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Research on the Path and Countermeasures of Digital Intelligence Technology Driving the Green and Low-Carbon Transformation of Oil and Gas Enterprises

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Abstract

Under the background of the continuous promotion of the "double carbon" goal and the adjustment of energy structure, oil and gas enterprises not only bear the basic function of ensuring energy security, but also face the realistic pressure of reducing carbon emission intensity and improving green development ability. Traditional oil and gas enterprises rely on resource investment, scale expansion and experience management for a long time, and there are still some shortcomings in production efficiency, energy consumption control, carbon emission monitoring and supply chain coordination. The rapid development of digital intelligence technology provides new tools and paths for oil and gas enterprises to break through the dilemma of low-carbon transformation. This paper focuses on how digital intelligence technology drives the green low-carbon transformation of oil and gas enterprises. Based on the theory of dynamic capacity, resource-based view and resource arrangement theory, it analyzes the mechanism of digital intelligence technology in the production and operation of oil and gas enterprises, energy management, supply chain coordination and carbon emission governance. The research shows that digital intelligence technology is not a simple technology substitution, but through data perception, intelligent analysis, resource restructuring and organizational collaboration, to promote the development of oil and gas enterprises from extensive management to refinement, intelligence and green. At present, the digital intelligent low-carbon transformation of oil and gas enterprises still faces problems such as weak data base, insufficient organizational coordination, lack of compound talents, long investment return cycle and rising security risks. For this reason, this paper puts forward four paths of intelligent production process, digital energy management, supply chain collaborative low-carbon and carbon emission management platform, and puts forward countermeasures and suggestions from the aspects of enterprise management, technology construction, personnel training, policy support and evaluation system construction. The research can provide theoretical reference and practical enlightenment for oil and gas enterprises to promote green low-carbon transformation.

Keywords: Digital intelligence technology, Digital transformation, Green and low-carbon transformation, Oil and gas enterprises.

1. Introduction

The oil and gas industry is an important basic industry for the operation of the national economy, and it is also a key area in energy consumption and carbon emission governance. For a long time, oil and gas enterprises have played an important role in ensuring energy supply, supporting the operation of the industrial system and promoting regional economic development. But with the acceleration of global climate governance, the development logic of traditional oil and gas enterprises is undergoing profound changes. In the past, the competitive advantage formed by resource development, capacity expansion and process experience accumulation has been difficult to fully adapt to the new requirements of green low-carbon development. How to reduce the energy consumption and carbon emission intensity of unit output while ensuring energy security has become a strategic issue for oil and gas enterprises.

From a practical point of view, the green low-carbon transformation of oil and gas enterprises is not a single issue of emission reduction, but a comprehensive change in the mode of production, management, technical system and business model. The upstream exploration and development link involves equipment operation, geological monitoring, well site management and energy consumption control; The middle reaches storage and transportation link involves network scheduling, leakage monitoring, safety warning and transportation efficiency; The downstream refining and sales links involve process optimization, energy utilization, product structure adjustment and market response. The inefficient operation of any link may lead to energy waste and increased carbon emissions. Therefore, the low-carbon transformation of oil and gas enterprises needs to move from local governance to system governance, and from single point energy saving to the whole chain optimization.

The rise of digital intelligence technology provides a new solution to the above problems. Big data, artificial intelligence, Internet of things, cloud computing, digital twin, blockchain and other technologies continue to

mature, enabling enterprises to more accurately obtain production data, more timely identify operational risks, more finely optimize resource allocation, and more conditions to embed carbon emission management into the daily business process. For oil and gas enterprises, the value of digital intelligence technology is not only to improve the level of automation, but also to reconstruct the ability of enterprise perception environment, scheduling resources, organization collaboration and continuous innovation. In other words, digital intelligence is an important support for the green low-carbon transformation of oil and gas enterprises, but its effect depends on whether the enterprise can transform technology investment into management ability, organizational ability and strategic ability.

