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Building Corporate Energy-Carbon Management Centers: Models, Bottlenecks, and Optimization Pathways

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Abstract: *Amid increasingly complex shifts in the international carbon regulatory regime and the intensification of green trade barriers, Chinese export enterprises are confronted with difficulties in achieving mutual recognition of carbon footprints. Building energy-carbon management centers constitutes an effective pathway to address these difficulties. Accordingly, this study systematically investigates upstream and downstream stakeholders involved in the construction of such centers, including system and technical service providers, manufacturing enterprises, and firms with green supply chain requirements. The findings reveal that enterprises generally advance energy-carbon management through models such as self-built center systems, public service platforms, or third-party services, achieving phased progress in improving policy frameworks, fostering local pilot innovations, and enhancing management efficiency. Nevertheless, deep-seated problems remain salient, including inadequate data traceability in energy-carbon management, incompatible standard systems that hinder international mutual recognition, and data security concerns that impede platform-based participation. To tackle these issues, efforts should be directed toward establishing a whole-industry-chain carbon data traceability system, promoting international alignment and mutual recognition of carbon accounting standards, and constructing secure and trustworthy public energy-carbon management centers, thereby systematically strengthening enterprises' carbon management capabilities and international competitiveness.*

Keywords: *energy-carbon management center, carbon footprint mutual recognition, green trade barriers*

1. Introduction

The international carbon regulatory regime is intricate and multifaceted, while green trade barriers are becoming increasingly stringent, causing Chinese export enterprises to frequently encounter compliance difficulties and cost pressures[1]. Mutual recognition of carbon footprints has emerged as a critical bottleneck for enterprises "going global". The establishment of a domestic carbon footprint management system and the accelerated construction of a dual control system for carbon emissions have also imposed clear requirements on corporate carbon management and energy conservation and carbon reduction management systems[2].

Building digital corporate energy-carbon management centers represents not only a key measure for aligning with international standards and overcoming green trade barriers, but also an intrinsic need for enterprises to respond to national policies, achieve cost reduction and efficiency gains, and build green competitiveness[3]. Systematically enhancing the monitoring and traceability of Scope 1, Scope 2, and Scope 3 carbon emission data, unifying accounting boundaries, and improving automated management efficiency will provide critical support for China in constructing an independent and controllable carbon accounting system, actively participating in global climate governance, and cultivating green new quality productive forces[4].

To explore the practical logic and real-world dilemmas of corporate energy-carbon management in the context of pursuing the "dual carbon" goals and addressing international green barriers, this study conducted a multi-regional field survey from April to September 2025. The survey covered five key provinces (municipalities) in the Beijing-Tianjin-Hebei region, the Yangtze River Delta, and the Pearl

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River Delta, employing a semi-structured, in-depth interview method combining online and offline formats. A total of 15 representative enterprises were interviewed. The sample selection followed the principle of whole-industry-chain coverage, with stratified sampling conducted around the upstream and downstream links of energy-carbon management center construction: the upstream focused on energy-carbon management service and technical support entities, including eight third-party verification bodies and software platform suppliers; the midstream incorporated manufacturing enterprises directly facing export and emission reduction pressures, encompassing five enterprises in sectors such as electronic information, steel, and cement; the downstream extended to two green supply chain management enterprises with explicit application demands for energy-carbon management in areas such as bidding, procurement, and trade compliance. Based on the above survey, this paper systematically examines the current status, major models, and typical problems associated with the construction of corporate energy-carbon management centers and attempts to distill replicable and scalable energy-carbon management pathways.

