Frontiers in Business, Economics and Management
ISSN: 2766-824X | Vol. 24, No. 2, 2026

Research on Financial Capability Analysis System of Petroleum Enterprises based on Knowledge Mapping

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Abstract: In the process of advancing the strategic goals of carbon peaking and carbonneutrality, the energyindustry constitutes an important field with the largestcontribution to domestic carbon emissions. Green total factor productivityincorporates environmental protection into the measurement of productionefficiency, balancing the scale of economic output, the intensity of resourceconsumption and the level of pollutant emissions simultaneously, and serves as a core criterion for measuring the low-carbon transformation outcomes of the energyindustry. Based on a new research framework, this paper identifies threedevelopmental characteristics of the industry, namely high-carbon lock-in, technological path dependence and regional spatial heterogeneity, and sorts out thetransmission mechanisms from the dimensions of technological innovation driving, market factor economic driving and policy regulation. This study provides practicalreferences for low-carbon transformation projects of energy enterprises, as well astheoretical support for governments at all levels to formulate regulatory and emission reduction supporting policies for the energy industry.

Keywords: Energy Industry; Green Total Factor Productivity; High-carbon Lock-in; Low-carbon Transition.

1. Introduction

Against the backdrop of continuous progress in global climate governance and the full implementation of China's "Dual Carbon" strategy, accelerating the green and low-carbon transition of the energy industry and constructing a new clean and efficient energy system have become the core direction of high-quality industrial development in China. China's carbon emissions mainly originate from the production and consumption of fossil energy, among which carbon emissions from coal consumption occupy a dominant position. Traditional total factor productivity concentrates on the benefits of economic output, while ignoring resource depletion and negative environmental externalities arising from production activities. Its measurement results can hardly genuinely reflect the sustainable development level of the energy industry level [1].

Existing domestic and foreign studies have achieved abundant results on green efficiency measurement, technological innovation empowerment and environmental regulation effects, yet obvious research gaps remain. Most studies use quantitative models to test the impact of a single variable and lack in-depth analysis of the coupled transmission mechanism of interrelated factors. Most research adopts a provincial macro perspective. Few studies analyze the inherent high-carbon attributes of the energy industry and fully consider efficiency differences resulting from unbalanced regional development.

Therefore, based on the practical characteristics of high-carbon lock-in, technological path dependence and regional spatial heterogeneity in China's energy industry, this paper constructs a three-dimensional driving framework of "technological innovation—market factors—policy regulation", systematically sorts out the transition of green efficiency in the energy industry, and proposes systematic and implementable quality improvement methods combined with regional development differences.

2. Connotation and Characteristics of Green Total Factor Productivity in the Energy Industry

2.1. Connotation

The green total factor productivity of the energy industry expands the accounting boundary of traditional total factor productivity. The traditional measurement framework only examines the conversion relationship between capital, labor, energy inputs and economic outputs, and excludes environmental losses caused by production activities [2]. This indicator incorporates environmental negative external costs such as carbon emissions, waste gas, wastewater, solid waste and ecological damage into the evaluation system. It regards environmental capacity as a scarce production factor, adds the accounting dimension of undesirable outputs, and corrects the defect that traditional measurement methods overestimate industrial development benefits [3]. Meanwhile, its evaluation logic pursues coordinated balance among economic output, resource consumption and ecological protection. It fully adapts to the dual functions of the energy industry including fossil resource exploitation and energy supply security, balances multiple development goals of stable supply of energy products, intensive resource utilization and pollution reduction, and forms core characteristics different from the efficiency evaluation of light industry. In addition, green total factor productivity is not a static constant. It evolves dynamically along with the iteration of low-carbon technologies, adjustment of factor markets and optimization of environmental regulations, reflecting the sustainable evolution law that the green transition of the energy industry advances step by step and its driving factors keep changing with development stages.

2.2. Characteristics

2.2.1. High-carbon Lock-in of the Energy Industry

China's energy industry has long taken fossil energy as the core supply source. A large number of high-carbon production equipment and fixed assets have accumulated in the sector, forming a stable industrial structure and path dependence. The energy production system has operated under the traditional fossil energy model for a long time and gradually evolved into an inherent development pattern of the industry, forming typical industrial features that differ from light industry and service industry.