Based on this, this paper focuses on three core issues: first, through which mechanisms digital intelligence technology drives the green low-carbon transformation of oil and gas enterprises; Second, what are the main obstacles oil and gas enterprises are facing in the process of promoting digital intelligent low-carbon transformation; Third, how to build the transformation path and policy suggestions in line with the characteristics of the industry. This paper attempts to introduce the dynamic ability and resource arrangement logic into the research of green low-carbon transformation of oil and gas enterprises in theory, and put forward the path design with operability in practice, so as to provide a reference for oil and gas enterprises to achieve high-quality development.

2. Literature Review

The theory of dynamic capabilities provides an important explanation for understanding the transformation of enterprises in a complex environment. Teece, Pisano and Shuen believe that dynamic capabilities emphasize the ability of enterprises to integrate, build and reconstruct internal and external resources, which can help enterprises cope with the fast changing external environment [1]. From the perspective of resource-based view, Barney pointed out that the sustainable competitive advantage of enterprises comes from valuable, rare, difficult to imitate and irreplaceable resources [2]. Sirmon, Hitt and Ireland further proposed that whether an enterprise can create value depends not only on what resources it owns, but also on how to structure, combine and use resources [3]. The above research provides a basic logic for the analysis of low-carbon transformation of oil and gas enterprises: green low-carbon transformation is not simply the process of adding new equipment or introducing new technology, but the process of systematic restructuring of enterprises around data, equipment, talent, capital and organizational processes.

The study of digital transformation further revealed the impact of digital intelligence technology on enterprise strategy and organizational change. According to Vial, digital transformation is a process in which digital technology causes significant changes in the organization and creates value. The key lies in the interaction between technology application and organization response [4]. Warner and W ä ger analyzed digital transformation from the perspective of dynamic capabilities, emphasizing that enterprises need to promote strategic updating through continuous learning, agile response and organizational remodeling [5]. After combing the relevant technologies of industry 4, Lu pointed out that the Internet of things, cloud computing, information physical systems and data analysis are promoting the production mode of manufacturing industry to intelligent and networked evolution [6]. Porter and Heppelmann pointed out from the perspective of intelligent Internet products that the improvement of product and device connectivity will change the competition mode and value creation logic of enterprises [7]. These studies show that the core value of digital intelligence technology is not only to improve efficiency, but also to promote the formation of new operation logic and competition logic.

In the research of green low-carbon transformation, the digital and emission reduction collaboration of the energy industry has gradually attracted attention. The IEA pointed out that digitalization can affect the energy consumption structure by improving the operation efficiency of energy systems, strengthening demand side management and optimizing energy allocation [8]. Later, the International Energy Agency further stressed that the oil and gas industry in the net zero transformation needs to achieve transformation through methane emission reduction, energy efficiency improvement, clean energy investment and low-carbon technology application [9]. Qi, Tao, Zuo and Zhao research around digital twin services, pointing out that digital twin can support manufacturing system upgrading through virtual reality mapping, dynamic simulation and intelligent optimization [10]. From the perspective of low-carbon technology innovation of manufacturing enterprises, Yang, Nie, Li and Wang found that digital transformation can promote low-carbon innovation by improving dynamic capabilities [11]. It can be seen that digital intelligence technology has become an important support for enterprise energy conservation and carbon reduction, process optimization and green innovation.

Research on the oil and gas industry pays more attention to the industry scene and technology implementation. Yang Jianfeng, Du Jinhu, Yang Yong and Fan Shaoming systematically analyzed the research and practice of digital transformation of the oil and gas industry, believing that oil and gas enterprises should promote business upgrading around industrial Internet, data platform and intelligent applications [12]. In general, the existing research has provided a rich theoretical basis from the perspective of dynamic capacity, resource management, digital transformation and energy low-carbon development, but there are still three aspects: first, the research on the green low-carbon transformation of the oil and gas industry still focuses on macro policies and general trends, and the discussion on the internal mechanism of the enterprise is not enough; Two is that the analysis of logarithm intelligence technology is easy to stay at the level of technology listing, lacking the combination with organizational capacity, resource arrangement and management reform; Three is the existing research on the specific implementation path, risk control and performance evaluation system. Based on this, this paper puts digital intelligence technology, dynamic capacity and resource arrangement into the same analysis framework to further explore the path of green low-carbon transformation of oil and gas enterprises.

