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Research on the Optimization Path of Green Operation Management of Energy Logistics under Dual Carbon Goals

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Abstract

Under the background of "dual-carbon" target, energy logistics, as a key link in the energy industry chain, is constrained by its high energy consumption and high emission problems in the process of green transformation. This paper focuses on the "three highs and one low" status quo of energy logistics (high proportion of traditional transportation, high energy consumption of equipment, high emission intensity, and low penetration rate of green technology), and constructs a three-dimensional optimization framework of "technology-policy-cost" through the literature research method and case study method to systematically analyze the core bottlenecks of green operation in the industry. The study analyzes the core bottlenecks of green operation in the industry. The study finds that the lack of technology standardization, dependence on imported core technologies, imbalance in cost sharing mechanism and insufficient policy synergy are the main obstacles, among which the penetration rate of new energy equipment in small and medium-sized logistics enterprises (SMEs) is only 9%, which is a significant gap with that of large enterprises. To address the above issues, this paper proposes three optimization paths: technology standardization and integration, policy incentives and cost sharing, and operation mode innovation, including the establishment of a unified carbon accounting standard, the promotion of the "rent-to-purchase" lightweight transformation mode, the construction of a carbon cost sharing mechanism based on the Shapley value method, and the development of multimodal transportation and shared energy storage modes. etc. Practical verification shows that these strategies can reduce carbon emissions per unit of cargo volume by 22.4%-28.7%, and reduce the cost of green transformation for small and medium-sized enterprises (SMEs) by 52%. The research results provide a replicable theoretical framework and practical solutions for the green operation of energy logistics, and help realize the dual-carbon goal.

Keywords *dual-carbon target; energy logistics; green operation; optimization path; carbon cost sharing; multimodal transport*

1. Introduction

As China's total energy consumption grows from 4.3 billion tons of standard coal in 2015 to 5.2 billion tons of standard coal in 2024 (data from the National Bureau of Statistics), energy logistics, as a key link connecting energy production and consumption, accounts for 18%-25% of the energy industry chain in terms of energy consumption and carbon emissions ("China Energy Logistics Green Development Report 2024"). Currently, there are "three highs and one low" in China's energy logistics: high proportion of traditional transportation (road transportation accounts for 65% of oil logistics), high energy consumption of equipment (fuel consumption of old tanker trucks is 30% higher than that of newer ones), high emission intensity, and low penetration of green technology (less than 10% coverage of photovoltaic pumping stations). This status quo not only leads to the industry's annual average energy loss of over 100 billion, but also restricts the realization of the dual-carbon goal.

The practical significance of this study is to provide a path for energy logistics enterprises to reduce carbon costs by refining replicable green operation optimization strategies; the theoretical significance is to construct a three-dimensional analysis framework of "technology-policy-cost" to fill in the gaps in the theoretical study of green operation in energy logistics.

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2. materials and methods

2.1 Analysis of the Current Status of Green Operations in Energy Logistics

In order to systematically explore the optimization path of green operation of energy logistics under the dual-carbon goal, this study ensures the theoretical depth and practical value of the research conclusions through the cross-application of multi-dimensional research tools.

(1) Literature research method: systematically sort out the theoretical achievements in the field of green logistics and energy management to construct a research and analysis framework. Through Chinese and foreign databases, literature search is conducted with the core keywords of "energy logistics", "green operation" and "dual-carbon target", focusing on screening highly cited literature and authoritative journals in the past five years. The results are summarized as follows The content of the literature search includes: (1) the application of green supply chain theory in energy logistics; (2) the mainstream methods of carbon emission accounting in energy logistics (e.g., LCA); (3) the policy mechanisms and technical paths of green operation in energy logistics at home and abroad. The theoretical gaps of the existing research are refined through literature analysis, and the research framework of "technology - policy - cost" three-dimensional synergistic optimization is clarified.

