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Brief Analysis of Intelligent Collaborative Management of Oil and Gas Field Enterprises under the "Dual Carbon" Goals: Based on the Integration and Innovation of Green Low-Carbon and Digital Technologies

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Abstract

The coordinated integration of digitalization and greenization ("dualization synergy") is an important trend driving energy transformation and a key path for oil and gas field enterprises to achieve the "dual carbon" goals. To seize the strategic opportunities of carbon neutrality and meet the demands of sustainable industry development, this paper analyzes the current bottlenecks in the low-carbon transformation of oil and gas field enterprises and explores corresponding implementation paths and safeguard measures. The research results show that: ①The carbon emission intensity in the production and operation of oil and gas fields is high; ②Oil and gas field enterprises lack green application technologies;③The digitalization foundation of oil and gas field enterprises is weak. On this basis, an intelligent collaborative management system covering "strategic layer - data layer - technology layer - management layer" is constructed, with "target systematization, path scenarization, and mechanism dynamicization" as the key mainlines:①Promote the alignment of dual mainline strategies to facilitate integrated development;②Build a big data platform to provide technical foundation support;③Empower green and low-carbon technologies with digitalization to drive industrial transformation and upgrading;④Improve the dualization synergy mechanism to ensure efficient implementation of the transformation. Finally, safeguard measures and policy suggestions such as "exploring a composite talent cultivation model and building a collaborative ecosystem" are proposed, providing theoretical references for the high-quality development of oil and gas field enterprises.

Keywords

"Double Carbon" Goals; Oil and Gas Field Enterprises; Dualization Synergy; Green and Low-carbon; Digitalization; Integrated Innovation; High-quality Development; Energy Transition.

1. Introduction

Currently, society is witnessing the fourth wave of "dual-transformation synergy" (Digital-Green Synergy), characterized by the integration of digitalization and greening [1]. In 2024, the Central Committee of the Communist Party of China and the State Council issued the Opinions on Accelerating the Comprehensive Green Transformation of Economic and Social Development, proposing to drive green transformation through digital technologies, deepen the integration of industrial digitalization, intelligence, and greening, and advance the application of artificial intelligence and big data to construct a digitally empowered ecosystem.

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In the same year, the Implementation Guidelines for Coordinated Digital-Green Transition and Development clarified two strategic priorities: promoting green and low-carbon development in digital industries and accelerating the application of digital technologies to enable green transformation across sectors. The guidelines further outlined a three-dimensional framework focusing on foundational capabilities, integrated technical systems, and synergistic industrial systems for digital-green integration.

Amid the surge of emerging technologies, the innovative fusion of green low-carbon practices and digital technologies offers a pathway for oil and gas field enterprises to transcend the limitations of traditional development models, accelerate transformation and upgrading, and secure competitive advantages in emerging sectors [2]. To address this imperative, this study analyzes the intelligent collaborative innovation mechanisms for oil and gas field enterprises under the "Dual Carbon" goals, integrating green low-carbon strategies with digital technologies. We propose a smart collaborative management framework anchored in "systematized objectives, scenario-based pathways, and dynamic mechanisms," spanning strategic, data, technical, and managerial layers. This framework aims to provide theoretical foundations and practical guidance for high-carbon-emitting oil and gas enterprises, steering the industry toward greener, more environmentally sustainable, and resilient development trajectories.

2. Current Status and Challenges of Oil and Gas Field Enterprises in "Dual Carbon" Transition

2.1. Current Situation Analysis

Facing increasingly stringent national energy-saving and emission-reduction requirements, as well as progressively refined policies and regulations, oil and gas field enterprises-as major energy consumers-are under unprecedented pressure to transform. **First, carbon emission intensity remains high in production and operation.** Due to complex processes and energy-intensive characteristics, emissions from oil and gas exploration, extraction, storage, and transportation can be categorized into direct emissions (greenhouse gases generated during production) and indirect emissions (carbon emissions from energy consumption). Direct emission sources include fossil fuel combustion, methane fugitive emissions, and process-related emissions, while indirect emissions stem from high-energy-consuming equipment operation, supply chain and material carbon footprints, and risks associated with abandoned wells and carbon storage. Among these, methane leakage is a key contributor to carbon emissions, and the high energy consumption of oilfield equipment remains a critical issue. **Second, oil and gas enterprises lack sufficient green application technologies.** Since 2021, state-owned energy giants such as CNPC, Sinopec, and CNOOC have actively developed large-scale carbon capture, utilization, and storage (CCUS) projects while promoting clean energy alternatives (e.g., geothermal and photovoltaic power). For instance, Jilin Oilfield (CNPC) established China’s first full-chain CCUS-EOR demonstration project, with an annual CO_2 storage capacity of 350,000 tons and a cumulative storage of approximately 2.25 million tons [3]. Nevertheless, domestic oil and gas enterprises still face challenges such as high CCUS costs, low oil displacement efficiency, safety risks, and stringent environmental regulations. **Third, the digital foundation of oil and gas enterprises remains weak.** Although most companies have gradually built IoT and big data platforms for production monitoring, oilfield data management still primarily follows a "physics-driven" model (i.e., relying on traditional equipment and manual operations for decision-making). Issues such as inconsistent data quality, severe data silos, and poor real-time interoperability persist. Moreover, constrained by economic efficiency, intelligent decision-making capabilities remain underdeveloped, lacking

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efficient data analytics and predictive modeling support, which falls far short of digital standards and lags behind advanced big data applications.