3. The Theoretical Logic of Digital Intelligence Technology Driving the Green Low-Carbon Transformation of Oil and Gas Enterprises

Digital intelligence technology drives the green low-carbon transformation of oil and gas enterprises, which is first manifested in the change of production information acquisition mode. Traditional oil and gas enterprises largely rely on manual inspection, experience judgment and periodic statistics, and data collection has hysteresis

and dispersion. After the application of technologies such as Internet of things, sensors, edge computing and 5G communication, the equipment operation status, energy consumption level, environmental parameters, transportation status and security risks can be captured in real time. Data has become a basic resource for enterprises to understand production systems, judge energy consumption and identify carbon emission risks. Without high-quality data, low-carbon management can only stay in the post statistics and rough estimation level; With real-time, continuous and structured data, it is possible for enterprises to embed low-carbon targets into the production and operation process.

Secondly, digital intelligence technology promotes the transformation of enterprise decision-making from experience judgment to intelligent analysis. The oil and gas production system has the characteristics of long process, many equipment, complex working conditions and high risks. AI, big data analysis and digital twin technology can model the production process, find the relationship between equipment abnormality, energy consumption fluctuation and process parameters, and provide optimization solutions for managers. In this way, enterprises can reduce invalid operations, reduce equipment failure rate, and improve energy utilization efficiency, so as to achieve energy conservation and carbon reduction.

Thirdly, digital intelligence technology promotes the change of enterprise resource arrangement. The low-carbon transformation of oil and gas enterprises needs to mobilize technology, capital, equipment, talents and external cooperation resources. If the resources are distributed in different departments and systems, even if the enterprise invests a large number of technical tools, it is difficult to form a synergistic effect. The digital intelligence platform can get through the links of production, procurement, storage and transportation, sales, finance and carbon management, so that enterprises can move from partial optimization to overall optimization. The focus of resource arrangement is no longer simply to increase resource input, but to let different resources play a role in the right scenario through data sharing and process reconstruction.

Finally, digital intelligence technology helps enterprises to form a dynamic ability for low-carbon development. The green low-carbon transformation is long-term and uncertain, and policy standards, energy prices, carbon market rules and technical routes are likely to change. Enterprises need to continuously perceive external changes, adjust strategies and processes in a timely manner, and translate low-carbon requirements into organizational actions. Digital intelligence technology can enhance the enterprise's perception of market, policy and production system, as well as the ability of rapid response and continuous optimization. Therefore, the deep logic of digital intelligence technology driven low-carbon transformation is to promote the transformation of oil and gas enterprises' development mode through data resource, resource capacity and capacity strategy.The main mechanisms through which digital intelligence technologies support the green and low-carbon transformation of oil and gas enterprises are summarized in Table 1.

Table 1. Mechanisms of digital intelligence technology driving the green and low-carbon transformation of oil and gas enterprises.

Type of digital intelligence technology	Main application scenarios	Mechanism of action	Expected low-carbon transformation effect
Internet of Things and sensor technology	Real-time monitoring of well sites, pipelines, refining units and storage tank areas	Collects equipment status, energy consumption, environmental parameters and operational risk data in real time	Improves energy consumption identification and reduces abnormal operation and energy waste
Big data analytics	Integrated analysis of production data, energy data, equipment data and carbon emission data	Cleans, integrates, models and analyzes multi-source data	Supports energy efficiency diagnosis, carbon accounting and management decision-making
Artificial intelligence	Predictive maintenance, process parameter optimization and production scheduling	Uses machine learning to identify equipment abnormalities, energy consumption fluctuations and optimal operating parameters	Reduces equipment failure rates and improves energy utilization efficiency
Digital twin	Virtual simulation of refining units, pipeline systems and storage facilities	Builds dynamic mapping between physical systems and virtual models to test different operation schemes	Optimizes production processes and reduces trial-and-error costs and unnecessary energy consumption
Blockchain	Supply chain traceability, carbon asset management and green procurement	Ensures trusted, transparent and tamper-resistant data sharing across supply chain participants	Enhances green supply chain coordination and reduces carbon emissions across the value chain
Cloud computing and industrial Internet platforms	Enterprise-level data platforms, remote operation and cross-department collaboration	Integrates data from production, management, environmental protection and finance systems	Improves organizational coordination and supports platform-based low-carbon management