(2) Case study method: typical enterprise cases in the field of oil and natural gas logistics are selected for in-depth analysis. Domestic cases include the "Green Pipeline" project of the National Pipeline Network Group and the "Pipeline + New Energy Vehicle" intermodal transportation pilot project of an oilfield. Overseas cases include ExxonMobil's electric oil and gas pipeline system, and enterprise practices under the EU's "Energy and Logistics Carbon Tariff" mechanism. Through the comparison of cases, replicable green operation models will be refined, and a three-dimensional evaluation system of "technology selection - cost-effectiveness - policy adaptation" will be formed.

2.1.1Current Status of Transportation Links

As a key link in the energy industry chain, energy logistics exerts a profound impact on energy security and the achievement of dual-carbon goals through its operational efficiency and environmental benefits. Petroleum and natural gas, as vital components of China's energy system, reflect both the development characteristics of the industry and the pain points in green transformation through the current status of their logistics and transportation links. Different energy types exhibit significant differences in transportation structure, energy consumption levels, and equipment technology application, all of which urgently require systematic analysis and resolution.

(1) Petroleum logistics: In China's petroleum logistics transportation structure, road transportation has long accounted for over 65%, with an average one-way empty load rate of 28%. For example, field measurements on a crude oil transportation route of Huabei Oilfield show that diesel tank trucks consume 38 liters of fuel per 100 kilometers, corresponding to 96 kg of carbon emissions. In contrast, although electric tank trucks have an electricity consumption of 180 kWh per 100 kilometers and only 43 kg of carbon emissions, their purchase cost is 45% higher than that of traditional tank trucks, resulting in new energy tank trucks accounting for less than 12% nationwide. In long-distance transportation, railway crude oil dedicated trains account for only 15%, and most suffer from low efficiency in transshipment connection. For instance, although the theoretical time efficiency of railway transportation from an oilfield to a refinery is 2 hours shorter than that of road transportation, the actual transportation cycle is extended by 8 hours due to incompatible loading and unloading equipment.

(2) Natural gas logistics: Long-distance pipeline transportation accounts for 75%, but contradictions in urban distribution links are prominent. Taking the Beijing-Tianjin-Hebei region as an example, diesel vehicles with National V or lower emission standards account for over 80% of natural gas urban distribution vehicles, with an average distribution efficiency of only 2.5 tons per hour, 35% lower than that of new energy vehicles. Moreover, the carbon emissions of a single distribution trip reach 78 kg, 2.3 times that of electric distribution vehicles. Although pilot cities such as Chengdu and Shenzhen have promoted LNG-powered distribution vehicles, affected by insufficient coverage of gas stations (an average of 50 kilometers per station), the daily operating mileage of vehicles is only 180 kilometers, a 20% reduction compared to diesel vehicles.

Petroleum and natural gas logistics have obvious shortcomings in transportation structure, equipment energy efficiency, and infrastructure, which not only restrict cost reduction and efficiency improvement in the industry itself but also exert significant pressure on the environment. High energy consumption and low efficiency under the dominance of road transportation, as well as obstacles in the promotion of new energy equipment and insufficient supporting infrastructure, have become key barriers to the green transformation of energy logistics.

2.1.2Current Status of Warehousing Links

(1) Oil depot operation: Among oil depots in use nationwide, traditional fixed-roof tanks account for 68%, with a volatilization loss rate of 0.35%, corresponding to a carbon emission intensity of 0.72 kg/ton·day. In contrast, floating-roof tanks equipped with vapor recovery systems can reduce the loss rate to 0.08% and carbon emissions by 61%. However, the average investment in transforming a single oil depot reaches 58 million yuan, and the investment recovery period is as long as 4.2 years based on current oil prices, resulting in only 32% of oil depots in the East China region completing transformation. A survey by a large petroleum company shows that untransformed oil depots lose an average of 12,000 tons of oil and gas volatilization annually, equivalent to 23,000 tons of CO_2 equivalent emissions.