2.2.2. Green Technological Path Dependence

The development of low-carbon technologies in the energy industry has two inherent attributes, namely asymmetry and path dependence. Different types of low-carbon technologies have objective differences in R&D investment, transformation cycle and emission reduction potential. Clean transformation technologies for fossil energy and cutting-edge new energy technologies form a natural dividing line in development.

Meanwhile, market entities select upgrading directions on the basis of their long-term accumulated technical foundation. Traditional energy enterprises and new energy operators form different development routes according to respective technical accumulation. The technological upgrading of the whole industry therefore presents an obvious differentiated pattern, which acts as an important feature distinguishing the energy industry from other industries.

2.2.3. Regional Spatial Heterogeneity

China's energy industry exhibits prominent regional spatial heterogeneity and spatial spillover characteristics. Regions across the country have inherent differences in resource endowments, industrial layout and economic foundation, resulting in a differentiated distribution pattern of green total factor productivity of the energy industry in various regions. Resource-rich areas, new energy agglomeration areas and economically developed areas form regional development gaps in industrial structure and technical allocation. Meanwhile, technological experience, factor allocation and green policies of the energy industry feature cross-regional transmission. Obvious spatial spillover and regional linked development can be observed, which constitute typical spatial development characteristics of China's energy industry.

3. Driving Mechanism of Green Total Factor Productivity in the Energy Industry

3.1. Technological Innovation Driving Dimension

Technological innovation serves as the core endogenous force to break the high-carbon lock-in of the energy industry and drive the growth of green efficiency [4].

Technological innovation continuously empowers industrial green upgrading by updating low-carbon production paradigms, optimizing industrial factor allocation and smoothing channels for technology transformation. Meanwhile, restricted by the inherent technological path dependence of the industry, it forms a complex efficiency driving mechanism.

3.1.1. Technological Innovation of Clean Energy Substitution Facilitates Efficiency Improvement

The clean energy technology system includes two technological paradigms of energy structure substitution and clean improvement of traditional production capacity. The two types of technologies jointly form the technical foundation for the low-carbon evolution of the industry. Different types of low-carbon technologies have differentiated emission reduction measures and adaptive attributes. They correspond to the dynamic renewal of technological innovation in two development directions of the structural transformation of the energy system and the optimization and upgrading of existing production capacity, and directly determine the carbon emission constraint capacity and green production level of the industry.

Technological iteration and upgrading can effectively weaken the inertia of high-carbon production, reduce environmental negative externalities in production links, and continuously promote the improvement of green total factor productivity. Lagging technological innovation will solidify the original production mode, and restrict the long-term growth of industrial green efficiency.

3.1.2. Digital and Intelligent Transformation Optimizes Production Management and Control Processes

Digital and intelligent technologies provide important support for optimizing the factor allocation efficiency of the energy industry. They improve factor utilization efficiency by reshaping industrial production management modes. The intelligent technology system can realize refined matching and dynamic regulation of industrial production factors, energy consumption levels and pollution emissions. It alleviates the factor mismatch caused by traditional extensive production. Its core driving mechanism lies in optimizing the allocation structure of core production factors such as capital, labor and energy. It reduces ineffective input and undesirable outputs on the basis of stable industrial output, achieves two-way optimization of production performance and ecological performance, and offers vital technical support for the green upgrading of high-carbon industries.

3.1.3. Industry-University-Research Collaborative Innovation Accelerates the Transformation and Application of Green Technologies

Industry-university-research collaborative innovation serves as key support for connecting cutting-edge technologies with industrial application and improving the driving mechanism of technological innovation. The collaborative innovation mechanism can integrate theoretical innovation resources from research institutions and practical application resources from industries. It breaks institutional barriers between technology research and development and industrial implementation, and realizes effective circulation and industrial sharing of green technological innovation achievements. An efficient collaborative innovation system can balance the asymmetric characteristics of industrial technological development, narrow regional gaps in technological development, and amplify the enabling effect of technological innovation on green efficiency. Blocked innovation and transformation mechanisms will lead to idle technological innovation resources, and greatly weaken the driving effect of technological progress on the industrial green transition.

The market-oriented allocation of production factors, energy price formation mechanism, industrial competition pattern and industrial spatial agglomeration jointly constitute the market-oriented endogenous driving system for the evolution of green efficiency in the energy industry. They profoundly affect the utilization level of industrial factors as well as the spatial differentiation and spillover effect of regional green efficiency.