2.2. Key Challenges

Despite the Chinese government's active promotion of the integration of green and digital technologies in recent years, overall, the dualization synergy of oil and gas field enterprises is still in a continuous exploration phase. They face challenges in several aspects, such as weak innovation capabilities in digital and green technologies, imperfect management and synergy mechanisms for dualization, and insufficient effectiveness of digital empowerment in industrial green transformation. Firstly, green and low-carbon technologies as well as digital technologies, which are emerging technologies supporting the new round of technological revolution and industrial transformation, are constrained by the knowledge and environmental externalities of technological innovation [4], resulting in insufficient core technology R&D. Key technologies like CCUS are not yet mature and lack the capability for large-scale application. The application of digital technologies (such as AI and digital twins) under complex geological conditions (such as ultra-deep wells and shale gas) is unstable. The "bottleneck" problems are urgent to be broken through, and the R&D risks are high. Most oil and gas field enterprises focus on "single-point breakthroughs" rather than systematic innovation, and the application of "green + digital" technologies is fragmented [5]. Secondly, due to the imperfect existing management mechanisms and the incomplete standard and specification systems, a comprehensive technical standard system for digital and green synergy transformation has not been formed, making it difficult to regulate and guide specific implementation. The mechanism and path for "dualization synergy" are unclear. Most oil and gas field enterprises regard digitalization (such as smart oil fields) and greenization (such as emission reduction) as independent tasks, lacking overall planning and disjointed dualization synergy goals. Meanwhile, data and business collaboration is inefficient, cross-departmental cooperation processes are lengthy, and there is a lack of synergy mechanisms in the oil and gas industry chain and across fields, with a significant shortage of compound talents. Lastly, the effectiveness of digital empowerment in industrial green transformation is insufficient. The application of technology is "heavy on form but light on effectiveness." Although enterprises have gradually built big data platforms, they are not deeply integrated with production processes and lack practical guiding significance. The innovation cycle of green and digital technologies in their early stages is long, with low investment return rates. The input and output of low-carbon transformation are significantly imbalanced, and the cost pressure is high.

3. “Dual-Carbon + Digital” Intelligent Synergy Management Framework and Implementation Pathways

With the key main lines of “goal systematization, path scening, and mechanism dynamization,” a smart synergy management system covering the “strategy layer - data layer - technology layer - management layer” is constructed to ultimately achieve a dual improvement in green competitiveness and digital efficiency (as shown in Figure 1).

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3.1. "Dual-Carbon + Digital" Intelligent Synergy Management Framework