(2) LNG storage tanks: The application rate of boil-off gas (BOG) recovery technology is only 30%. Field measurements at a LNG receiving station in North China show that the

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methane concentration in directly emitted BOG reaches 98%, and its greenhouse effect intensity is 28 times that of CO_2. Although BOG re-liquefaction technology can recover over 90% of boil-off gas, each set of equipment costs over 80 million yuan and requires supporting cryogenic compressors (with localization rate less than 20), resulting in an average BOG emission rate of 7.5% for LNG storage tanks in South China, wasting approximately 180 million cubic meters of natural gas annually.

2.2 Quantification of Green Operation Benefits

Driven by the dual-carbon goals, the energy logistics industry urgently needs to achieve the synergy of cost reduction, efficiency improvement, and emission reduction through the application of green technologies. The application effects and economic feasibility of different green technologies in various links of energy logistics vary significantly. To intuitively present the environmental benefits and cost recovery cycles of green technologies, this study constructs a "Green-Benefit Matrix" (see Table 2-1), selecting typical technologies such as electric tank trucks, floating-roof tank transformation, and photovoltaic pump stations for quantitative analysis based on industry practice data.

Table 2-1 "Green-Benefit Matrix"

Green Technology	Typical Application Scenario	Carbon Emission Reduction Rate	Cost Recovery Period
Electric tank trucks	Short-distance petroleum transportation	55%-60%	3.5-4years
Floating-roof tank transformation	Crude oil warehousing	40%-45%	3-3.5years
Photovoltaic pump stations	Pipeline booster stations	30%-35%	2.5-3years

The analysis results of the "Green-Benefit Matrix" indicate that various green technologies exhibit different advantages and limitations in carbon emission reduction and cost recovery. Although electric tank trucks achieve significant carbon emission reduction, their high purchase cost leads to a longer cost recovery period; floating-roof tank transformation and photovoltaic pump stations, while achieving considerable emission reduction effects, have relatively shorter cost recovery cycles and more prominent economic benefits. This suggests that energy logistics enterprises should comprehensively weigh environmental and economic benefits based on their own business scenarios and financial strength when selecting technologies, prioritizing green technologies with high adaptability and optimal investment return rates to promote the sustainable development of green operations in energy logistics.

3. Analysis of Key Bottlenecks and Contradictions in Green Operations

3.1 Technical-Level Obstacles

3.1.1Lack of Standardization System

The technical standard system for green operations in China's energy logistics exhibits significant fragmentation. The discrepancy rate in carbon emission accounting methods across different energy types reaches 40%. For instance, petroleum logistics follows GB/T 32150 Energy Consumption Accounting Method for Petroleum and Petrochemical Industry, while natural gas logistics adheres to GB/T 28749 Energy Consumption Calculation Method for Liquefied Natural Gas (LNG) Production, Storage, and Transportation Systems. Fundamental differences exist between the two in boundary definition and emission factors, resulting in a lack of comparability in carbon data among enterprises. A survey of a cross-provincial energy logistics enterprise shows that the carbon intensity accounting results of its petroleum and natural gas businesses differ by a factor of 2.3, directly affecting applications for green credit and carbon asset trading.

The lag in standardization of new energy equipment interfaces is particularly prominent. The compatibility between the current GB/T 22344 Technical Specifications for Charging Interfaces of Electric Freight Vehicles and enterprise-customized interfaces is less than 30%. A North China oil depot, due to mismatched charging interfaces between electric tank trucks and the park's power grid standards (DC 1000V vs. AC 380V), invested an additional 1.8 million yuan in transforming its power distribution system, accounting for 18% of equipment purchase costs. Furthermore, data transmission protocols for intelligent monitoring systems remain unifiedno—for example, the interoperability rate between the Modbus protocol used in oil depots and the OPC UA protocol in natural gas stations is less than 50%, increasing full-chain data integration costs by 25%.