2. Background and Challenges: Intensifying International Regulatory Pressures

The European Union's new green trade barrier system, centered on carbon footprint management, is accelerating its formation and entering substantial implementation phases, posing systematic challenges to the export of China's key industries[5]. The EU Batteries and Waste Batteries Regulation officially entered into force in August 2023, requiring that electric vehicle batteries sold on the EU market in the future provide a carbon footprint declaration covering the entire lifecycle from raw material extraction to end-of-life recycling (Scope 1 to Scope 3). Starting from July 2024, electric vehicle batteries and industrial batteries with a capacity exceeding 2 kWh are required to submit carbon footprint declarations in phases. In February 2025, the carbon footprint requirement for electric vehicle batteries became mandatory[6]. Concurrently, carbon footprint regulatory rules are showing a trend of systematic expansion into China's competitive new energy sectors, such as photovoltaics and wind power. France has adopted product carbon emission intensity as a key evaluation criterion in tenders for 100 kW photovoltaic projects; some Italian power purchasers have incorporated product carbon footprint scoring in wind turbine tenders[7]. Notably, the EU Carbon Border Adjustment Mechanism entered its transitional period in October 2023 and is scheduled for full implementation on January 1, 2026, at which point relevant high-carbon imported products will be required to pay corresponding charges. These concurrent regulatory developments underscore the systemic shift in international trade rules, where carbon performance is becoming a decisive factor in market access and competitiveness. For China's export-driven new energy industries, the urgency to embed digital and traceable carbon management systems has never been greater. The EU's Carbon Border Adjustment Mechanism, in particular, is expected to cover more sectors beyond steel, aluminum, and fertilizers, potentially extending to downstream products and amplifying the compliance burden on complex supply chains.

3. Survey Findings

3.1. Current Status

3.1.1. Accelerated Improvement of the Corporate Energy-Carbon Management Policy System

In March 2025, the Ministry of Industry and Information Technology issued the Guidelines for the Construction of Digital Energy-Carbon Management Centers in Industrial Enterprises and Parks, explicitly requiring that such centers achieve precise metering, refined control, intelligent decision-making, and visualized presentation of energy consumption and carbon emissions. The guidelines cover 12 core functions, including energy consumption inquiries, energy consumption volume and intensity calculations, energy consumption analysis, and energy-use strategy recommendations, while standardizing technical scheme requirements across seven dimensions, such as system architecture, infrastructure setup, and data collection. Concurrently, the Ministry of Ecology and Environment and other ministries have been constructing a carbon footprint management system, issuing the national general standard GB/T 24067 Greenhouse gases-Carbon footprint of products- Requirements and guidelines for quantification, publishing documents such as the 2023 electricity carbon footprint factor data announcement, and launching the National Greenhouse Gas Emission Factor Database. These efforts provide fundamental data support for greenhouse gas emission factors to the public and offer a critical data foundation for precise carbon footprint traceability, accounting, and international mutual recognition. This comprehensive guideline reflects China's strategic intent to harmonize energy and carbon data

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governance, bridging the gap between industrial digitization and decarbonization objectives. Moreover, the national greenhouse gas emission factor database not only serves domestic accounting but is also a prerequisite for establishing internationally accepted carbon footprint benchmarks, thereby strengthening the foundation for mutual recognition negotiations.

3.1.2. Local Pilot Innovations and Experiences

Various localities, drawing on regional industrial characteristics, have actively explored and developed a series of innovative practices in digital energy-carbon management. In June 2025, Dalian, Liaoning Province, launched Northeast China's first "one-stop" carbon footprint public service platform, embedding accounting models for 21 product categories across nine major industries, including petrochemicals and equipment manufacturing. The platform has served 32 local enterprises, compressing the traditional calculation cycle from 2-3 months to within three days and reducing corporate certification costs by over 50%. Upon its launch, the platform signed agreements with key energy-consuming and carbon-emitting enterprises, certification bodies, and financial institutions, preliminarily establishing a carbon management ecosystem encompassing accounting, certification, and financial services. It was also integrated into the Dalian Free Trade Zone's integrated service platform as a "dual carbon" service module, deeply embedding into export business processes to resolve trade bottlenecks for exporting enterprises. Zhejiang Province, leveraging its textile industry base, has built a textile product carbon footprint database and promoted the development of corresponding group and local standards, effectively driving improvements in regional carbon efficiency evaluation. Henan Province has steadily advanced the construction of digital energy-carbon management centers; several enterprises in Xinxiang city were selected as provincial-level pilots. By deploying IoT monitoring devices, these enterprises achieved real-time collection and early warning responses for carbon emission data, substantially improving management efficiency[8]. In some Province, the local government has pioneered an industrial carbon account system that assigns carbon ratings to enterprises based on real-time energy data, linking these ratings to green finance incentives; early results show enhanced corporate motivation for energy conservation and emission reduction. Similarly, Jiangsu Province has piloted a "carbon code" for textile products, enabling consumers and supply chain partners to scan and access product-level carbon footprints, thereby transforming carbon management into a market differentiator.