4. The Mechanism of Digital Intelligence Technology Empowering the Low-Carbon Transformation of Oil and Gas Enterprises

First, the intelligent perception mechanism. The production sites of oil and gas enterprises are widely distributed, the types of equipment are complex, and the operation environment is changeable. Through sensors, industrial Internet and remote monitoring system, enterprises can monitor well pads, pipelines, refining units, tanks and transport vehicles in real time. Intelligent perception not only improves the level of safety management, but also provides a basis for energy conservation and carbon reduction. For example, continuous monitoring of

equipment temperature, pressure, vibration and energy consumption data can identify abnormal operation status in advance and reduce energy waste caused by equipment failure and inefficient operation.

Second, the predictive maintenance mechanism. Once the equipment of oil and gas enterprises breaks down, it will often lead to downtime, maintenance, energy waste and even safety accidents. Based on the historical operation data and machine learning model, enterprises can establish an equipment health status assessment system to conduct predictive maintenance of key equipment. Compared with the traditional regular maintenance, predictive maintenance can more accurately arrange the repair time, avoid excessive maintenance and sudden downtime. Its low-carbon value is to reduce the invalid energy consumption, reduce the waste of spare parts, extend the life of equipment, and maintain the stable operation of the production system.

Third, process optimization mechanism. There is a lot of space for optimization in refining, gathering, compression, storage and transportation. Digital twin and process simulation technology can map the actual production system to the virtual environment, helping enterprises test different process parameters and operation schemes without affecting the actual production. Through simulation and optimization, enterprises can find a lower energy consumption, more efficient and safer production mix. The carbon reduction effect brought by process optimization is often not dependent on a single equipment update, but through the system parameters to achieve continuous improvement.

Fourth, supply chain coordination mechanism. The green low-carbon transformation of oil and gas enterprises should not only focus on the internal, but also extend to the supply chain and industrial chain. Upstream raw material procurement, midstream transportation and storage, and downstream sales services will affect the overall carbon emission level. Through the big data platform and block chain traceability technology, enterprises can improve the transparency of the supply chain and identify high energy consumption, high emissions and low efficiency links. Green procurement, path optimization, inventory coordination and transportation scheduling can reduce the waste of resources in the whole chain, and make low-carbon management expand from the interior of the enterprise boundary to the industrial ecosystem.

Fifth, the carbon emission control mechanism. Traditional carbon emission management mostly relies on manual reporting and periodic accounting, which has lag and error. Digital intelligence technology can promote the integration of carbon emission data collection, accounting, analysis and disclosure. By building a carbon management platform, the enterprise integrates energy consumption, production load, emission factors and Carbon Asset Management into a unified system to achieve dynamic monitoring and trend analysis of carbon emissions. This will not only help enterprises meet regulatory requirements, but also help the management to incorporate carbon cost into business decisions.

5. Oil and Gas Enterprises' Digital Intelligence and Low Carbon Transformation

Oil and gas enterprises to promote digital intelligent low-carbon transformation, first of all, face the problem of weak data base. Some enterprise historical systems were built earlier, data standards were not unified, equipment interfaces were not compatible, and production data, energy data and management data were distributed in different platforms. The low quality of data will directly affect the results of intelligent analysis, making the algorithm model difficult to play a role. The weak data base will also lead to the fact that although the enterprise has built a digital platform, it can't really support low-carbon decision-making.

Secondly, the lack of organizational coordination restricts the transformation effect. Digital low carbon transformation involves production, technology, safety, environmental protection, finance, human resources and strategic management. If each department still pushes forward according to the traditional line, it is easy to have repeated construction, data barriers and fuzzy responsibilities. The low-carbon transformation is not a task that the environmental protection department can complete alone, but requires the overall process reengineering and organization collaboration of the enterprise. The organizational mechanism remains unchanged, and it is difficult for the technical system to be truly embedded in business management.