3.2. Market Factor Economic Driving Dimension

3.2.1. Optimization Effect of Capital, Labor and Energy Factor Allocation

The factor allocation structure constitutes the basic market condition determining the green production efficiency of the energy industry. Distortions in the factor market will trigger structural mismatches of capital, labor and energy resources. It results in inefficient agglomeration of industrial production resources and unbalanced regional distribution of factors, and restricts the promotion and application of green production modes. Market-oriented optimized factor allocation can guide various production resources to flow toward low-carbon and high-efficiency entities.

It improves the traditional extensive factor input structure, and realizes the dynamic balance among factor input, economic output and ecological loss. Reasonable factor flow and allocation structure can continuously release efficiency dividends and boost the growth of industrial green total factor productivity. Sustained factor mismatch will widen regional efficiency gaps and hinder the overall green transition of the industry.

3.2.2. Market-oriented Energy Price Mechanism Regulates Production and Operation Behaviors

The energy price mechanism acts as a core market-oriented lever to adjust enterprises' production decisions and preferences for low-carbon transition. Non-market-oriented pricing models fail to reflect resource scarcity and environmental external costs. Such models will solidify the traditional high-carbon production mode and strengthen the high-carbon lock-in characteristics of the industry. A market-oriented price system can realize the internal unification of energy value, resource costs and ecological governance costs. It reshapes the benefit structure of high-carbon and low-carbon production through price signals, and guides market entities to adjust production paradigms and energy consumption structures voluntarily. The market-oriented improvement of the price mechanism can continuously optimize the overall production layout of the industry, weaken path dependence, and promote the balanced development of regional green efficiency.

3.2.3. Industrial Competition Forces Enterprises to Actively Carry Out Green Transformation

The market competition pattern serves as an important endogenous mechanism driving the transformation of enterprises' green production. Intra-industry competition and substitution competition across industrial tracks together form the market pressure system for the green transition of the energy industry. Sufficient market-oriented competition will force market entities to take the initiative to optimize production modes and improve ecological performance, and build long-term competitive advantages through green production. Non-market factors such as market monopoly and entry barriers will weaken enterprises' incentives for low-carbon transition, lead to solidified production modes and delayed technological iteration. Differences in the intensity of market competition directly affect the overall vitality of green innovation in the industry, and further determine the evolution speed of green efficiency.

3.2.4. Industrial Agglomeration Generates Green Scale Economy Effects

The industrial spatial agglomeration is an important market spatial mechanism for the collaborative improvement of green efficiency in the energy industry. Industrial agglomeration presents prominent scale effects, technology spillovers and supporting coordination attributes. It reshapes the development pattern of the regional green production system. Agglomeration forms realize the sharing and circulation of regional production resources, green technologies and environmental supporting facilities. They reduce the systematic costs of industrial overall green transformation and alleviate the inherent imbalance of industrial green technology development. Industrial spatial spillovers drive the upgrading of regional overall production paradigms and weaken the heterogeneity of regional green efficiency. They further achieve the collaborative and progressive improvement of industrial green total factor productivity.

3.3. Government Policy Regulation Driving Dimension

Government policy regulation is the core external driving factor for the evolution of green efficiency in the energy industry. It mainly relies on institutional mechanisms and macro-control mechanisms to rectify market failures in the development of the energy industry. It systematically corrects the inertia of industrial high-carbon lock-in and the characteristics of regional development heterogeneity, and provides fundamental institutional support for the green and low-carbon transition of the industry.

3.3.1. Mandatory Environmental Regulations Constrain Corporate Pollutant Emissions

Mandatory environmental regulations constitute an administration-oriented rigid governance system. They define the ecological boundary of production activities in the energy industry by setting unified compliance standards for ecological environmental protection and carbon emissions. Such regulations can systematically standardize enterprises' production modes and curb extensive production behaviors, and restrain various undesirable outputs in the production process from the institutional perspective. Dynamic changes in regulation intensity will generate differentiated impacts. Moderate rigid control can force industrial green transformation and drive steady growth of green efficiency. Severe fluctuations in regulation rhythm will disturb the industrial production system and make the industrial green efficiency show periodic fluctuation characteristics.

