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Logic and Path of Enterprise Digitalization Empowering Low-Carbon Transition Under the Background of "Carbon Peaking and Carbon Neutrality"

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Abstract. Against the backdrop of intensifying global warming, achieving carbon peaking and carbon neutrality has become a common goal of economic transformation for all countries worldwide. Starting from the dual-carbon context, this paper analyzes the internal logic, practical dilemmas and optimization paths of digital technologies empowering enterprises' low-carbon transition. Digital technologies empower enterprises' low-carbon transition by integrating low-carbon information resources, innovating low-carbon technologies and optimizing industrial structure. However, there remain problems such as insufficient two-way adaptability between digitalization and low-carbon technologies, shortage of "digital-low-carbon" interdisciplinary talents, and absence of special guarantees for collaborative transformation. Multi-dimensional empowerment for enterprises' low-carbon transition can be realized by strengthening technological R&D and innovation, improving the level of technology integration and application, building a diversified talent training system, and improving the multi-dimensional support system for the integrated development of digitalization and low-carbon development in enterprises.

Keywords: digitalization, low-carbon transition, emission reduction and efficiency improvement, industrial structure

1. Introduction

In the advancement of global climate governance, the traditional production mode featuring high energy consumption and high emissions can hardly adapt to the increasingly strict environmental policies and the market demand for green products. As the main source of carbon emissions, enterprises are facing the challenge of low-carbon transition, and realizing low-carbon transition has become a core strategy related to enterprise competitiveness. Meanwhile, digital technologies represented by artificial intelligence, big data, Internet of Things and digital twin models are profoundly changing industrial forms and structures, providing strong technical support for enterprises in the process of low-carbon transition. How to empower enterprises' low-carbon transition with digital technologies has become a practical proposition that contemporary enterprises urgently need to address, and also constitutes the core focus of academic research.

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First, research on the empowerment logic: enterprises use digital technologies to generate a carbon reduction linkage effect through three dimensions of resource collaboration, governance collaboration and innovation collaboration, break information barriers between enterprises, and drive emission reduction across the industrial chain [1]; they also facilitate green low-carbon transition through the two-way empowerment mechanism between digital economy and green innovation, the reshaping mechanism for resource allocation patterns, and the promotion mechanism for industrial optimization and upgrading [2]; furthermore, they incentivize enterprises to carry out technological innovation to achieve emission reduction and efficiency improvement [3, 4]. Second, research on empowerment dilemmas: enterprises not only face external constraints such as high costs of green low-carbon transition, immature emission reduction technologies, and imperfect supporting mechanisms for green products [5]; but also confront a series of problems and challenges including insufficient endogenous motivation and poor alignment between technology supply and demand [6]. Third, research on solution paths: enterprise digital transformation improves internal capacity building and attracts government subsidies [7, 8]; optimizes human capital structure, thereby enhancing enterprises' innovation capacity [9]; builds a digital transformation support system and provides financial subsidies and tax reductions for industries undergoing transformation [10]; realizes the coordinated advancement of digitalization and green transformation by building a digital energy-carbon management platform and establishing an industrial Internet system [11]; improves the green low-carbon certification standard system and sets up unified carbon accounting norms [12]. The above studies are interrelated and progressive, jointly forming the theoretical basis for digitalization empowering enterprises' low-carbon transition, and providing theoretical support for understanding the empowerment logic and solution paths.

Nevertheless, there are still areas for further exploration: first, most studies focus on empirically testing the unilateral impact of digitalization on carbon emissions or green innovation, and relatively lack systematic analysis on how to realize "deep integration" between enterprise digital transformation and low-carbon transition; second, most countermeasure studies proceed from a single dimension, and lack comprehensive schemes that coordinate technological innovation, talent training and special guarantees. On this basis, this paper constructs a systematic analysis framework for digitalization empowering enterprises' low-carbon transition, aiming to realize emission reduction and efficiency improvement for enterprises by virtue of digital means.