3.1.2Dependence on Imported Core Technologies

The localization rate of cryogenic LNG transportation equipment is only 22.7%. Core components such as -162℃ cryogenic centrifugal pumps and BOG compressors primarily rely on enterprises like Kawasaki Heavy Industries (Japan) and Linde Group (Germany), with procurement costs 3–5 times higher than domestic components. Data from a coastal LNG receiving station shows that the unit purchase price of imported cryogenic pumps reaches 1.2 million USD, 4.3 times that of domestic products with the same parameters. Moreover, the maintenance cycle lasts up to 3 months, leading to an 18% higher equipment failure rate compared to domestic components.

Insufficient precision of sensors in intelligent monitoring systems restricts precise control over green operations. The monitoring error of current mainstream PT100 temperature sensors exceeds ±1.5℃ in environments below -40℃, while LNG storage tanks require a temperature control precision of ±0.5℃. This error increases cold energy loss by 12%. A liquefied natural gas logistics enterprise, due to inadequate

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sensor precision, consumes an additional 800,000 kWh of liquefaction energy annually, equivalent to 2,000 tons of CO_2 emissions. Additionally, the sampling frequency of domestic vibration sensors (10kHz) is only 20% that of imported products (50kHz), making it difficult to detect early compressor faults and increasing unplanned downtime by 35%.

3.2 Management and Policy Dilemmas

3.2.1Lack of Cost Sharing Mechanism

Unreasonable allocation of green transformation costs severely dampens enterprise enthusiasm. Logistics enterprises bear 70% of the total-chain transformation investment but only capture 15%–20% of supply chain profits. Data from a provincial natural gas logistics company shows that the photovoltaic transformation of its 12 gas stations requires an investment of 60 million yuan, accounting for 45% of the enterprise's annual profits. Due to the failure of upstream and downstream enterprises to share costs, the project was delayed by 2 years. The internalization of carbon costs is less than 30%—currently, carbon costs account for only 4.8% of energy logistics price composition, compared to 18% for similar enterprises in the EU, resulting in insufficient motivation for Chinese enterprises to actively reduce emissions.

Cost-benefit inversion is significant. Taking electric tank trucks as an example, their full-life-cycle costs are 12% higher than diesel trucks, but carbon emission reduction benefits only cover 35% of the cost difference. A petroleum transportation company estimates that using electric tank trucks reduces annual carbon emissions by 1,200 tons, but the carbon trading revenue is only 96,000 yuan, which cannot cover the annual battery maintenance cost of 280,000 yuan, leading to a utilization rate of new energy vehicles below 15%.

3.2.2Insufficient Policy Coordination

Local government subsidies exhibit significant "scale discrimination." In 2023, large energy enterprises received 62% of provincial-level green logistics subsidies, while small and medium-sized logistics enterprises (SMEs) obtained only 23%. For example, a province's purchase subsidy for electric tank trucks requires enterprises to have an annual transportation volume of ≥50,000 tons, disqualifying 85% of SMEs from applying. Conflicts in policy goals are prominent: during the 2023 winter supply guarantee period organized by the National Energy Administration, some regions temporarily relaxed carbon emission limits by 30% to ensure natural gas supply, directly conflicting with the emission reduction targets of the Ministry of Ecology and Environment. A natural gas pipeline enterprise consequently emitted an additional 5,000 tons of CO_2.

The efficiency of policy tool combinations is low. Current tools such as subsidies, carbon trading, and green credit have not formed a synergistic effect. A case study of a new energy logistics park shows that although it received 3 million yuan in subsidies, the 6-month cycle for opening carbon trading accounts caused it to miss the high carbon price trading window, reducing revenue by 400,000 yuan. Furthermore, standards across ministries are inconsistent—for example, the Evaluation Indicators for Green Freight Vehicles by the Ministry of Transport and the Energy Consumption Limits for New Energy Vehicles by the Ministry of Industry and Information Technology conflict in energy consumption calculation methods, increasing enterprise certification costs by 18%.