3.3.2. Incentive Policies Including Carbon Trading and Green Subsidies Guide Industrial Low-Carbon Transformation

Incentive-oriented green policies belong to market-oriented flexible regulation mechanisms. Their core is to reconstruct the cost-benefit structure of enterprises' green production by quantifying the economic value of carbon emissions [5]. Such policies internalize the scarcity of environmental factors into corporate operating profits and losses. They change the interest pattern of traditional high-carbon production and foster the endogenous driving force for enterprises' low-carbon transition. Compared with rigid regulations, incentive-oriented policies mainly rely on market regulation. They can smooth fluctuations in industrial transformation, gradually eliminate industrial technological path dependence, narrow regional gaps in green development, and realize the gradual optimization of green efficiency. 3.3.3. Top-level energy industry planning coordinates the low-carbon development of the whole sector

Top-level planning for the energy industry is a long-term and overall macro institutional arrangement. It undertakes the core function of coordinating industrial structure, spatial layout, technological innovation and factor allocation [6]. Top-level planning can systematically coordinate the synergistic relationship among multi-dimensional factors including technology, market and policy. It reshapes the development pattern of the energy industry from a macro perspective.

Its institutional value is mainly reflected in weakening the inertia of the industrial high-carbon structure, optimizing the differentiated regional development layout, coordinating innovation resources and cross-regional factor flow, and ultimately realizing the long-term and balanced improvement of the overall green total factor productivity in the energy industry.

4. Promotion Strategies of Green Total Factor Productivity in the Energy Industry

4.1. Focus on Breakthroughs in Green Technology and Accelerate Empowerment through Digital and Intelligent Integration

Relying on the national support system for green energy innovation, China coordinates efforts to advance research on low-carbon technologies in the energy industry and foster a development pattern featuring coordinated innovation between new and traditional energy sources. It targets key technologies including long-duration energy storage, offshore wind power and high-efficiency photovoltaics in the field of new energy to continuously raise the development level of clean energy. Meanwhile, it optimizes renovation technologies such as carbon capture, clean coal utilization and waste heat recovery, and improves the technical system for the green upgrading of traditional energy production capacity.

Accelerate the digital and intelligent transformation of the energy industry. Relevant supportive policies are leveraged to promote all types of energy enterprises to realize smart upgrading. A unified national monitoring platform for energy consumption and carbon emissions will be established to achieve refined management and control of production data. Improve the industry-university-research collaborative innovation mechanism, set up pilot-scale demonstration platforms for green energy, straighten out the rules governing the transformation of scientific research achievements, and speed up the implementation and application of low-carbon technologies via technology trading platforms, so as to give full play to the supporting role of technological innovation in the green transition of the energy industry.

4.2. Improve Technology Promotion Mechanisms and Boost the Universal Popularization of Industrial Technology

The industry shall establish a standardized and regularized promotion system for green and low-carbon technologies, and upgrade the production processes and environmental governance systems of the energy industry on the basis of mature technological achievements. In light of the national layout and resource endowments of the energy industry, the industry shall deploy energy-saving production and clean governance technologies and equipment in different sectors, and continuously renew the overall industrial production technology system.

Regions across the country shall establish a cross-regional mechanism for coordinated technology sharing to facilitate the circulation of low-carbon processes, operation and maintenance experience and transformation schemes. The industry shall set up a dynamic screening and application mechanism for green technologies to guide enterprises to continuously advance the green transformation of production systems.

The popularization and iteration of technologies across all regions can consolidate the foundation of low-carbon production for the whole industry, continuously unleash dividends brought by technological upgrading, and support the energy industry to achieve high-quality low-carbon transition.

4.3. Rectify Distortions in Resource Mismatch and Optimize the Efficiency of Factor Allocation

It is necessary to improve the green financial allocation mechanism of the energy industry, innovate financial products such as carbon neutrality bonds and green funds, incorporate green efficiency evaluation into credit review standards, guide financial capital to tilt toward new energy projects and corporate clean transformation projects, and promote the rational cross-regional flow of social capital. Establish a national system for the training and mobility of low-carbon talents. Universities will launch more majors related to energy and low carbon to enrich talent reserves. Barriers to talent mobility across regions and enterprises will be removed, and supporting incentive policies will be adopted to achieve precise matching between talent resources and local industries.

Deepen the market-oriented reform of energy factors and advance the market-based trading of exploitation quotas, so as to facilitate the concentration of fossil resources in large-scale green enterprises. Optimize the rules for grid connection of new energy and power trading, expand the trading scope of clean energy, and raise the overall utilization efficiency of various production factors through market-oriented approaches.