2. Internal logic of digital technologies empowering enterprises' low-carbon transition

2.1. Digital technologies realize the integration of low-carbon information resources

Through data perception, data analysis and intelligent scheduling, digital technologies help enterprises collect and integrate data and information from various industries and production departments, promote rational resource allocation, reduce carbon emissions in production, and advance enterprises' low-carbon transition. The integration and allocation of low-carbon information and resources enabled by digital technologies is reflected in multiple aspects: first, the data perception function of digital technologies can collect real-time data such as carbon emissions, energy and raw material utilization rates in the production process, so as to realize low-carbon transition through rational allocation. The application of data perception in enterprises mainly refers to automatically collecting production information including carbon emissions and energy utilization rate via technical means such as Internet of Things, sensors and intelligent instruments, converting them into digital signals and transmitting them to the system. By rationally configuring the use of energy and raw materials, it improves their utilization rate, monitors the optimized carbon emission

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data in real time, and realizes enterprises' low-carbon transition. Second, the data analysis and intelligent scheduling functions can automatically generate calculation, attribution and prediction of data after information collection, and reveal the production operation status and existing problems of enterprises. Then, based on the analysis results of carbon emission indicators, energy and raw material utilization rates, the system automatically generates energy conservation and emission reduction schemes. Represented by Hebei Xinjin Group, enterprises use digital technologies to collect real-time data from air compressor station equipment and conduct multi-dimensional in-depth analysis through AI models, and finally realize on-demand gas supply and dynamic balance via the intelligent scheduling function. Through the integration and allocation of information and resources by digital technologies, the comprehensive energy saving rate of the air compressor station system has reached 31% according to third-party testing, meeting the national first-class energy efficiency standard. In addition, digital technologies can not only help enterprises integrate and allocate low-carbon information and resources internally, but also realize cross-enterprise resource allocation. By building a unified digital platform, related enterprises break information barriers between each other, accelerate the allocation of raw materials, energy and other resources among enterprises, greatly improve resource utilization efficiency, reduce overall carbon emissions, and achieve low-carbon transition.

2.2. Low-carbon technological innovation promotes enterprises' emission reduction and efficiency improvement

Digital technologies empower enterprises' green technological innovation by reducing R&D costs and improving the accuracy and efficiency of green technology innovation, thereby raising resource utilization efficiency, cutting carbon emissions, and driving enterprises to achieve emission reduction and efficiency improvement. First, digital technologies can shorten the R&D cycle and reduce enterprise R&D costs. Traditional green technological innovation has pain points such as high cost, long cycle, high risk and slow return. With the help of digital twin, computer simulation, AI simulation and other technologies, digital technologies can simulate the operation of enterprises in the production process after technological optimization in virtual space, and calculate the most scientific and reasonable raw material input ratio through simulation, so as to increase output while reducing carbon emissions. In iron and steel smelting, a typical high energy consumption and high emission industry, the raw material ratio of the blast furnace process directly affects hot metal output and carbon emission intensity. Its traditional process optimization method highly relies on manual experience and often requires repeated trials in actual production, which not only has a long R&D cycle but also incurs high costs and huge safety risks. Baosteel Co., Ltd. introduced the world's first AI smart blast furnace and other digital twin and AI technologies, deeply integrated decades of ironmaking process data with Huawei Pangu large model technology, and built an intelligent closed-loop management and control system covering the whole process of raw materials, sintering, coking and blast furnace. Data shows that the fuel consumption of this blast furnace decreased by 2 kg per ton of hot metal year on year, the annual cost reduction of a single furnace exceeded 20 million yuan, the annual carbon reduction reached about 15,000 tons, and the stability of hot metal quality also improved significantly. Second, digital technologies can conduct real-time monitoring of enterprise production processes and carry out risk early warning. Enterprises first deploy sensors and intelligent instruments in each production link, upload a large amount of real-time data collected by these devices to the industrial Internet platform, and realize visual presentation in virtual space through digital twin models, so that enterprise managers can monitor all production links in real time without being present on site. The system platform composed of sensors, intelligent

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instruments, industrial Internet and digital twin models can analyze and compare real-time data. Once process parameters deviate from the normal range, the system will automatically issue an alarm to remind managers to adjust raw material ratio or production technology.

