

Empowering Mechanism, Practical Dilemmas and Optimization Strategies of Digital-Intelligent Technology in Government Low-Carbon Governance

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Abstract: Digital-intelligent technology provides crucial technical support for addressing government low-carbon governance dilemmas and improving regional low-carbon governance capacity. This paper systematically explores the empowering mechanism and practical dilemmas of digital-intelligent technology in low-carbon governance. The results indicate that digital-intelligent technology empowers government low-carbon governance in three core aspects: decision-making, process and governance mode. It transforms empirical and lagging governance decision-making into scientific prediction, fragmented decentralized governance into multi-subject collaborative co-governance, and extensive administrative management into refined precise governance. In practice, digital low-carbon governance is restricted by three prominent dilemmas: cognitive bias of technological omnipotence, misalignment between technology and institutional systems, and insufficient comprehensive capacity of diverse governance subjects. This paper proposes targeted optimization strategies to correct cognitive deviations, promote technology-institution collaborative adaptation and make up for multi-subject capacity deficiencies, aiming to provide theoretical references and practical guidance for improving government low-carbon governance efficiency.

Keywords: Digital-intelligent Technology; Government Low-carbon Governance; Empowering Mechanism; Dual Carbon Strategy.

1. Introduction

Climate change has increasingly threatened global sustainable development. In 2024, the global average temperature rose by about 1.55°C above the pre-industrial level, atmospheric CO₂ concentration reached a record high of 426 ppm, and extreme climate events occurred more frequently[1]. As the world's largest carbon emitter, China emitted 12.6 billion tons of carbon dioxide in 2024, accounting for 33.3% of global total emissions, facing severe domestic emission reduction pressure and international environmental responsibilities[2]. To cope with global climate change, China launched the Dual Carbon strategy in 2020. The 20th National Congress of the Communist Party of China further incorporated steady progress in carbon peaking and carbon neutrality into the construction agenda of Chinese-style modernization in 2022[3].

Carbon emission governance is a complex systematic project involving energy restructuring, interest adjustment and industrial and residential behavioral transformation. With cross-domain, dynamic and complex characteristics, it cannot be effectively managed by traditional hierarchical government governance models. The current low-carbon governance system has obvious practical limitations. Traditional monitoring relying on enterprise self-declaration and manual verification leads to long data cycles and delayed statistical results. Departmental segmentation causes scattered, inconsistent carbon data and incomplete data integration mechanisms[4]. Carbon reduction policy implementation overly depends on administrative supervision, resulting in passive enterprise compliance and insufficient public participation, making carbon reduction a government-dominated unilateral task[5]. In addition, static performance evaluation indicators fail to eliminate external interference,

unable to accurately assess policy implementation effects. Fundamentally, these problems derive from the inherent contradiction between rigid, lagging bureaucratic management and the real-time, systematic characteristics of carbon emission changes.

The application of digital-intelligent technologies such as IoT, artificial intelligence, blockchain and cloud computing provides a new breakthrough for traditional low-carbon governance reform [6]. These technologies support real-time emission monitoring, data sharing and intelligent decision optimization for carbon reduction. However, their practical application is constrained by inconsistent data standards, insufficient grassroots technical capabilities and potential data security risks. Moreover, the full release of technological governance efficacy relies on adaptive matching between digital technology and institutional and organizational environments. Given the lack of systematic research on digital empowerment mechanisms and institutional adaptation frictions in existing studies, this paper systematically analyzes the empowering logic, practical dilemmas and optimization strategies of digital-intelligent technology in government low-carbon governance to maximize technological governance value.

2. Literature Review

With the rapid development of digital-intelligent technology, academic research on digital-enabled carbon governance has grown rapidly. Existing studies mainly focus on three dimensions: the empowering effects, practical application scenarios and operational dilemmas of digital technology in carbon emission governance. In terms of empowering effects, digital technology cannot produce unilateral positive governance outcomes. Relevant studies confirm that digital technology optimizes energy scheduling

and emission supervision, reduces industrial carbon emission intensity, and realizes synergistic pollution and carbon reduction[7][8]. However, such positive effects have obvious regional heterogeneity, which are more significant in regions with mature environmental governance systems and green economic foundations[9]. Notably, digital technology has typical double-edged sword attributes. While improving energy utilization efficiency, the high energy consumption of digital data centers and computing operations may offset part of carbon reduction benefits, making practical technological empowerment far more complex than theoretical cognition[10].