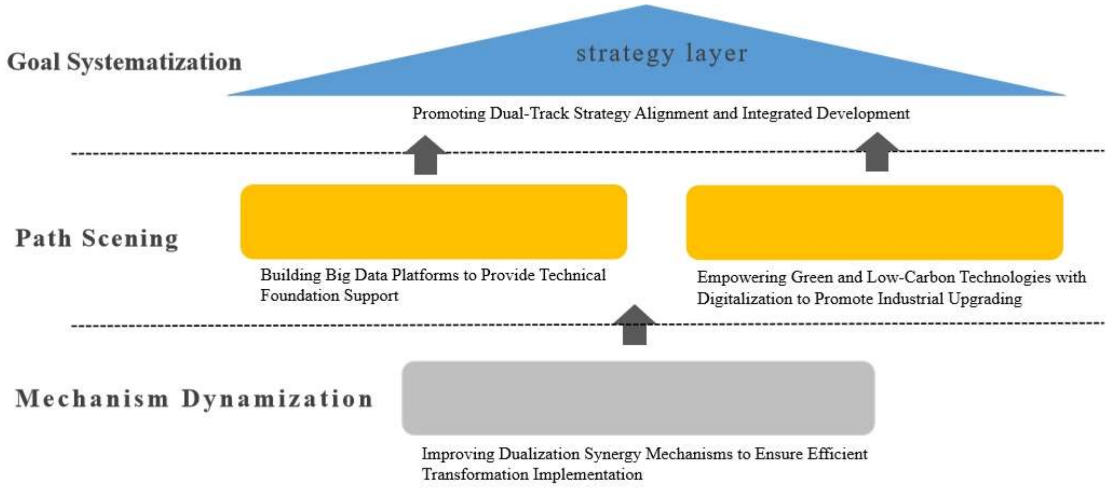

Figure 1. "Dual-Carbon + Digital" Intelligent Synergy Management Framework

3.2. Implementation Pathways for "Dual-Carbon + Digital" Intelligent Synergy Management

3.2.1. Goal Systematization

Promoting Dual-Track Strategy Alignment and Integrated Development: Under the current urgent situation of energy transition, oil and gas field enterprises should profoundly understand the importance of the national carbon reduction targets. They need to incorporate their own "dual-carbon" goals (such as reducing carbon emission intensity by 20% before 2030 and by 60% before 2060) and digital transformation goals (such as achieving a data real-time sharing rate of 90% and a digital twin coverage rate of 60%) into the overall strategic planning. This will clarify the supporting role of digital technologies in dual-carbon transformation, ensuring that both are unified at the strategic level and support each other. By constructing an integrated "dual-carbon + digital" strategy framework, enterprises can fully leverage the advantages of digital technologies in carbon emission monitoring, energy management, and process optimization. This will accelerate the construction and application of intelligent energy systems, achieving precise carbon reduction and efficient operations. Guided by dual-carbon goals, enterprises can promote the in-depth application of digital technologies, facilitate the intelligent and green transformation of production processes, enhance core competitiveness, and lay a solid foundation for sustainable development.

3.2.2. Path Scening

Building Big Data Platforms to Provide Technical Foundation Support: The big data platform of oil and gas field enterprises is an important foundation for the coordinated development of dualization. It aims to integrate the entire chain of data (such as geological data, equipment operation data, energy consumption data, and carbon emission data) through the application of cloud computing and big data technologies. This enables real-time monitoring, early warning, and prediction of the production process, providing more accurate decision-making support and promoting the digital and low-carbon transformation of oil and gas fields. For example, deploying IoT sensors to monitor methane in real-time can reduce methane gas leakage in multiple links. Big data can predict the likelihood of equipment failures, maintaining relatively stable carbon emission intensity during production. Accelerating the construction of a carbon emission data management system to achieve interconnectivity with the production information system can improve the efficiency and accuracy of data collection [6].

Empowering Green and Low-Carbon Technologies with Digitalization to Promote Industrial Upgrading: At present, the carbon reduction methods of Chinese oil and gas field

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enterprises are mainly divided into four categories: "CCUS," "carbon emission reduction," "carbon substitution," and "carbon trading" [7]. Among them, "CCUS" captures, utilizes, and safely stores carbon dioxide through technological innovation, while "carbon emission reduction" lowers carbon emissions by optimizing oil and gas development technologies. These two methods can help reduce carbon emissions from the source and multiple links of the industrial chain. "Carbon substitution" involves developing and utilizing new energy sources to fundamentally replace oil and gas energy, which can achieve ideal net-zero carbon emissions to a certain extent [8]. It is important to note that not all green technologies require digital packaging. Targeted technological transformations can achieve the most significant effects (as shown in Table 1).

Table 1. dualization synergy

Green and low-carbon technologies	Digital technologies	Synergistic application scenarios
CCUS carbon capture and storage	Digital twin simulation optimizes storage pathways	Simulate geological storage risks to reduce leakage probability;Optimize process parameters such as water injection and fracturing
R&D of low-carbon fracturing fluids	Blockchain records the carbon footprint of chemicals	Transparent management of supply chain carbon emissions: Blockchain records carbon emissions during the production, transportation, and use of fracturing fluids, aiding in carbon reduction optimization
Clean energy substitution	AI predicts the power output of wind and solar energy	Dynamically adjust clean energy to ensure stable power supply: Dispatch of hybrid wind-solar-storage microgrids and optimization of equipment operation and maintenance

In the oil and gas industry chain, CCUS carbon capture and storage simulate oil and gas field development scenarios through digital twins (that is, virtual models created with digital technology corresponding to physical entities) to optimize storage paths and reduce ineffective energy consumption [9]. At the same time, blockchain technology (that is, a distributed ledger technology used to securely record oil and gas production, transaction, and carbon emission data) can help oil and gas field enterprises achieve transparent and traceable supply chain carbon footprints. This encourages upstream and downstream companies to jointly set emission reduction targets and make more scientific decisions. In addition, AI technology can analyze historical data and real-time information to capture the complex relationship between meteorological conditions and power generation through algorithms. It dynamically adjusts the energy structure to optimize the utilization efficiency of new energy, ensure stable power supply, and reduce dependence on fossil fuels.