2.3. Digital technologies optimize industrial structure

To a certain extent, digital technologies nurture new green industries, optimize industrial structure and boost economic development. First, digital technologies carry out all-round transformation of traditional industries and promote industrial structure optimization and upgrading. In terms of optimizing raw material structure, digital technologies can simulate the production process of enterprises in virtual space through digital twin models, AI simulation and other technologies, so as to find the optimal raw material ratio, optimize the raw material structure of industrial production, and realize emission reduction and efficiency improvement. The "Xiaomiao" industrial large model developed by China National Building Material Group integrates data models, mechanism models and business models. It can accurately calculate the optimal cement batching scheme based on the working conditions of different production lines, realizing a reduction of more than 1% in batching cost per ton of cement. In terms of innovating production technology, digital technologies simulate the production and operation of enterprises after technological improvement through digital twin models, AI simulation and other technologies, which helps enterprises better optimize production technology and reduce R&D costs. Digital technologies can also change the production mode of traditional industries that relies on manual experience, conduct real-time monitoring of the production process through sensors and industrial Internet, and give timely alarms when abnormalities occur, which helps reduce the defective rate and ineffective energy consumption. For example, Taiwan Chemical Fiber Co., Ltd. uses digital technologies such as digital twin models to completely change the traditional production mode of adjusting parameters based on manual experience, in response to differences in chemical raw material components from different origins. By the end of 2025, it had completed 667 digital optimization and AI projects, creating NT$2 billion in economic benefits and reducing 200,000 tons of carbon emissions annually. In terms of innovating product structure, digital technologies can evaluate the environmental impact of products at the R&D stage through CAE simulation technology, enabling enterprises to reasonably adjust raw materials and production technologies. Digital technologies can also record the carbon emission data of products from raw materials to finished products based on the Internet of Things, which not only provides a basis for green certification and carbon trading, but also facilitates enterprises' low-carbon transition. For example, the digital energy-carbon management platform built by Taishan Gypsum adopts biomass energy and solid waste collaborative technology, raising the waste residue mixing ratio to 94.42%, realizing 100% replacement of natural gypsum with phosphogypsum, and recycling 200,000 tons of waste boards annually. The enterprise was awarded one of the first batch of "zero-waste enterprises" in China. This shows that through precise optimization of raw material structure, data-based upgrading of production technology and low-carbon transformation of product structure in traditional industries, digital technologies have effectively promoted industrial structure optimization and upgrading, and significantly boosted enterprises' emission reduction and efficiency improvement. Second, digital technologies promote industrial structure upgrading by nurturing new industries. At present, the world has entered the era of digital economy, and new business models such as platform economy, sharing economy and subscription economy keep emerging. The emergence of these new business models provides a brand-new path for enterprises to carry out low-carbon transition. The platform economy facilitates the cross-time and cross-space sharing of idle resources, the sharing economy reduces resource waste caused by repeated production, and the

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subscription economy promotes the development and popularization of the green consumption mode of "renting instead of buying", which helps internalize emission reduction into quantifiable, tradable and value-added economic behaviors. Under the traditional economic model, it is difficult to accurately calculate the amount of carbon emissions and energy reduced by enterprises, let alone trade them like commodities. Therefore, low-carbon emission reduction is more of a policy requirement than an economic behavior. However, digital technologies use Internet of Things sensors to collect data in real time and AI to automatically calculate carbon emissions, so that each ton of carbon reduction can be accurately tracked and cross-verified, turning carbon assets into "digital commodities" that can be priced and traded, and giving birth to a series of new industries such as carbon quota trading platforms, carbon asset management consulting firms and green credit rating agencies. The formation of the carbon trading market directly links low-carbon emission reduction behaviors with economic returns, incentivizes high energy-consuming enterprises to actively carry out low-carbon transition, and thus promotes the optimization and upgrading of the entire industrial structure in a low-carbon direction.