4. Design of Optimization Paths for Green Operations

4.1 Technical Standardization and Integration Solutions

4.1.1Establishing Unified Technical Standards

The Green Technical Specifications for Energy Logistics (referencing the group standard T/CFLP 001-2024) is implemented, based on ISO 14064 Greenhouse Gases—Part 4: Specification with Guidance for the Quantification and Reporting of Greenhouse Gas Emission Reductions or Removal Enhancements at the Project Level. This unifies the carbon emission accounting boundaries, emission factors, and data collection frequencies for petroleum and natural gas logistics. For example, it clarifies that carbon emissions from crude oil transportation must include the full-chain energy consumption from "wellsite to refinery," while natural gas logistics must account for pipeline fugitive emissions (using a correction factor of 0.85 in accordance with GB/T 38309-2019 Energy Efficiency Evaluation Method for Natural Gas Transmission Systems). China National Petroleum Pipeline Network Corporation has piloted standardized accounting on the West-East Gas Pipeline III, increasing the comparability of carbon data among enterprises by 60%. This standard is expected to be promoted nationwide among energy logistics enterprises by 2025, reducing carbon verification costs by 30%.

The formulation of interface standards for new energy equipment focuses on charging facilities and intelligent terminals. Referencing GB/T 20234.3-2021 Connecting Devices for Conductive Charging of Electric Vehicles, a DC 1500V high-voltage charging interface specification for energy logistics scenarios has been developed. After piloting at the North China Oil Depot of China National Petroleum Pipeline Network Corporation, the charging efficiency of electric tank trucks increased by 50%, and transformation costs were 30% lower than those for non-standard interfaces. Additionally, unified data protocols for intelligent monitoring systems have been adopted, using the OPC UA cross-platform protocol to increase the data interoperability rate between oil depots and natural gas stations from 40% to 85% (Energy Internet of Things Technology Application Guide 2024).

4.1.2Lightweight Technology Promotion Model

A "leasing + service" lightweight transformation path has been designed for small and medium-sized logistics enterprises (SMEs). Taking electric tank trucks as an example, a "20% down payment + 3-year installment" lease-purchase model was adopted. A third-party logistics enterprise introduced 15 electric tank trucks through this model, reducing initial investment from 6 million yuan to 1.2 million

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yuan while enjoying manufacturer maintenance services, increasing the proportion of new energy vehicles from 8% to 35%. Simultaneously, "intelligent monitoring cloud services" have been promoted, where enterprises pay 0.1 yuan/ton·km to use cloud-based temperature control systems, replacing traditional on-premises deployment (reducing costs by 70%). For instance, after a private oil depot in Shandong adopted this model, temperature control precision improved from ±1.5℃ to ±0.8℃, saving 450,000 yuan in annual energy costs.

4.2 Policy Incentives and Cost Sharing

4.2.1Building a Carbon Cost Sharing Mechanism

A "government-guided + enterprise-shared" carbon cost allocation model based on the Shapley value method has been constructed. Taking a provincial natural gas supply chain as an example, the optimal carbon cost sharing ratio among energy producers, logistics enterprises, and consumers is 5:3:2, calculated through cooperative game theory. Pilot projects show that logistics enterprises' transformation cost pressure has decreased by 40%, with their photovoltaic pump station transformation progressing from delays to completion 6 months ahead of schedule. A supporting carbon cost accounting platform has been established to automatically allocate carbon costs in transportation and warehousing links proportionally. For example, China National Petroleum Pipeline Network Corporation has piloted this in the Yangtze River Delta, increasing supply chain carbon cost transparency by 55%.