Thirdly, the long investment return cycle affects the enthusiasm of enterprises. The digital intelligent transformation of oil and gas enterprises often requires large capital investment, including sensor installation, network construction, platform development, system integration, data governance and personnel training. Compared with traditional energy-saving projects, the income of digital intelligence projects is indirect and long-term, and it may not directly reflect the profit growth in the short term. If the enterprise lacks long-term strategic patience, it is prone to "heavy construction, light application" or "pilot hot, promotion difficult" problems.

The lack of compound talents is also an important bottleneck. The low-carbon transformation of oil and gas enterprises requires talents who not only understand oil and gas technology and safety production, but also master data analysis, artificial intelligence, platform architecture and carbon management knowledge. In reality, engineering and technical personnel may not be familiar with digital technology, and information technology personnel may not understand oil and gas production logic. The dislocation of talent structure will lead to the disconnection of business requirements and technical applications, affecting the implementation of digital intelligence projects.

In addition, security risks and compliance pressures cannot be ignored. Oil and gas enterprises belong to high-risk industries, and industrial control systems, production data and energy scheduling systems have high security requirements. With more devices accessing the network, the risk of network attack, data leakage and system failure also increases. When promoting digital intelligence and low-carbon transformation, enterprises must consider network security, data security and production security at the same time, and cannot ignore the safety bottom line in order to pursue digital speed.The major dilemmas and underlying causes faced by oil and gas enterprises in the process of digital intelligent low-carbon transformation are shown in Table 2.

Table 2. Main dilemmas and causes of digital intelligent low-carbon transformation in oil and gas enterprises

Main dilemma	Specific manifestation	Underlying cause	Impact on low-carbon transformation
Weak data foundation	Scattered data, inconsistent standards and incompatible equipment interfaces	Historical information systems were built separately, and a unified data governance system is lacking	Reduces the accuracy of carbon accounting, energy efficiency analysis and intelligent decision-making
Insufficient organizational coordination	Production, environmental protection, finance and technology departments promote projects separately	Traditional functional management remains strong, and cross-department coordination is insufficient	Makes it difficult for digital intelligence projects to be embedded into real business processes
Long investment return cycle	Large investment is required for platform construction, equipment transformation and system integration	The benefits of digital intelligence projects are long-term and indirect	Weakens short-term investment motivation and may lead to difficulty in scaling up pilot projects
Shortage of compound talents	Oil and gas professionals may not understand algorithms, while technical staff may not understand production logic	Talent training systems do not fully match the needs of industrial transformation	Affects technology selection, model development and application implementation
Rising security risks	Industrial control systems, production data and energy scheduling systems are connected to networks	Network security, data security and production safety are increasingly coupled	Increases operational risks and restricts the openness of key digital application scenarios
Imperfect standard system	Carbon data definitions, platform interfaces and green supply chain evaluation standards are inconsistent	Industry standards for digital low-carbon transformation are still being improved	Raises coordination costs and weakens the comparability of carbon management results

6. Digital Intelligence Technology Driven Oil and Gas Enterprises Green Low-Carbon Transformation Path

First, promote the intellectualization of the production process. Oil and gas enterprises should give priority to high energy consumption, high risk and high value links to carry out intelligent transformation, such as key production units, long-distance pipelines, compressor units, tank farms and refining core equipment. Enterprises can first complete the data collection and online monitoring of key equipment, and then gradually establish the equipment status evaluation model and predictive maintenance system. After the conditions are mature, digital twin technology can be further introduced to simulate and optimize the production process. The focus of intelligent production process is not to build a "large and comprehensive" system at one time, but to cut in from key scenarios, and drive the follow-up promotion with verifiable energy-saving and consumption reduction effects.

Second, promote the digitalization of energy management. Oil and gas enterprises should establish a unified energy data management platform to include data such as electricity, gas, steam, water, fuel and residual heat utilization into unified monitoring. Through the analysis of energy consumption by link, equipment and period, the enterprise can identify the energy waste point and abnormal fluctuation point. Further, enterprises can also optimize the energy structure in combination with new energy utilization, energy storage system and intelligent micro network construction. The core of energy management digitalization is to transform energy management from monthly statistics to process control, so that energy conservation and carbon reduction become a part of daily operations.