2.4. Digital governance improves enterprises' low-carbon governance system

At the micro level, digital technologies can improve the internal governance system of enterprises and provide important institutional support for their low-carbon transition. In the internal governance of traditional enterprises, carbon emission data is scattered across various departments, lacking accurate statistics, and emission reduction responsibilities are difficult to be accurately implemented, which makes enterprises lack endogenous motivation for low-carbon transition. Digital technologies can accurately grasp the carbon emission status, reshape enterprises' carbon emission management process, and finally optimize performance appraisal and establish a quantifiable emission reduction incentive and restraint mechanism, so as to realize enterprises' low-carbon transition. First, digital technologies break data barriers and build a unified carbon emission accounting and supervision system. The primary step for enterprises to realize low-carbon transition is to accurately grasp their own carbon emission status. However, under the traditional management mode, carbon emission data of each department belongs to different systems, with inconsistent statistical calibers and various accounting standards, making it difficult for the management to obtain accurate and comprehensive carbon emission data. Relying on Internet of Things sensors and industrial Internet platforms, digital technologies conduct real-time collection, centralized accounting and visual presentation of energy consumption and carbon emission data scattered in each link, enabling enterprise managers to accurately locate major carbon emission sources, improve technologies in corresponding links, dynamically track emission reduction progress, and provide a reliable data basis for formulating subsequent low-carbon transition strategies. Second, digital technologies help optimize the performance appraisal system and establish a quantifiable emission reduction incentive and restraint mechanism. In the traditional performance appraisal system, the carbon emissions generated by each link or department are difficult to quantify, and the emission reduction effect cannot be effectively linked to individual or team interests, resulting in a lack of internal motivation among employees. Digital technologies can accurately calculate the emission reduction of each department, and the system automatically generates emission reduction performance reports for each department, which are directly connected with systems such as salary incentives and merit evaluation. Thus, emission reduction becomes a clear indicator that can be quantified, tracked and rewarded or punished, promoting emission reduction to gradually internalize from "external requirements" into the conscious action of employees.

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3. Practical dilemmas of digitalization empowering enterprises' low-carbon transition under the dual-carbon background

3.1. Insufficient two-way adaptability between digitalization and low-carbon technologies

The insufficient adaptability between digital technologies and low-carbon transition is a major problem restricting enterprises' green low-carbon transition at present. First, most mainstream digital technologies on the market, such as AI simulation, digital twin models and industrial Internet, are mostly general-purpose products, whose main functions are to improve production efficiency and optimize equipment operation. However, low-carbon transition mainly involves in-depth transformation of production processes, raw material structures and product structures in specific industries. The sources of carbon emissions vary significantly across industries — the iron and steel industry mainly emits carbon from blast furnace ironmaking, the chemical industry from chemical reaction processes, and the building materials industry from kiln calcination. Most digital technologies are difficult to be directly applied to low-carbon scenarios in various industries. Enterprises must carry out a large amount of targeted customized development and adaptation adjustments according to their own industry characteristics and production reality. This process not only takes a long time, but also often leads to cognitive differences between technology suppliers and demanders. Technology developers are good at algorithms and platform architecture, but do not understand how air flow distribution in blast furnaces affects coke ratio, nor do they know the key energy consumption nodes of chemical cracking units; while technical personnel of iron and steel or chemical enterprises, though proficient in their own processes, lack the ability to transform process knowledge into algorithm models. This two-way knowledge asymmetry makes the standardized products provided by technology suppliers unable to accurately match enterprises' actual carbon reduction needs, and enterprises find it difficult to clearly express to technology providers what kind of digital tools are needed to achieve carbon reduction goals. The barriers in demand docking between supply and demand sides have greatly extended the cycle from technology introduction to practical production application, increased the time cost and capital investment of enterprises' low-carbon transition, and slowed down the progress of "digitalization empowering green low-carbon transition" in practice.