In terms of application scenarios, current research explores digital technology applications in decision simulation, process supervision and industrial practice. Algorithm models realize carbon emission trend prediction and policy effect simulation; IoT and blockchain build intelligent monitoring and traceability systems for carbon data; industrial Internet technology promotes full-life-cycle digital carbon management in high-energy-consuming industries represented by the steel industry[4][11][12]. Nevertheless, restricted by inconsistent cross-industry data interfaces and incompatible business systems, existing applications are limited to single links and individual industries, failing to form full-scale and full-process governance networks.

In terms of practical dilemmas, existing studies summarize three major constraints. Technically, algorithmic black boxes and unexplainable machine learning models reduce carbon data transparency and verification credibility[11]. In terms of governance capacity, grassroots institutions focus on hardware construction rather than operational management, and frontline staff lack professional carbon accounting and data analysis capabilities, causing disconnection between digital systems and actual supervision[13]. Institutionally, unclear carbon data property rights and imperfect cross-

departmental coordination mechanisms hinder the implementation of carbon dual-control policies[14]. Overall, digital technology optimizes governance tools but cannot resolve structural contradictions within the low-carbon governance system.

Existing research lays a solid foundation for this paper, but most studies regard digital technology as a simple governance tool, ignoring its systematic reshaping effect on governance decision-making, organizational structure and institutional mechanisms. The internal logic of digital empowerment and institutional friction formed by technological embedding have not been fully explored. On this basis, this paper conducts a comprehensive and in-depth analysis of digital empowerment paths, practical dilemmas and optimization strategies to supplement and enrich relevant theoretical research.

3. Empowering Mechanism of Digital-Intelligent Technology for Government Low-Carbon Governance

The empowerment of government low-carbon governance by digital-intelligent technology is a multi-level and interactive systematic process. External driving factors including the Dual Carbon goals, rapid iteration of digital-intelligent technology and growing social demand for carbon reduction promote the formation and development of the basic technical layer. The technical foundation penetrates and reconstructs the multi-dimensional governance layer, and all dimensions reinforce and dynamically adjust with each other, ultimately promoting the comprehensive improvement of government low-carbon governance capabilities (see Figure 1).

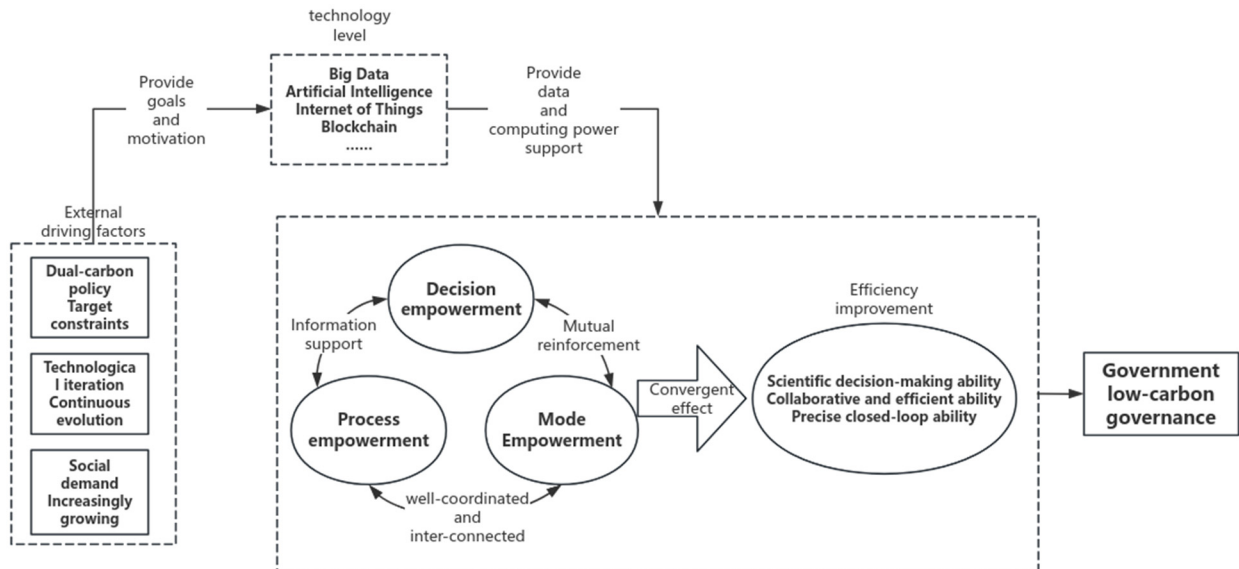


Fig 1. Empowering Mechanism of Digital-Intelligent Technology for Government Low-Carbon Governance