Third, promote supply chain coordination and low carbon. Oil and gas enterprises should extend low-carbon requirements to supplier selection, logistics and transportation, inventory management and customer service. By establishing a supplier carbon performance evaluation mechanism, enterprises can include carbon emission level, energy utilization efficiency and environmental protection compliance into procurement decisions. Through the optimization of transportation path and vehicle scheduling, the no-load, detour and repeated transportation can be reduced. For key products and key materials, block chain traceability and digital voucher management can be explored to improve the transparency of the supply chain. The key to collaborative low carbon supply chain is to transform the low-carbon target into executable procurement rules, logistics rules and cooperation rules.

Fourth, promote a platform for carbon emission control. Oil and gas enterprises should gradually build a carbon emission management platform to achieve the integration of carbon data collection, accounting, analysis, early warning and disclosure. The platform should not only serve environmental protection and compliance, but also serve business decision-making. Enterprises can combine carbon emission indicators with production plans, equipment operation, energy procurement and investment decisions to form a carbon cost awareness. In the future, with the gradual improvement of the carbon market mechanism, enterprises also need to improve their carbon asset management ability, and integrate the emission reduction income, carbon quota and green financial instruments into strategic management.

Fifth, promote the synergy of organizational capacity. The digital low carbon transformation needs to adjust the organizational structure and management mechanism simultaneously. Enterprises should establish a transformation mechanism led by senior management, led by business departments, supported by technical departments, and coordinated by environmental protection and financial departments. For key projects, the cross department project team mode can be used to clarify business objectives, technical routes, investment budgets, evaluation indicators and responsibility division. Organizational capacity collaboration can avoid digital intelligence projects staying in the technical department, and promote technology to truly enter the production scene and management process.Based on the above analysis, the transformation paths, key tasks, implementation measures and expected outcomes are further summarized in Table 3.

Table 3. Paths and countermeasures for digital intelligence technology driving the green and low-carbon transformation of oil and gas enterprises.

Transformation path	Key task	Implementation measures	Expected outcome
Intelligent production process	Improve the operating efficiency of production systems	Deploy sensors in key equipment, pipelines, storage tanks and refining units, and build online monitoring and predictive maintenance systems	Reduces equipment failure rates, downtime losses and invalid energy consumption
Digital energy management	Improve energy utilization efficiency	Build an energy data management platform to dynamically monitor and optimize electricity, gas, steam, water, fuel and waste heat utilization	Reduces energy consumption per unit of output and improves energy allocation efficiency
Low-carbon supply chain coordination	Extend low-carbon management to the industrial chain	Establish supplier carbon performance evaluation mechanisms, optimize logistics routes and explore blockchain-based traceability	Reduces indirect emissions from procurement, transportation and inventory management
Platform-based carbon emission governance	Improve carbon emission management capability	Build an integrated platform for carbon data collection, accounting, analysis, early warning and disclosure	Improves carbon accounting accuracy and supports carbon asset management and low-carbon decision-making
Organizational capability coordination	Ensure the implementation of digital intelligence technologies	Establish cross-department project teams involving business, technology, environmental protection and finance departments	Avoids repeated construction and improves the effectiveness of digital intelligence projects
Compound talent development	Strengthen continuous transformation capability	Provide interdisciplinary training in oil and gas business, data analytics, artificial intelligence and carbon management	Enhances independent innovation and continuous optimization capability

7. Countermeasures and Suggestions

From the enterprise level, oil and gas enterprises should incorporate digital intelligence and low-carbon transformation into the company's strategy, rather than regard it as a separate information project or environmental protection project. Enterprises need to define the medium and long term transformation goals, and establish an evaluation system around indicators such as energy consumption intensity, carbon emission intensity, equipment efficiency, failure rate, unit output cost and green investment return. Only when the goal is clear, the project construction will not be decentralized and fragmented.

In terms of technology construction, enterprises should adhere to the principle of "Scene traction, data first, step-by-step promotion". The construction of digital intelligence should not blindly pursue advanced concepts, but should start from the real business pain point. For enterprises with weak foundation, priority should be given to data collection, data standards and system interconnection; For enterprises with better foundation, we can focus on promoting the construction of intelligent algorithm, digital twin and carbon management platform. The technical route should serve energy conservation, carbon reduction, efficiency and safety, rather than simply pursue the number of systems and the scale of platforms.