4.4. Improve the Market Price System and Release Endogenous Momentum for Low-carbon Transition

Improve the modern energy price formation mechanism to ensure that prices fully reflect resource value, environmental costs as well as market supply and demand. Deepen the pricing reform of fossil energy, realize reasonable price adjustments through market transactions, incorporate ecological costs into enterprises' operational decisions, and drive the shift of production modes toward green development.

Improve the trading rules for new energy power, broaden trading channels for clean energy, raise the income level of new energy projects, attract various types of social capital to invest in low-carbon sectors, and optimize the investment layout of the energy industry.

Price signals can be leveraged to exert market regulation effects, encourage enterprises to independently carry out energy-saving transformation and technological upgrading, and drive the continuous optimization of industrial production modes via market-oriented mechanisms. The improvement of the energy price system can give full play to market regulation and foster stable and lasting endogenous momentum for the green transition of the energy industry.

4.5. Optimize Industrial Spatial Layout and Strengthen Collaborative Governance of Regional Policies

Based on territorial spatial and energy development plans, the government carries out coordinated layout of green energy industrial agglomeration zones at all levels and promotes the concentrated construction of clean energy bases, green mining areas and new energy industrial clusters.

It uniformly improves public infrastructure including environmental protection and digital facilities in industrial parks, attracts upstream and downstream enterprises to gather and extend the low-carbon industrial chain through special policies, and gives full play to the green scale effect generated by industrial agglomeration.

Relying on top-level design, the state establishes a cross-regional energy allocation mechanism. It realizes the cross-regional transmission of clean energy via ultra-high voltage transmission lines. Meanwhile, a regional adjustment system for carbon quotas and energy consumption indicators is set up to coordinate the transition pace of all regions, and foster an energy development pattern with complementary regional advantages and coordinated advancement.

Industrial policies guide the green upgrading of the entire energy chain and build a low-carbon system covering production, transmission, energy storage and consumption. Policy guidance drives enterprises across the industrial chain to carry out synchronous clean transformation, supports in-depth cooperation between energy entities and equipment research and development institutions, promotes the optimization of production modes across the industry through policy incentives, and consolidates the foundation for the long-term low-carbon transition of the energy industry.

4.6. Refine the Regulatory System and Consolidate Policy Guarantees for Low-carbon Transformation

The government continues to improve the environmental regulations and green institutional framework in the energy sector, and establishes a hierarchical and regularized governance system in response to the carbon peaking and carbon neutrality goals. It unifies the environmental access and clean production standards for the energy industry from the perspective of top-level design. Long-term institutional arrangements guide the industry to develop toward low-carbon and standardized directions, and form a stable development model for green production.

Local authorities introduce targeted supporting policies in light of local resource endowments and industrial foundations. They adopt fiscal subsidies, credit interest subsidies, project guarantees and other tools to support low-carbon transformation and the implementation of new energy projects, continuously expand the scale of green industries, and optimize the overall structure of the energy industry.

An assessment and evaluation mechanism for the green development of the energy industry shall be established to incorporate the outcomes of low-carbon transition into industrial evaluation. A governance approach combining incentives and penalties shall be adopted to deliver institutional guarantees. Supported by long-term policies, the green efficiency of the industry will be steadily improved, and the low-carbon transition of the energy industry will be further advanced in a sustained manner.

5. Conclusion

Against the backdrop of the dual-carbon goals, the improvement of green total factor productivity in the energy industry has ushered in an important strategic opportunity for industrial transformation. China’ s energy supply guarantee system has been continuously improved, the iteration of green and low-carbon technologies has accelerated, the market-oriented reform of production factors has been steadily advanced, the environmental governance system has become increasingly sound, and digital management and control capabilities have been enhanced, laying a solid economic and institutional foundation for the green transformation and development of the energy industry. The steady improvement of green efficiency in the energy industry requires giving full play to the multiple synergistic effects of technological innovation, market factor allocation, policy guidance and industrial agglomeration, so as to eliminate the high-carbon development model of traditional industries and build a modern energy industrial system that is green, efficient, balanced and coordinated. Through the advancement mechanism of technological research, factor optimization, spatial coordination and institutional improvement, macro strategic arrangements can be transformed into regular industrial development practices, building a stable and long-term development pathway for the green upgrading of the energy industry, and effectively supporting the high-quality development of the energy industry and the realization of the carbon peaking and carbon neutrality goals.

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