3.1. Empowering Governance Decision-Making: From Empirical Judgment to Scientific Prediction

Carbon emission sources cover multiple fields such as energy, industry, transportation and construction, with wide distribution and dynamic changes. Traditional low-carbon

governance relies on enterprise self-declaration and manual verification, featuring long data cycles and low accuracy. Government decision-making is limited by insufficient information, data lag and over-reliance on empirical experience. Digital-intelligent technology effectively solves these deficiencies from the perspectives of information acquisition and processing, promoting the transformation of

governance decision-making from empirical lagging mode to scientific forward-looking mode.

In terms of information acquisition, IoT sensors and satellite remote sensing technology jointly build a three-dimensional full-coverage carbon monitoring network, realizing real-time dynamic monitoring of key emission sources and breaking the temporal and spatial limitations of traditional periodic sampling monitoring[7]. Real-time data acquisition eliminates information lag and supports forward-looking governance intervention instead of passive post-event correction[10].

In terms of information processing, deep learning-based AI technology realizes the transformation from empirical induction to algorithmic deduction. It can process massive monitoring data, identify abnormal emission patterns, predict emission trends and simulate policy effects under different scenarios[15]. Regulators can adjust energy scheduling and industrial control measures in advance according to algorithmic prediction results, formulate differentiated emission control standards for different industries, and quantitatively evaluate policy effects, effectively improving the scientificity and accuracy of low-carbon decision-making [16].

3.2. Empowering Governance Process: From Decentralized Fragmentation to Collaborative Co-Governance

Traditional low-carbon governance is restricted by departmental segmentation and information closure, forming a fragmented governance pattern dominated solely by the government, with insufficient collaboration between government, enterprises and the public[4]. Digital-intelligent technology optimizes multi-subject interactive relationships and reconstructs platform-based governance mechanisms, driving the transformation from decentralized fragmented governance to multi-subject collaborative co-governance.

Digital governance platforms break inter-departmental data barriers, integrate carbon data resources from multiple functional departments, and realize linked disposal of abnormal emission problems within the government[17]. Real-time data sharing between government and enterprises transforms the traditional command-obedience administrative relationship into equal consultative cooperation. Digital platforms also broaden public participation channels, enabling the public to participate in emission supervision and policy feedback, and integrate social forces into the low-carbon governance system[18]. The platform-based interactive mechanism changes the traditional one-way administrative control mode and significantly improves governance participation and response efficiency[19].

3.3. Empowering Governance Mode: From Extensive Control to Precise Governance

Traditional low-carbon governance adopts extensive management modes relying on regular manual inspections and rigid unified administrative standards. It has obvious time lags in abnormal emission identification and lacks real-time flexible adjustment capabilities, focusing mostly on post-event accountability rather than pre-event prevention[20]. This passive and homogeneous governance mode cannot adapt to the dynamic and differentiated characteristics of carbon emissions. The embedding of digital-intelligent technology promotes the transformation of governance mode to refined and precise governance.

Digital technology realizes precise governance of heterogeneous governance objects through multi-source data integration and intelligent analysis. Big data and machine learning algorithms conduct accurate profiling of emissions in different regions and industries, identify differentiated emission characteristics and reduction potential, and formulate targeted control schemes and carbon quota allocation standards[16]. Differentiated governance for high-energy-consuming industries and service industries avoids resource misallocation caused by unified extensive management[21].

In terms of process supervision, IoT automatic monitoring equipment realizes 24-hour uninterrupted monitoring of key emission sources, eliminating manual inspection blind spots[22]. The matching intelligent early warning system can automatically identify abnormal data fluctuations and locate emission sources. Law enforcement personnel can complete rapid verification and disposal based on precise platform data, forming a real-time closed-loop management mechanism for carbon emission behaviors and greatly improving supervision efficiency[23].