3.1.3. Enterprise Applications Focusing on Data Traceability, Cost Reduction, and Efficiency Gains

Enterprises have actively applied digital technologies to enhance energy-carbon management effectiveness, achieving notable results in cost reduction and efficiency gains. Echeng Steel, through the construction of a digital intelligent energy-carbon management and control system, has utilized digital modules to achieve precise prediction and balanced dispatch of energy media such as gas, oxygen, and steam, saving 3.12 million yuan annually in demand charges. Through intelligent modules, the scheduling connection time for casting and rolling plans was shortened by 30%, the hot charging rate increased to 84.6%, and external electricity purchasing costs dropped by 220 million yuan. The By-Health production base, relying on its energy management center, promoted photovoltaic power generation applications and green packaging retrofitting. In 2024, its total annual energy consumption decreased by over 20% year-on-year, and it was included in the Ministry of Ecology and Environment's list of exemplary ESG cases, generating a strong industry demonstration effect[9]. Furthermore, a leading home appliance manufacturer incorporated a digital product passport system that tracks carbon emissions across the entire life cycle, which not only reduced internal energy costs but also successfully met the upcoming EU Digital Product Passport requirements, securing continued market access.

3.2. Major Models

3.2.1. Enterprise Self-Built Model

The self-built model is predominantly observed in large key emitting enterprises and export-oriented firms. Enterprises rely on their own capabilities to deploy digital energy-carbon management platform systems. These platform systems directly connect, via IoT technology, to control systems such as PLCs and DCSs on production lines, as well as high-precision smart meters and gas meters, to automatically collect energy consumption data from all processes in real time. The system is embedded with carbon accounting rules compliant with international standards such as ISO 14064 and ISO 14067, converting data into carbon emission data and generating product carbon footprint reports that meet the basic requirements of international regulations such as the EU CBAM. This provides a direct basis for addressing international green trade barriers and for digitalized energy conservation and carbon reduction management[10].These self-built centers often integrate advanced analytics and AI to optimize production

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scheduling based on carbon price signals, enabling proactive adjustment to minimize carbon costs. However, the high initial investment and need for specialized talent limit this model to well-resourced enterprises, creating a capacity gap among smaller firms.

3.2.2. Public Service Platform Model

The public service platform model is typically spearheaded by departments such as provincial and municipal bureaus of industry and information technology, ecology and environment, development and reform, and industrial park management committees. The core objective of such platforms is to resolve carbon accounting bottlenecks for regional enterprises and reduce overall compliance costs. Existing platforms are primarily energy-carbon management platforms, which still fall somewhat short of the positioning and functionality of energy-carbon management centers. These platforms are typically equipped with carbon accounting models and localized emission factors applicable to local dominant industries. Enterprises log in through an online portal, input required energy consumption and production activity data as guided, and the platform automatically completes the calculations and generates standardized carbon accounting reports, thereby reducing the cost of energy-carbon management and shortening the accounting cycle. This lays a solid foundation for the subsequent construction of regional carbon management systems, the realization of carbon data mutual recognition, and even the development of carbon inclusive markets[11]. Some platforms are evolving toward "carbon management brain" functions by aggregating multi-enterprise data to identify regional energy efficiency benchmarks and provide tailored improvement advice, thus moving beyond simple accounting to proactive optimization. Nevertheless, their effectiveness hinges on the willingness of enterprises to share production data, which remains a critical barrier.

3.2.3. Third-Party Service Model

Under the third-party service model, enterprises procure energy-carbon management services provided by professional consulting firms. These firms typically possess international and domestic certification qualifications, offering enterprises a full-process outsourcing service ranging from initial carbon verification, energy-carbon center deployment, and carbon footprint verification to final assistance in applying for international certifications. This model effectively helps small and medium-sized export enterprises lacking professional talent and technical reserves to mitigate trade risks and rapidly establish carbon management capabilities that meet supply chain requirements. However, the quality of service varies significantly among providers, and enterprises may face risks related to data confidentiality during the handover of sensitive process information. Additionally, the cost of outsourced certification and continuous monitoring can be substantial for firms with thin margins, potentially offsetting the compliance benefits.