In terms of personnel training, enterprises should strengthen the construction of composite talents. Through internal training, post rotation, school enterprise cooperation and external introduction, talents who understand oil and gas business as well as digital technology and carbon management can be trained. Especially the grassroots production personnel and middle managers need to understand how digital intelligent tools serve production and management, otherwise it is difficult for the technical system to form a sustainable application. Universities and scientific research institutions should also focus on the demand of low-carbon transformation of the oil and gas industry, carry out relevant curriculum construction and application research, and provide talent support for the industry.

In terms of risk management, enterprises should simultaneously establish data security, network security and production security mechanisms. The higher the degree of digital intelligence, the closer the system connection, and the stronger the spillover of security risks. Enterprises should protect key systems by levels, and establish data authority management, backup and recovery, emergency response and security audit systems. For the key scenarios involving the industrial control system, it should be fully tested before going online to avoid the impact of system instability on production safety.

From the policy level, the government should strengthen the guidance and support for the digital intelligent low-carbon transformation of oil and gas enterprises. We can reduce the initial investment pressure of enterprises through green finance, tax preferences, special funds, pilot demonstration and standard formulation. For demonstration projects with promotion value, they should be supported to form replicable experience. At the same time, we should promote the construction of carbon accounting standards, data interface standards and green supply chain evaluation standards to provide institutional basis for enterprises to carry out low-carbon management.

Industry associations and scientific research institutions should also play a bridge role. On the one hand, oil and gas enterprises can be organized to carry out the experience exchange of digital intelligent low-carbon transformation, and promote the precise docking between technology suppliers and application enterprises; On the other hand, it can establish industry database and case database to form the transformation path reference of different types of enterprises. For small and medium-sized oil and gas service enterprises, it is more necessary to lower the digital threshold through public platforms and industry collaboration, to avoid low-carbon transformation only staying in large enterprises.

8. Conclusion

Digital intelligence technology is becoming an important driving force for the green low-carbon transformation of oil and gas enterprises. This paper studies that the impact of digital intelligence technology on oil and gas enterprises is not limited to production automation, but through data perception, intelligent decision-making, resource arrangement and organization collaboration, to promote enterprises to form dynamic capabilities for low-carbon development. In order to achieve a real green low-carbon transformation, oil and gas enterprises cannot only rely on single point technology applications, but should embed digital intelligence technology into the whole process of production and operation, energy management, supply chain coordination and carbon emission governance.

From the perspective of mechanism, intelligent perception can improve the recognition ability of enterprises on production system and energy consumption, predictive maintenance can reduce equipment failure and invalid energy consumption, process optimization can improve production efficiency and resource utilization level, supply chain collaboration can promote low-carbon management to extend to the industrial chain, and carbon emission governance platform can help enterprises integrate carbon management into business decisions. The above mechanisms together constitute the internal logic of digital intelligent low-carbon transformation of oil and gas enterprises.

From the perspective of practical path, oil and gas enterprises should focus on promoting intelligent production process, digital energy management, supply chain collaborative low-carbon, carbon emission governance platform and organizational capacity collaborative. Each path does not exist in isolation, but supports and promotes each other. The intelligent production provides data basis for energy management, the digital energy management provides accounting basis for carbon governance, the supply chain cooperates with low-carbon to expand emission reduction boundaries, and the collaborative organizational capacity ensures the real implementation of technology applications.

Of course, the digital intelligent low-carbon transformation of oil and gas enterprises still faces problems such as weak data base, strong organizational barriers, insufficient talent supply, long investment return cycle and rising security risks. In the future, we should further strengthen empirical research, combined with the first-line data of enterprises, to evaluate the actual impact of different digital technology on energy consumption intensity, carbon emission intensity, equipment efficiency and economic performance. At the same time, digital intelligence technology and new energy, energy storage CCUS、 The collaborative mechanism between carbon trading and green finance provides more systematic theoretical support and practical solutions for the high-quality development of oil and gas enterprises.

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