4. Practical Dilemmas of Digital-Intelligent Technology Empowering Government Low-Carbon Governance

Digital-intelligent technology has significant governance potential, but its efficacy has not been fully released in practical low-carbon governance. Three intertwined and mutually restrictive dilemmas, including technological omnipotence cognitive bias, technology-institution structural misalignment and insufficient multi-subject governance capacity, jointly restrict the improvement of digital low-carbon governance efficiency.

4.1. Cognitive Bias of Technological Omnipotence

The cognitive bias of technological omnipotence generally exists in digital low-carbon governance practice, which overemphasizes technical instrumental value while ignoring the multi-dimensional complexity of low-carbon governance involving economy, society and ecology. Firstly, excessive reliance on algorithmic authority leads to governance judgment inertia. Decision-makers equate algorithm outputs with objective facts, ignoring the limitations of historical data-based models in capturing sudden policy and market changes. Algorithmic black boxes reduce decision transparency, and over-reliance on algorithms weakens on-site verification awareness, resulting in disconnection between governance measures and actual emission scenarios[11][22].

Secondly, the blind pursuit of massive real-time data forms the "data equals truth" fallacy. Governance subjects ignore data authenticity risks caused by enterprise data falsification and sensor monitoring errors. Excessive real-time data accumulation also causes information overload, submerging effective emission trend signals. The lack of professional carbon accounting ability further leads to inaccurate governance judgment [4][23].

Thirdly, instrumental rationality overruns value rationality. The single goal of emission reduction efficiency replaces the core value of low-carbon governance such as regional coordinated development and ecological justice. Unified

algorithm standards fail to adapt to differentiated development conditions of different regions and industries, making digital governance a rigid technical operation divorced from sustainable development goals.

4.2. Adaptation Misalignment Between Digital-Intelligent Technology and Governance Institutions

The data-sharing, standardized and iterative attributes of digital-intelligent technology conflict with the hierarchical, segmented and stable operational logic of bureaucratic governance systems, forming prominent structural adaptation misalignment. Firstly, data interoperability requirements conflict with departmental interest barriers. Functional departments regard carbon data as core strategic resources and lack active data sharing willingness. Cross-level data transparency also weakens the discourse power of intermediate departments, aggravating vertical governance tension[22].

Secondly, rapid technological iteration mismatches the slow update rhythm of institutional systems. Digital technology realizes real-time monitoring and dynamic early warning, while existing low-carbon governance institutions still focus on static accounting and post-event evaluation. The absence of supporting systems such as carbon data property rights and benefit distribution further restricts the release of technological governance potential [14][24].

Thirdly, unified national technical standards conflict with differentiated local governance demands. Unified digital platform specifications cannot adapt to regional differences in industrial structure and emission characteristics, compressing local flexible governance space. Passive adaptation to unified technical norms leads to disconnection between digital construction and local practical needs [4][22].

4.3. Insufficient Digital Application Capabilities of Multiple Governance Subjects

The transformation of digital technological advantages into

actual governance efficacy depends on the comprehensive digital capabilities of governance subjects, while governments, enterprises and the public all have prominent capacity deficiencies, forming the common dilemma of "emphasizing construction over application" [13]. Grassroots government staff lack compound capabilities covering carbon professional knowledge and digital platform operation, unable to conduct in-depth data mining and algorithm interpretation, resulting in idle core functions of digital governance platforms [18].

Enterprise digital transformation shows obvious imbalance. Large enterprises have sufficient funds and technology to build professional digital carbon management systems, while numerous small and medium-sized enterprises are restricted by cost and talent constraints, long relying on manual data declaration, which reduces the overall accuracy of industrial emission data [25].

In addition, public digital literacy has obvious urban-rural and age differences, and imperfect public-friendly platform functions restrict public supervision and participation. Insufficient public professional cognition and participation willingness make it difficult to form multi-subject collaborative governance synergy [17].

5. Optimization Strategies for Digital-Intelligent Technology Empowering Low-Carbon Governance

The optimization of digital-intelligent low-carbon governance is a systematic and collaborative improvement process. Targeting the three core dilemmas of cognitive bias, institutional misalignment and capability deficiency, this paper proposes a three-dimensional optimization framework including cognitive correction, institutional adaptation and capacity building to reshape governance value logic, break institutional friction and consolidate technological application foundations (see Figure 2).