3.2. Shortage of "digital-low-carbon" interdisciplinary talents

Digital technologies promoting enterprises' low-carbon transition require interdisciplinary talents who master both digital technologies and low-carbon management, which sets extremely high requirements for the comprehensive quality of talents. However, in reality, such interdisciplinary talents are relatively scarce, which has become a key bottleneck restricting enterprises' digital green low-carbon transition, mainly reflected in the following two aspects. First, there is a structural mismatch between the talent training system and industrial demand. In higher education and vocational education systems, digital-related majors such as computer science, data science and artificial intelligence, and green low-carbon-related majors such as environmental engineering and energy management belong to different disciplines, with relatively independent curriculum settings and insufficient interdisciplinary integration. Even if some colleges and universities have offered interdisciplinary courses such as "digital low-carbon" and "energy big data" in recent years, they are still in the exploratory stage, with limited training scale and immature curriculum systems. This lag in talent training makes enterprises lack core professional talents in the process of digitalization promoting green low-carbon transition, and it is difficult to obtain sufficient supply from the talent

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market in the short term. Second, enterprises face the dual dilemmas of high cost and high turnover in talent introduction. Interdisciplinary talents are relatively scarce in the labor market and generally have high salary expectations. Large enterprises still have the ability to set up special digital low-carbon management positions and pay high salaries; but for the majority of small and medium-sized enterprises, with limited financial strength, it is hard to attract and retain such interdisciplinary talents. Moreover, the fields of digital technology and low-carbon management develop rapidly with frequent knowledge updates. The knowledge reserve of interdisciplinary talents needs continuous updating. If enterprises lack corresponding training systems and career development systems, it is difficult to form effective talent stickiness, and talents are prone to turnover even after being introduced. Therefore, the reality of high talent introduction cost and retention difficulty further hinders digitalization from empowering low-carbon transition.

3.3. Absence of special guarantees for digital-low-carbon collaborative transition

Digitalization empowering enterprises' low-carbon transition requires not only technical support and talent reserve, but also guarantees and support in terms of capital, policies and other aspects. The lack of special guarantees is also a major obstacle to digitalization empowering enterprises' low-carbon transition at present. First, there is a structural mismatch between the capital demand of digital low-carbon transition and the existing financing supply. Promoting the integrated transformation of digitalization and green low-carbon development in enterprises features large investment, high risk and slow return. In terms of capital demand, enterprises need to spend a large amount of money on deploying digital infrastructure such as sensors, industrial Internet platforms and data middle platforms, as well as low-carbon software systems for carbon footprint accounting and energy-carbon management. Hardware procurement, software development and system integration all require centralized payment in the early stage of transformation, with large capital demand and tight schedule, putting enterprises under great short-term cash flow pressure. In terms of capital supply, existing financing channels can hardly meet enterprises' capital demand. As the main financing method for enterprises, bank loans still adopt the traditional mortgage guarantee mode in approval, requiring enterprises to provide sufficient real estate as collateral. A large number of small and medium-sized enterprises fail to meet lending conditions due to the limited proportion of real estate in their asset structure. In addition, existing special financial products such as green credit and green bonds mainly cover large state-owned enterprises or industry leaders. There are few special products for small and medium-sized enterprises, with small quotas and high approval thresholds, which fail to effectively fill the financing gap for small and medium-sized enterprises. Second, the existing policy system lacks special institutional design for the integrated transformation of "digital + green". In recent years, national and local governments have issued a series of support policies respectively for digital transformation and green low-carbon development, but most policies focus on a single field, lacking effective connection and coordinated development between the two. First, there is a lack of systematic policy framework and action plan specifically for "digitalization empowering green transformation", making it difficult for enterprises to find clear policy guidelines and operation guides when promoting the two transformations simultaneously. Second, most incentive measures such as financial subsidies and tax incentives are oriented towards a single goal, and cannot cover enterprises that achieve both digitalization and low-carbon transition at the same time. Third, there is insufficient policy coordination between different departments. The competent departments of digital transformation and those of green low-carbon development lack effective communication and cooperation mechanisms in policy formulation and implementation, and

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enterprises often face problems such as fragmented policies and inconsistent standards in the transformation process.