3.2.3. Mechanism Dynamization

Improving Dualization Synergy Mechanisms to Ensure Efficient Transformation Implementation: First, in terms of organizational structure, a dual-carbon digitalization promotion group should be established to coordinate resources from technology, production, environmental protection, finance, and other departments. This breaks down departmental barriers and forms a collaborative working model. At the same time, an integrated "dual-carbon + digital" assessment mechanism should be constructed, incorporating carbon emissions and data sharing into departmental KPIs to ensure that all departments work together to advance digital transformation under the dual-carbon goals. Second, in terms of process reengineering, a cross-departmental collaboration mechanism should be established. A data-sharing responsibility list should be formulated to clarify the responsibilities of each department in data collection, transmission, analysis, and application. This ensures timely and barrier-free

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data flow. The approval process should be optimized to achieve cross-departmental joint approval and execution, improving work efficiency and promoting the digital and intelligent upgrade of business processes. Third, in terms of emergency response, a flexible adjustment mechanism should be established. Regular assessments of the impact of technological, market, and policy changes on dual-carbon digital transformation should be conducted, and strategies and work priorities should be adjusted in a timely manner. The ability to warn against risks should be strengthened. Digital means should be used to monitor changes in the internal and external environment in real-time to ensure a rapid response in the face of uncertainties and to ensure the smooth progress of transformation work.

4. Implementation Guarantees and Policy Support

4.1. Exploring a Talent Cultivation Model Centered on "Digital + Green"

Oil and gas field enterprises need to build a training system that combines industry-university-research collaborative innovation and policy guidance, focusing on the "digital + green" composite talent strategy: On one hand, they should join forces with universities to build technology research and education practice platforms. Through mechanisms such as joint university-enterprise research (e.g., major scientific research projects on dualization synergy), special fund support (e.g., R&D of dual-carbon technologies and digital platforms), and targeted talent delivery, they can accelerate the cultivation of comprehensive talents proficient in digital carbon control technologies and oil and gas business [10]. On the other hand, relying on national policy support, they should introduce incentive measures such as tax preferences and scientific research subsidies to attract top teams in the fields of clean energy and green digitalization from home and abroad. Meanwhile, they should establish a learning map that can adapt to the training of dual-carbon digital talents. According to the talent ability level, they should build a fair, clear, and well-defined promotion channel with a clear path. In this process, continuous follow-up and supervision of dual-carbon digital talents should be carried out to achieve dynamic tracking and closed-loop management of talent selection, training, and assessment, forming a sustainable talent ecosystem that matches the dual-carbon strategy.

4.2. Building a Synergistic Ecosystem based on "Digital + Green" Technology

Oil and gas field enterprises should leverage their industrial advantages to actively build a "digital + green" collaborative ecosystem. With enterprises as the hub, they should connect technology research and development, industrial collaboration, and policy resources to drive the co-creation of ecological value. First, they should take the lead in forming cross-industry innovation alliances with universities, technology companies, financial institutions, and other entities [11]. Focusing on scenarios such as methane intelligent monitoring, CCUS digital control, and green electricity substitution, they should conduct joint technology research to promote the application of integrated technologies like blockchain carbon certification and digital twin energy efficiency optimization from laboratories to well sites. For example, they can collaborate with Huawei to develop AI carbon-saving algorithms suitable for complex geological conditions. Second, they should call on the government to formulate industry standards and technical specifications for "dual-carbon digitalization," unify carbon emission standards across the industry, and improve the carbon trading market mechanism. On this basis, the government should provide appropriate tax and financial incentives and special fund support to promote the research and application of relevant technologies. For instance, a "technology adaptation subsidy" could be established to provide special support for technology R&D in complex geological conditions. Third, they should promote international ecological integration, take the lead in formulating international standards for digital carbon accounting in the oil and gas industry, export digital carbon control solutions through the Belt and Road energy cooperation projects, and participate in the Global Methane Pledge (GMP). By

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transforming ecological potential into international discourse power, they can ultimately form an open digital green ecosystem network centered on oil and gas fields.

5. Conclusion and Outlook

At present, the world is accelerating into a new round of technological revolution characterized by the synergy of digitalization and greenization. As representatives of traditional high-carbon industries, oil and gas field enterprises are bearers of both challenges and opportunities. By constructing a "dual-carbon + digital" intelligent synergy management framework, driving precise carbon control with data, optimizing energy efficiency through technology integration, and integrating resources through ecological co-construction, enterprises have the opportunity to break through the multiple constraints of technological bottlenecks, cost pressures, and management silos, achieving a win-win situation of carbon reduction and efficiency improvement. In the future, with the increasing maturity of new energy technologies and the deep integration of carbon markets and digital technologies, oil and gas field enterprises are expected to transform from "energy suppliers" to "zero-carbon technology integrators." While ensuring energy security, they can lead the global paradigm shift towards sustainable development.

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