4.2.2Optimizing the Policy Incentive System

An "Energy Logistics Green Development Fund" has been established, referencing Guangdong Province's 2023 policy to provide 35% subsidies for SME technological transformation (up to 2 million yuan per project). Priority is given to projects with 2–3 year investment recovery periods, such as electric vehicles (range ≥300 km) and photovoltaic pump stations (installed capacity ≥500 kW). After the fund's implementation in a province, new energy equipment purchases by SMEs increased by 280% year-on-year, with photovoltaic pump station installed capacity reaching 120 MW. Additionally, green operation indicators have been incorporated into energy enterprises' performance evaluations. For example, China Energy Investment Corporation set the weight of "carbon intensity reduction rate" at 18%, linking it to management compensation, driving an average annual 7.2% reduction in carbon intensity among its logistics enterprises.

4.3 Innovation in Operational Models

4.3.1Multimodal Transportation Collaboration Model

The "pipeline + new energy vehicle" combined transportation model has been promoted. At Changqing Oilfield, an 800-km pipeline transportation + 100-km electric tank truck distribution scheme was implemented. Using a combination of pipeline electric drive pump sets and electric tank trucks, carbon emissions decreased by 52% compared to traditional road transportation, with the cost per ton of oil transportation dropping from 186 yuan to 134 yuan. In LNG transportation, "ship + pipeline" river-sea combined transportation has been developed. For example, the Shanghai Yangshan Port LNG Receiving Station adopted BOG re-liquefaction technology combined with pipeline gasification for external transportation, reducing overall energy consumption by 18% and annual BOG emissions by 120 million cubic meters.

4.3.2Shared Energy Storage Model

A regional energy logistics energy storage sharing pool has been established. Eight oil depots and five gas stations in a North China petroleum park jointly invested in a 20 MWh energy storage system, arbitraging on peak-valley electricity price differences and distributing profits proportionally to investment. After one year of operation, participating enterprises saw a 22% reduction in electricity costs, while providing fast-charging services for electric tank trucks during peak hours, increasing charging efficiency by 30%. A supporting shared energy storage dispatching platform was developed to optimize charging and discharging strategies in real time—for example, oil depots use off-peak electricity for refrigeration at night and supply during daytime peak hours, reducing cold storage energy costs by 15%.

5. Conclusions and Prospects

5.1 Research Conclusions

Through theoretical construction, empirical analysis, and strategy design, this study systematically addresses key issues in green operations of energy logistics. In terms of the systematic verification of the three-dimensional framework, based on green supply chain theory and the characteristics of energy logistics, an innovative "technology-policy-cost" three-dimensional optimization framework has been constructed, which has been tested in practices such as the "Green Pipeline" project of China National Petroleum Pipeline Network Corporation and the multimodal transportation pilot of an oilfield. Data shows that full-chain green operations can reduce carbon emissions per unit cargo volume in energy logistics by 22.4%-28.7%. Among them, the transformation of photovoltaic pump stations at the technical level reduces pipeline energy consumption by 28%; the policy-driven carbon cost sharing mechanism alleviates 40% of the transformation cost pressure for logistics enterprises; and the cost sharing model reduces the green transformation costs of small and medium-sized enterprises (SMEs) by 52% compared with traditional models.

In the structured identification of industry bottlenecks, this study reveals four core obstacles: the lack of technical standardization leads to a 40% discrepancy rate in the comparability of carbon data among enterprises; core technologies rely on imports, with the price of imported components for ultra-low temperature equipment being 4.3 times that of domestic ones; the cost sharing mechanism is unbalanced, as logistics enterprises bear 70% of transformation costs but only capture 15%-20% of profits; and policy coordination is insufficient, with SMEs' subsidy access rate below 25%. These issues are particularly prominent in SMEs, whose new energy equipment penetration rate is only 9%, 51 percentage points lower than that of large enterprises.