3.3. Existing Problems

3.3.1. Inadequate Data Traceability in Energy-Carbon Management

Digital energy-carbon management centers are required to directly collect energy consumption data from production equipment through IoT technology. However, the survey found that the equipment coverage rate for energy-carbon metering in enterprises is less than 70%, indicating gaps in the data collection process. Existing systems show significant shortcomings in supply chain carbon data traceability, making it difficult to ensure the continuity of data across the entire process from raw material procurement to product delivery. Some enterprises still rely on manual entry for carbon data recording, which makes verifying data authenticity challenging and directly undermines the international credibility of carbon footprint accounting results. This lack of automated collection is often attributable to retrofitting difficulties in older production lines and the absence of standard communication protocols across different equipment generations, resulting in data islands. Moreover, upstream suppliers, particularly small and medium-sized ones, frequently lack the incentive and capability to provide verified carbon data, breaking the chain of custody and undermining the credibility of full-lifecycle carbon claims.

3.3.2. Incompatible Standard Systems Hindering International Mutual Recognition

On the one hand, domestic carbon accounting rules exhibit "multi-track parallelism." For instance, the steel industry adopts the process-based boundary method, while the automotive industry emphasizes the full lifecycle method, leading to discrepancies exceeding 20% in carbon footprint results for the same product. On the other hand, the national electricity carbon footprint factor of 0.6205 $kgCO_2e/kWh$ shows a significant gap compared to the 0.85–0.95 $kgCO_2e/kWh$ typical of mainstream international databases. Relevant EU regulations only recognize the "direct green power connection" calculation method, which

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weakens enterprises' negotiating position. Approximately 80% of export enterprises require repeated international certifications, substantially increasing compliance costs. The divergence is not merely technical but also reflects differing policy assumptions: for instance, the EU's Product Environmental Footprint method allocates recycling credits differently than China's prevailing approach, creating systematic gaps. Without authoritative bridging methodologies, enterprises must navigate dual reporting, which consumes resources and delays market responsiveness.

3.3.3. Data Security Concerns Affecting Enterprise Participation in Platform-Based Management

Large leading enterprises, out of concern for protecting core trade secrets, harbor significant reservations about using public service platforms or third-party platforms. Their primary concerns are that sensitive information, such as production process parameters and energy consumption data, transmitted through cloud-based platforms may pose leakage risks, and they are reluctant to submit critical data to public service or third-party entities. Typically, they only report energy consumption per unit product for major energy-consuming industrial enterprises and other necessary regulatory data, while preferring to adopt a self-built energy-carbon management center model for other aspects of energy-carbon management. Although this ensures data security, it increases the difficulty of data integration and mutual recognition. The varying capabilities of third-party service platforms in areas such as data security further exacerbate these concerns. This hesitation has led to a fragmented data landscape where large enterprises operate in isolation and small firms rely on disparate service providers, impeding the formation of a unified carbon data ecosystem. Consequently, the potential for cross-sectoral benchmarking and collective negotiation with international bodies remains largely untapped, weakening China's overall carbon governance efficacy.

4. Policy Recommendations

4.1. Establish a Whole-Industry-Chain Carbon Data Traceability System

Emphasis should be placed on adopting economically feasible technological pathways. Low-cost IoT collection devices should be promoted, and energy-carbon metering devices for key processes should be deployed on a priority basis in small and medium-sized enterprises to achieve full data collection coverage in phases. The adoption of lightweight blockchain technologies is encouraged to establish low-cost yet reliable data evidence preservation. For supply chain carbon data traceability, data sharing channels can be established on a priority basis between key industry enterprises and core suppliers, using standardized data interfaces to reduce implementation costs. Enterprises that meet the requirements of the Guidelines for the Construction of Digital Energy-Carbon Management Centers in Industrial Enterprises and Parks should be granted corresponding recognition, such as priority government procurement, and be included in a "trusted mutual recognition list." The traceability system should also incorporate a phased roadmap, starting with pilot supply chains in electronics and automotive sectors where product complexity is high and trade exposure is significant. By demonstrating feasibility and cost-effectiveness in these pilots, broader adoption can be catalyzed, and technical standards can be refined iteratively. Furthermore, linking carbon data traceability to green finance instruments, such as sustainability-linked loans, can provide tangible incentives for upstream suppliers to participate.