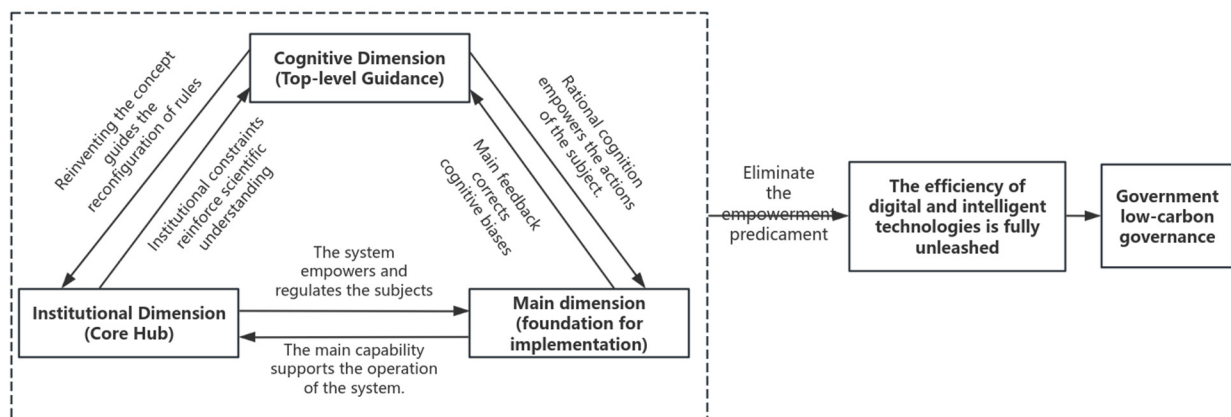


Fig 2. Optimization Strategies for Digital-Intelligent Technology Empowering Government Low-Carbon Governance

5.1. Correcting Cognitive Bias and Establishing Rational Governance Concepts

The cognitive bias of technological omnipotence essentially reflects the suppression of value rationality by instrumental rationality. Correcting this deviation requires clarifying the instrumental positioning of digital technology

and returning to the value core of low-carbon governance.

Firstly, balance instrumental rationality and value rationality. It is necessary to take ecological justice, intergenerational equity and regional coordinated development as the core goals of low-carbon governance, and realize the application of instrumental rationality under the guidance of value rationality [26]. Algorithm design should abandon the single goal of emission reduction efficiency and

incorporate multi-dimensional constraints such as regional development stages, industrial transformation costs and social equity. For example, carbon quota allocation algorithms can set differentiated weights to balance emission reduction responsibilities and economic development needs of different regions [25]. Meanwhile, governance should retain flexible disposal space for special scenarios to avoid rigid algorithmic constraints eroding governance flexibility, realizing the organic integration of technological empowerment and fair governance values [27].

Secondly, break blind superstition over algorithmic authority and establish a “algorithm assistance + manual judgment” dual verification mechanism. Algorithmic prediction results should serve as decision-making references rather than rigid execution instructions. Governance subjects should retain manual intervention authority in key links such as abnormal emission early warning to avoid negligence of on-site verification caused by excessive algorithm dependence [28]. A normalized algorithm review mechanism should be established to conduct ethical review and impact assessment of core algorithms applied in carbon peaking path prediction and policy evaluation. Technological means such as decision path analysis and algorithm visualization can improve algorithm transparency and avoid systematic misjudgment caused by basic data deviations[29].

Thirdly, optimize data cognition and prioritize data quality over data quantity. A full-process data verification mechanism should be constructed to identify data deviations through multi-source cross-verification and sensor calibration audits, ensuring data authenticity [30]. Governance subjects should avoid information overload caused by blind pursuit of real-time data, and strengthen professional training in carbon accounting and scenario cognition to improve data interpretation capabilities. Institutional arrangements such as algorithm filing and source code audit can ensure the openness and controllability of technological applications [31].

5.2. Promoting Technology-Institution Collaborative Adaptation to Eliminate Governance Friction

To resolve the structural tension between digital-intelligent technology and bureaucratic governance systems, it is essential to build a collaborative adaptation mechanism covering data sharing, institutional iteration and standard optimization.

Firstly, reconstruct incentive compatibility mechanisms to promote cross-departmental data sharing. Targeting departmental interest barriers, a complete system of carbon data property right definition and benefit distribution should be established to guarantee the rights and interests of data contributing departments [32]. Data sharing performance should be incorporated into departmental annual assessments and cadre evaluation systems to improve active sharing willingness. Meanwhile, a hierarchical and classified data management system should be built to clarify security responsibility boundaries, eliminate risk concerns, and form a virtuous cycle of controllable risk and incentive-compatible data sharing.