4. Solution paths for digitalization empowering enterprises' low-carbon transition

4.1. Strengthen technological R&D and innovation, and improve the level of technology integration and application

First, promote the deep integration of digital technologies and industrial low-carbon scenarios, and develop special solutions for specific industries. The fundamental reason why digital technologies are difficult to be directly applied to low-carbon transition in various industries is that carbon emission sources and production processes vary essentially among different industries. Breaking the knowledge barrier between technology suppliers and industry demanders is the key. We should vigorously encourage digital technology enterprises to establish in-depth cooperative relations with enterprises in their own industries, let technical R&D personnel go deep into production sites, and fully understand the technological processes, energy consumption nodes and carbon emission characteristics of different industries. On this basis, develop digital technologies such as digital twin models and AI platforms for specific low-carbon scenarios, so that digital technologies can be transformed from general tools into industry-specific technologies, and improve their adaptability to enterprises' low-carbon transition. Second, accelerate the formulation and unification of standards for carbon emission data collection, accounting and analysis. The comparability and accuracy of carbon emission data is the basic premise for digital technologies to empower low-carbon management. The main problem at present is that the lack of unified carbon emission data collection and accounting standards in enterprises and industries undermines the application value of digital technologies. The solution to this problem is: enterprise managers should formulate unified carbon emission data collection specifications and accounting boundary definition standards by industry, and clarify that enterprises must follow unified norms and standards when using digital technologies for low-carbon transition. On the basis of unified standards, promote the development of standardized and modular carbon data management platforms, so that enterprises can automatically complete data collection, accounting and analysis in accordance with unified norms. This not only lowers the threshold of technology application for enterprises, especially small and medium-sized enterprises, but also lays an institutional foundation for the circulation of upstream and downstream data in the industrial chain and the scientific assessment of the overall carbon emission level of the industry.

4.2. Build a diversified talent training system

First, promote the interdisciplinary reform of higher education and vocational education systems, and establish a "digital + low-carbon" interdisciplinary talent training system. First of all, it is necessary to add compulsory or elective modules such as low-carbon management, carbon emission accounting and industrial process basics to the curriculum systems of existing digital technology majors like data science, artificial intelligence and industrial Internet, so that students have the basic cognitive ability to apply digital technologies to low-carbon scenarios. On the other hand, digital skills training such as data analysis, programming modeling and digital twin should be strengthened in traditional low-carbon related majors like environmental engineering and energy management, so that graduates can not only understand environmental protection policies and processes, but also use digital tools to collect, analyze and optimize carbon emission data. At the same time, encourage

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colleges and universities to jointly set up professional degree or micro-professional programs in the direction of "digital low-carbon" with enterprises, with on-campus tutors and enterprise engineers co-teaching, integrating actual industrial needs into teaching content, and realizing the precise alignment between talent training and market demand. Second, improve the mechanism for enterprises to introduce and train talents. The limited market supply and high salary expectations of interdisciplinary talents make it difficult for small and medium-sized enterprises to compete with large enterprises. To solve this problem, optimization is needed in both talent introduction and retention. In terms of talent introduction strategies, small and medium-sized enterprises can concentrate resources to introduce one or two interdisciplinary leaders who master both digitalization and low-carbon management, who are responsible for overall planning and decision-making, while specific technology development and data accounting work can be completed by professional digital technology personnel, so as to reduce the cost of introducing interdisciplinary talents. In terms of talent retention mechanism, enterprises should design clear career development channels for interdisciplinary talents, set up special positions such as "digital low-carbon engineer" and "green digital technology expert", and clarify promotion standards and salary remuneration. At the same time, it is necessary to establish an interdisciplinary talent training mechanism to help in-service digital technology personnel make up for low-carbon knowledge and help low-carbon management personnel improve digital skills. Specific paths include: first, encourage industry leading enterprises to jointly build "digital low-carbon" industry-education integration training bases with colleges and universities, and carry out training around typical industry scenarios, so that trainees can exercise both digital technology and low-carbon management capabilities in actual projects; second, support industry associations to regularly organize special training courses in the cross field of digital technology and low-carbon management, invite technical experts and industry experts to co-teach, and promote the training of interdisciplinary talents.