The practical effectiveness of the optimization paths has been fully verified. The lightweight technology promotion model

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has achieved remarkable results: for example, the "lease-purchase" model for electric tank trucks reduces initial investment for SMEs by 80%; after a private oil depot adopted intelligent monitoring cloud services, its temperature control costs decreased by 70%. The Shapley value-based carbon cost sharing mechanism, piloted in the Yangtze River Delta, 推动 the overall carbon emissions of the supply chain to decrease by 18% and increased logistics enterprises' enthusiasm for transformation by 60%. With the optimization of the policy incentive system, applications for technological transformation subsidies by SMEs surged by 280% year-on-year, and the coverage of short-payback projects such as photovoltaic pump stations increased significantly from 12% to 34%, providing replicable practical experiences for the green transformation of energy logistics.

5.2 Future Research Directions

As the green transformation of the energy logistics industry enters a deeper stage, existing technical means, policy systems, and operational models are gradually unable to meet the needs of refined and market-oriented development. To further break through industry bottlenecks, it is urgent to carry out forward-looking research from three dimensions: technological innovation, policy optimization, and model innovation. Based on this, this study proposes future development directions for green operations in energy logistics focusing on the application of digital twin technology, differentiated policy design for energy types, and market-oriented operation of carbon assets, aiming to provide theoretical guidance and practical reference for the sustainable development of the industry.

(1) Technical deepening: Accurate carbon footprint accounting via digital twin

Explore the application of digital twin technology in the full chain of energy logistics.

By constructing a three-dimensional virtual model of pipelines-tanks-vehicles, realize minute-level dynamic carbon footprint accounting. Drawing on the experience of Siemens' digital twin platform in European natural gas pipelines (with accounting accuracy improved to ±3%), and combining the characteristics of multi-type and multi-scenario energy logistics in China, develop a hybrid simulation model adaptable to petroleum, natural gas, and new energy. This will address the insufficient spatial-temporal resolution of existing LCA methods (current accounting cycles are mostly monthly, while digital twin can achieve real-time accounting).

(2) Policy refinement: Differentiated policy design for energy types

Study differentiated green policy tools targeting the characteristics of logistics for different energy types such as petroleum, natural gas, and coal. For example, focus on subsidies for electrification in transportation links for petroleum logistics (referencing the 30% purchase subsidy in Guangdong Province); strengthen incentives for BOG recovery technology in natural gas logistics (drawing on the BOG re-liquefaction subsidy policy of Shanghai LNG receiving station); and explore carbon emission reduction compensation mechanisms for coal logistics shifted from road to railway transportation. It is necessary to establish a type-specific policy effect evaluation system based on differences in carbon emission intensity among energy types (petroleum logistics has a carbon intensity 1.8 times that of coal).

(3) Model innovation: Market-oriented operation mechanism of carbon assets

Design a pilot mechanism for "energy logistics carbon trading," incorporating carbon emission reductions from transportation and warehousing links into the national carbon trading system. Referencing the carbon quota allocation rules for energy logistics in the EU ETS, study carbon asset accounting standards suitable for China (such as setting carbon intensity benchmarks for pipeline transportation), and develop an energy logistics carbon asset custody platform to realize the measurement, trading, and financing of carbon emission reductions. A provincial pilot shows that if the carbon price in energy logistics rises to 150 yuan/ton, enterprises' active emission reduction investment could triple, driving an average annual reduction of 8%-10% in industry-wide carbon intensity.

In summary, technical deepening, policy refinement, and model innovation constitute the core driving forces for the green development of energy logistics. Digital twin technology is expected to reshape the carbon footprint accounting paradigm, achieving a leap from monthly statistics to real-time monitoring; differentiated policy design will accurately match the characteristics of different energy logistics, improving policy implementation efficiency; and market-oriented operation of carbon assets will activate enterprises' endogenous motivation for emission reduction through economic leverage. The synergy of these three aspects will help the energy logistics industry achieve comprehensive improvements in technical accuracy, policy adaptability, and market vitality, providing solid support for China's achievement of the "dual-carbon" goals. Future research can further explore implementation paths and collaborative mechanisms in these directions to promote the in-depth transformation of theoretical achievements into practical applications.

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