Secondly, build agile institutional iteration mechanisms to adapt to technological rapid upgrading. Guided by agile governance theory, shorten the institutional update cycle and build a dynamic regulatory system matching technological iteration [33]. Implement pilot exploration and fault tolerance

mechanisms to allow orderly trial of new digital technologies and optimize governance rules based on practical feedback [34]. Establish a policy dynamic evaluation and knowledge base system to track the application effects of real-time monitoring and algorithm prediction technologies, and timely adjust quota allocation standards and assessment indicators.

Thirdly, explore the flexible adaptation mode of unified standards and differentiated local governance. On the premise of unified national basic data standards and interface specifications, reserve customized development interfaces for local governments to realize the governance mode of “unified basic standards + flexible scenario application”[35]. Grant local governments independent discretion in early warning threshold setting and regulatory measure selection to adapt to regional emission characteristics. Establish a dynamic technical standard adjustment mechanism to optimize norms based on local practical feedback, avoiding passive adaptation of local governance to unified technical standards and realizing the integration of technological standardization and governance localization.

5.3. Making Up Subject Capacity Deficiencies to Consolidate Technological Application Foundations

The transformation of technological advantages into governance efficacy relies on the comprehensive capacity improvement of governments, enterprises and the public. Targeted capacity building measures should be implemented to eliminate multi-dimensional capability bottlenecks.

Firstly, build a compound talent training system for government digital low-carbon governance. Establish hierarchical and classified training mechanisms: strengthen professional capabilities in carbon modeling and data quality control for technical personnel, cultivate digital strategic thinking for management personnel, and improve intelligent equipment operation and abnormal data identification capabilities for frontline law enforcement personnel. Incorporate digital literacy and technological application capabilities into civil service assessment and promotion systems to form a closed-loop incentive mechanism and comprehensively upgrade grassroots digital governance capabilities.

Secondly, strengthen digital assistance for SMEs to bridge the industrial digital divide. Build public service platforms for technological integration and innovation to provide low-cost cloud services, standardized data collection tools and simplified carbon accounting modules for SMEs [21]. Unify the technical standards for government-enterprise data docking to reduce the access threshold for SMEs. Give full play to the leading role of benchmark enterprises to drive digital transformation of upstream and downstream SMEs through supply chain collaboration, forming a integrated digital governance ecosystem of large, medium and small enterprises.

Thirdly, improve public digital literacy and expand effective public participation. Optimize digital platform interfaces with aging-friendly and rural-friendly designs to reduce participation thresholds for vulnerable groups. Embed popular science and interactive feedback modules in governance platforms, and carry out digital and low-carbon popular science activities such as rural technology training and elderly digital literacy courses to improve public governance cognition and participation willingness. Establish a public opinion absorption and response mechanism, open

digital channels for emission information inquiry and illegal reporting, and integrate public supervision into the governance closed loop to form multi-subject collaborative governance synergy.

6. Conclusion

Digital-intelligent technology has been widely applied in carbon emission governance and has become a core driving force for promoting the modernization of low-carbon governance. This paper systematically explores the internal mechanism, practical dilemmas and optimization strategies of digital-intelligent technology empowering government low-carbon governance. The research conclusions are as follows: digital-intelligent technology reconstructs the information acquisition mechanism through IoT monitoring and algorithmic deduction, realizing the transformation of governance decision-making from empirical judgment to scientific prediction; it integrates multi-source data resources and reconstructs subject interaction modes through digital platforms, promoting the transformation of governance processes from decentralized fragmentation to collaborative co-governance; it realizes refined identification and dynamic regulation of emission behaviors based on big data analysis and machine learning, driving the transformation of governance modes from extensive control to precise governance.

However, the transformation of technological potential into governance efficacy is restricted by three core dilemmas: cognitive bias of technological omnipotence represented by blind faith in algorithmic authority; structural institutional misalignment caused by the contradiction between technological characteristics and hierarchical system operation; and universal capacity deficiencies of governments, enterprises and the public in digital professional governance. Therefore, this paper proposes to realize collaborative optimization from three dimensions: cognitive correction, institutional adaptation and capacity building, so as to break through the practical bottlenecks of digital-intelligent low-carbon governance and provide sustainable technical and institutional support for the accelerated realization of China's Dual Carbon strategic goals.

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