Taking the coordinated development of the whole industrial chain as the path, this paper proposes to coordinate the layout of upstream resource terminals and downstream consumption terminals, so as to realize the strategic transformation of power generation enterprises from single power producers to integrated comprehensive energy service providers. At the upstream resource end, enterprises appropriately take equity stakes in high-quality coal bases to hedge price risks of fuel procurement, and realize carbon footprint tracking and low-carbon management of the entire supply chain. At the downstream consumption end, coal-fired units are fully utilized for collaborative solid waste disposal to conduct harmless treatment of municipal domestic sludge and various industrial solid wastes. While generating incremental revenue from waste disposal service fees, solid wastes are adopted to replace raw coal, thereby cutting fossil energy consumption. A digital smart energy management and control system is constructed for end-use energy scenarios. Targeting three core energy-consuming sectors including industrial production, building energy supply and transportation, integrated energy supply schemes featuring electricity-hydrogen clean energy substitution and complementary supply of cooling, heating, electricity and gas are implemented to fully tap comprehensive value-added benefits at the energy consumption terminal. This approach breaks the development bottleneck of traditional power generation enterprises characterized by single profit channels and heavy reliance on electricity sales revenue, and builds a diversified, coordinated, low-carbon and sustainable profit framework.

3.4. Supporting Path of Digital and Low-carbon Technological Innovation

Digital and low-carbon technologies serve as the underlying efficiency support for the transformation and upgrading of the entire industrial chain. For power production, a remote AI management and control system for smart power plants is developed to monitor energy consumption and carbon emission data in real time. Intelligent algorithms are leveraged to optimize the operating conditions of generating units, which effectively cuts auxiliary power consumption

and labor costs for operation and maintenance. From the perspective of regional energy operation, a market trading platform for virtual power plants is established. It connects distributed energy resources with grid peak shaving and the spot power market, fundamentally mitigating the resource waste arising from wind and solar curtailment. At the technology research and development end, continuous upgrades are carried out on high-power wind turbines, high-efficiency photovoltaic equipment and complete sets of industrial waste heat recovery devices. Meanwhile, a digital accounting platform for full-life-cycle carbon footprints is built to accurately quantify carbon emission reduction performance across diverse scenarios. This maximizes the asset appreciation gains generated by carbon allowances and voluntary greenhouse gas emission reduction projects [5].

3.5. Guarantee Path of Market and Financial Instruments

Market mechanisms and diversified financial tools ease capital pressure and establish long-term incentive systems. Internally, a standardized ESG governance framework and green supply chain access standards are formulated to drive upstream and downstream decarbonization. Externally, enterprises participate comprehensively in carbon quota, green power, green certificate, capacity price and peak shaving auxiliary service markets to convert environmental and regulating value into operating income. Financially, carbon-neutral green bonds, new energy REITs and low-carbon special credit are issued to revitalize heavy assets. Enterprises fully apply VAT refund and income tax incentives for wind and solar projects, and set up internal green investment funds to continuously lower comprehensive financing costs.

4. Analysis of Comprehensive Transformation Performance Based on Shanghai Electric Power

4.1. Phased Characteristics of Financial Performance

2015–2020 marks the investment stage of transformation. Massive investment in ultra-low emission renovation and new energy construction expanded capital expenditure and raised asset-liability ratio. Driven by high coal prices, the operating net profit margin of coal power dropped from 50% to 24%. Wind and photovoltaic sectors maintained a stable net profit margin of 62%–67%, yet their revenue proportion was limited, leading to overall profit pressure. In comparison, M&A of green assets delivers stable cash flow within 3 years while self-construction takes 3–5 years with larger upfront capital occupation. Small and medium regional power enterprises can shorten payback periods by priority M&A strategies.

2021–2025 is the performance release period. A large number of wind, solar and comprehensive energy projects were put into operation. By 2025, Shanghai Electric Power's total installed capacity reached 25.813 GW, with clean energy accounting for 61.83%. Profit from overseas new energy businesses rose by 110.61% year-on-year. Operating cash flow improved continuously and asset-liability ratio declined steadily. Offshore wind and wind-solar-storage integrated projects deliver far higher internal return rates than conventional coal power, making green sectors the core profit driver of the enterprise.