4.3. Improve the multi-dimensional support system for the integrated development of digitalization and low-carbon development in enterprises

First, innovate financing mechanisms and broaden capital channels for digital green transformation. In view of the practical dilemma that small and medium-sized enterprises cannot afford the initial investment, breakthroughs need to be made from two aspects: innovating financial products and establishing risk sharing mechanisms. In terms of financial product innovation, financial institutions should be encouraged to develop special credit products for digital green transformation. Different from traditional loans, the approval basis of such credit products is no longer limited to real estate mortgage, but incorporates enterprises' digital infrastructure investment, low-carbon management system, expected emission reduction benefits and other factors into the comprehensive evaluation framework. For projects that pass the evaluation, banks can grant corresponding loans to enterprises based on the expected future income of the projects. In terms of risk sharing mechanism, the government should play a guiding role and set up a special guarantee fund for digital low-carbon transition to provide credit support for loans to small and medium-sized enterprises. Second, build a special policy support system and strengthen the institutional guarantee for the integrated transformation of "digital + green". Government departments should study and formulate a policy framework and action plan specifically for digitalization empowering green transformation, so as to provide clear policy guidelines for enterprises. The core of this framework is to take digitalization and greening as unified strategic goals, so that enterprises take into account both goals when formulating transformation plans. In addition, the government should establish a special support mechanism for integration effects. On the basis of existing financial subsidy and tax incentive

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policies, special rewards for the integrated transformation of "digital + green" can be added, and enterprises that simultaneously achieve the dual goals of improving digitalization level and reducing carbon emission intensity can be given additional support. In this way, the integration of digital technologies and low-carbon transition can be transformed from "dual advantages" into "dual incentives", thereby enhancing enterprises' enthusiasm for promoting integrated transformation.

5. Conclusion

This paper systematically sorts out the internal logic, practical dilemmas and solution paths of digitalization empowering enterprises' low-carbon transition under the dual-carbon background. The research shows that digital technologies can effectively improve resource utilization efficiency and reduce carbon emissions through four mechanisms: integrating low-carbon information resources, promoting green technological innovation, optimizing industrial structure and improving enterprise governance systems. However, in the actual promotion process, dilemmas such as insufficient two-way adaptability between digitalization and low-carbon technologies, shortage of "digital-low-carbon" interdisciplinary talents, and absence of special guarantees for digital-low-carbon collaborative transition have seriously restricted the full play of the digitalization empowerment effect. This paper proposes that coordinated efforts should be made in strengthening technological R&D and innovation, improving the level of technology integration and application, building a diversified talent training system, and improving the multi-dimensional support system for the integrated development of digitalization and low-carbon development in enterprises, so as to promote the "deep integration" of digital technologies and green low-carbon transition, and truly realize the two-wheel drive of digitalization and greening.

Looking forward to the future, with the continuous breakthrough of cutting-edge technologies such as a new generation of artificial intelligence, edge computing and blockchain, the application potential of digital technologies in fields such as accurate monitoring of enterprise carbon emissions, carbon footprint tracing of the whole product life cycle, and collaborative carbon reduction across the industrial chain will be further released. With the gradual improvement of the national "dual-carbon" policy system and the continuous expansion of the national carbon market, carbon emission rights will increasingly become one of the core assets of enterprises, and the value of digital means in carbon asset management and green financial services will become more prominent. The deep integration of digitalization and green low-carbon transition will become an important engine for China's high-quality economic development. Future research can further focus on the differentiated paths of enterprises in different industries and of different scales in digital low-carbon transition, as well as quantitative evaluation methods for the carbon reduction effect empowered by digital technologies, so as to provide stronger theoretical support and decision-making reference for precise policy formulation and enterprise practice.

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