4.2. Promote International Alignment and Mutual Recognition of Carbon Accounting Standards

Industry associations should take the lead in formulating and revising national standards for product carbon footprint accounting and corporate carbon accounting, clearly defining unified accounting boundaries and emission factor prioritization rules, and promoting pilot programs for mutual recognition with international standards such as ISO 14067. First, authoritative industry bodies should organize dialogues with the EU and other major trading partners to promote the conversion and alignment of carbon accounting methodologies. Second, a differentiation mechanism between China-specific carbon footprint factors and international factors should be established, with continuous publication of carbon footprint factor announcements and white papers on differentiation explanations to provide a basis for corporate international certification. Third, Sino-foreign mutual recognition pilot programs should be launched in regions such as the Guangdong-Hong Kong-Macao Greater Bay Area, which have already explored regional mutual recognition, to investigate the establishment of bilateral mutual recognition mechanisms and reduce the costs of repeated certifications for enterprises. These pilot programs should include mutual observation of verification processes and joint capacity-building workshops to build trust among regulatory bodies. Additionally, China could proactively propose sector-specific mutual

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recognition agreements for batteries and photovoltaic products, leveraging its market share to negotiate reasonable equivalence pathways, thereby preventing carbon footprint requirements from becoming de facto trade barriers.

4.3. Build Secure and Trustworthy Public Energy-Carbon Management Centers

A tiered and classified system of energy-carbon management centers should be established. First, public service platforms should be promoted to adopt a “data stays on the factory premises” model, whereby core enterprise process parameters are retained locally, and only desensitized carbon accounting results are uploaded. Second, relevant management specifications for energy-carbon data security should be formulated, clearly defining the data security responsibilities of participating entities such as platform operators and third-party service providers. Third, large enterprises should be encouraged to adopt a “public-private hybrid cloud” deployment model, with sensitive data stored in a private cloud and public services connected through a public cloud, thereby achieving interconnection and interoperability while safeguarding data security. To further bolster trust, the adoption of privacy-enhancing computation techniques, such as federated learning and multi-party computation, should be explored to allow collaborative carbon benchmarking without exposing raw operational data. Moreover, an independent third-party audit mechanism for platform security and data governance should be established, with regular transparency reports published to alleviate enterprise concerns.

5. Conclusion

Based on a survey of representative enterprises, this study systematically analyzes the current status, models, and salient problems in the construction of corporate energy-carbon management centers, and proposes targeted optimization pathways. The research indicates that while the construction of such centers has made positive progress under policy guidance and local practices, the three major bottlenecks of data traceability, standard mutual recognition, and data security still require focused breakthroughs. From establishing a whole-industry-chain traceability system and promoting international mutual recognition of standards to building secure and trustworthy public platforms, countermeasures at all levels must be advanced in a coordinated manner to effectively enhance corporate carbon management capabilities and international competitiveness.

Further analysis indicates that the three models-self-built, public service platform, and third-party service are not mutually exclusive but rather complementary in practice, with their suitability determined by enterprise size, export exposure, and digital maturity. The data traceability bottleneck remains the central challenge, as it simultaneously involves technical limitations in metering coverage, inconsistencies in accounting standards, and concerns over data security. Addressing this bottleneck therefore requires synchronized progress across all three dimensions. In terms of optimization pathways, a tiered approach may be the most feasible: large enterprises can be guided to share desensitized carbon benchmarks through hybrid cloud architectures, while public platforms concentrate on providing localized emission factors and accessible interfaces for small and medium-sized enterprises. The scaling of regional pilot experiences into national implementation hinges on establishing uniform technical specifications and sustained investment in personnel training and system maintenance. Embedding these centers into existing green procurement frameworks and carbon market mechanisms would further reinforce their practical utility, helping enterprises move beyond compliance tasks toward routine carbon management.

This study has certain limitations. The sample size is relatively limited and concentrated in key regions and industries. Thus, the generalizability of the findings requires further validation. Future research can expand the sample coverage, conduct comparative analyses across industries and regions, and track and evaluate the implementation effects of various countermeasures, thereby providing more robust empirical support for policy optimization. Additionally, cross-national comparative studies examining how other manufacturing economies are developing their digital carbon management infrastructures could yield valuable insights for policy transfer and adaptation. The dynamic interaction between regulatory evolution and technological innovation in carbon accounting also warrants longitudinal investigation to guide proactive policy design.

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