4.2. Continuous Improvement of Environmental Performance

Relying on multiple measures including low-carbon unit retrofits, new energy expansion, carbon capture and solid waste recycling, Shanghai Electric Power has achieved all-round progress in environmental governance over the past decade. All operational coal-fired units have undergone complete ultra-low emission upgrades with optimized dust removal systems, cutting total emissions of sulfur dioxide and nitrogen oxides by over 60% in ten years, with pollutant indicators consistently exceeding national standards. Its energy mix has grown cleaner, with wind and power generation expanding at an annual growth rate above 15%, driving steady declines in carbon emission per kilowatt-hour. The Changxing Island CCUS project commercially captures more than 30,000 tons of carbon dioxide yearly, while Caojing Power Plant co-incinerates municipal sludge to reduce coal use and landfill pollution, realizing coordinated benefits of pollution abatement, carbon sequestration and resource regeneration. Overall, the firm's full-process clean production capacity keeps improving, and a complete low-carbon operation system has gradually taken shape.

4.3. Improvement of Social Value and ESG Performance

The enterprise has continuously improved its ESG governance system, with progressive annual increases in its overall and dimensional scores of environmental, social and governance performance. It has been recognized as an ESG Model Enterprise among listed companies in the Yangtze River Delta for consecutive years due to its robust sustainable development management capabilities. In terms of business practice, the enterprise has deployed integrated energy projects in key urban areas including Lingang and Qiantan, covering low-carbon energy demands of millions of industrial and residential end-users. Meanwhile, its overseas new energy projects have boosted local employment and infrastructure development, and exported mature domestic technologies and operational experience for low-carbon power stations. Furthermore, the enterprise actively fulfills social responsibilities by participating in the formulation of low-carbon industry standards, rural photovoltaic assistance programs, and environmental public welfare initiatives. These practices continuously enhance its industrial influence and public recognition and realize the organic integration of economic value, ecological benefit and social responsibility.

4.4. Differentiation Law of Short-term and Long-term Performance in Energy Transition

From a temporal perspective, the first three years of transformation are dominated by massive capital investment accompanied by short-term financial pressure, while environmental improvement merely yields marginal effects. Over the medium-to-long term of five years or more, green assets generate consistent and stable operating cash flows, driving the simultaneous improvement of financial, environmental and social triple bottom line performance.

From a business dimension, the profitability of conventional thermal power is vulnerable to fluctuations in fuel prices and carbon prices, which only serves as a basic source of cash flow support. In contrast, green businesses including wind power, photovoltaic power and integrated

energy services deliver higher profit margins and greater operational stability, acting as the core driver for the enterprise's long-term value growth.

5. Conclusion

First, the green transformation of thermal power integrated energy enterprises is jointly driven by external policy and market constraints as well as internal operational upgrading demands, while transformation frictions arise from high asset specialization, frequent policy adjustments and high cost of low-carbon technologies. Given China's ongoing industrialization and rigid electricity demand, a progressive parallel model of stock renovation and new energy expansion must be adopted instead of blanket coal power shutdown.

Second, taking Shanghai Electric Power as a typical case, thermal power enterprises can realize all-round low-carbon upgrading through five coordinated paths: clean renovation of existing coal-fired units, scaled new energy development, full industrial chain extension to comprehensive energy services, digital low-carbon technological innovation, and market & financial supporting mechanisms. Different business segments can implement differentiated measures according to resource endowments.

Third, green transformation presents obvious temporal differentiation in performance. Large-scale upfront investment brings periodic financial pressure, while green businesses generate stable long-term cash flow with simultaneous growth of environmental and social benefits. Green M&A and circular industrial chain layout deliver higher comprehensive return than independent construction. The power industry generally faces common bottlenecks including high commercial cost of low-carbon technologies, insufficient incentives of carbon market and limited green financing channels for small and medium enterprises.

Fourth, smooth green transformation requires multi-stakeholder coordination. Enterprises shall formulate phased transformation plans and prioritize low-cost energy-saving retrofits, and adopt M&A to shorten investment payback cycles. Industrial associations can build shared platforms for low-carbon technologies and set up transition funds to resolve frictions such as unit retrofitting and staff resettlement. At the macro policy level, classified governance and the "establish first, phase out later" principle shall be adhered to. The national carbon market should be expanded with moderate carbon price hikes, while supporting policies for energy storage, virtual power plants and low-carbon equipment R&D shall be perfected to balance energy security and carbon neutrality targets.

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