

FROM DUAL-CARBON MANAGEMENT TO GREEN INNOVATION: THE SYNERGISTIC PATHWAYS OF CARBON ACCOUNTING AND CARBON FOOTPRINT IN TECHNOLOGY ENTERPRISES

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Abstract: Under the national dual-carbon strategy, technology enterprises face increasing pressure to reduce carbon emissions resulting from intensive energy use, complex supply chains, and long product life cycles. Identifying effective pathways for achieving green innovation under carbon constraints has become an essential issue for sustainable corporate development. This study establishes a “dual-carbon management” theoretical framework that integrates organizational-level carbon accounting with product-level carbon footprint assessment. Drawing on existing literature, the study examines the roles of carbon accounting in carbon governance, strategic planning, and internal incentive mechanisms, as well as the contributions of carbon footprint analysis to life-cycle assessment, material optimization, and product Eco-design. It further explores the synergistic mechanisms between the two, including data complementary, governance alignment, strategic coordination, and value-chain integration. Based on these insights, the study proposes key principles for constructing green innovation paths, emphasizing data integrity, systemic thinking, innovation-oriented governance, life-cycle perspective, value-chain collaboration, and dynamic adjustment. A representative case of a technology enterprise is analyzed to illustrate how dual-carbon management supports the development of low-carbon technologies, process improvements, and green product innovation. The results show that carbon accounting provides a foundation for organizational carbon governance, while carbon footprint offers detailed life-cycle insights. The integration of these two mechanisms forms a multi-level system that enhances strategic decision-making, operational transformation, and supply-chain-wide collaboration. This study contributes theoretical insights and practical guidance for technology enterprises seeking green innovation pathways under carbon constraints.

Keywords: Carbon accounting; Carbon footprint; Green innovation; Technology enterprises; Dual-carbon management

1 INTRODUCTION

In the context of global climate governance and China’s “dual-carbon” strategy, technology enterprises are facing unprecedented pressure to reduce carbon emissions while sustaining innovation-driven growth. As key actors in digitalization, advanced manufacturing, and high-tech industries, technology enterprises contribute significantly to carbon emissions through energy consumption, complex supply chains, and product life-cycle impacts. At the same time, they are also essential drivers of low-carbon technological transformation, green upgrading, and sustainable industrial development. Against this backdrop, exploring how internal carbon management mechanisms stimulate green innovation has become an urgent theoretical and practical issue.

Carbon accounting and carbon footprint—representing organizational-level and product-level carbon management, respectively—have emerged as crucial tools for strengthening corporate responses to environmental challenges. Carbon accounting provides systematic procedures for identifying, measuring, and reporting organizational greenhouse gas emissions, forming the foundation for corporate carbon governance, carbon disclosure, and strategic decision-making[1]. Carbon footprint analysis, grounded in life-cycle assessment, enables enterprises to quantify emissions throughout the entire value chain of products and services, thereby identifying emission hotspots, guiding technological improvement, and supporting green product development[2]. Although both mechanisms play important roles in low-carbon management, existing research tends to examine them independently, overlooking the potential synergistic effects between organizational carbon governance and product life-cycle carbon management.

At present, most studies on corporate green innovation emphasize external regulatory drivers, environmental policies, or market incentives, while relatively little attention has been paid to how internal carbon management systems jointly shape enterprises’ innovation behaviors. For technology enterprises—characterized by rapid technological iteration, intensive knowledge production, and high sensitivity to environmental uncertainty—the combined application of carbon accounting and carbon footprint may form a “dual-carbon management system” that not only enhances data accuracy and transparency, but also embeds carbon constraints and environmental value into innovation processes. However, the internal logic, mechanisms, and pathways through which these two carbon management tools interact to promote green innovation remain insufficiently explored.

Therefore, this study aims to investigate the synergistic pathways through which carbon accounting and carbon footprint jointly influence green innovation in technology enterprises. Drawing on interdisciplinary perspectives from carbon accounting, sustainability management, and innovation theory, this research constructs a theoretical framework

demonstrating how dual-level carbon management—organizational carbon governance and product life-cycle carbon management—shapes innovation motivation, capability formation, and strategic transformation. Specifically, the study examines the interaction between carbon accounting and carbon footprint, analyzes their integrated mechanisms in data governance, internal control, resource allocation, and value-chain collaboration, and identifies the pathways through which they stimulate green technological, managerial, and product innovation[3].

The significance of this research is threefold. Theoretically, it enriches the literature on corporate green innovation by introducing a dual-carbon management perspective and by clarifying the micro-level mechanisms underlying low-carbon innovation in technology enterprises. Practically, it provides guidance for technology enterprises to build comprehensive carbon management systems, optimize innovation strategies, and enhance competitiveness under carbon-constrained conditions. At the policy level, the research offers insights for improving carbon disclosure regulations, promoting life-cycle environmental governance, and accelerating the green transformation of high-tech industries.

2 LITERATURE REVIEW AND THEORETICAL BASIS

2.1 Carbon Accounting and Carbon Management

Carbon accounting has become a foundational component of corporate environmental management as global climate policies increasingly emphasize transparency, standardization, and accountability in greenhouse gas (GHG) reporting. Early studies on carbon accounting primarily focused on the development of measurement and reporting frameworks for organizational carbon emissions, with international standards such as the Greenhouse Gas Protocol and ISO 14064 providing structured guidance on defining emission boundaries, identifying emission sources, and quantifying direct and indirect emissions. This body of research established carbon accounting as a systematic approach to documenting corporate GHG emissions and supporting compliance with environmental regulations.

Over time, scholars expanded the focus of carbon accounting from narrow technical measurement to broader issues of governance, strategy, and performance management. In particular, the role of carbon accounting in enhancing information transparency, reducing environmental uncertainty, and supporting corporate decision-making has been well recognized. Research has shown that high-quality carbon accounting systems facilitate internal carbon budgeting, carbon performance evaluation, and the integration of carbon metrics into corporate financial and strategic planning[4]. Such developments signify a shift from carbon accounting as a reporting tool to carbon accounting as a strategic management instrument embedded within enterprise governance structures.

In addition to internal governance implications, carbon accounting has also been examined through the lens of external stakeholders. Studies demonstrate that accurate and credible carbon disclosure can reduce information asymmetry between firms and investors, enhance corporate reputation, and improve access to green finance. These findings underscore the significance of carbon information quality—driven by robust accounting practices—in shaping stakeholders' perceptions and influencing firms' environmental and financial outcomes[5].

Carbon management, as an extension of carbon accounting, encompasses organizational strategies, institutional arrangements, and operational practices that aim to monitor, control, and reduce carbon emissions. Research in this field highlights that effective carbon management requires not only accurate emissions data but also the establishment of internal carbon governance mechanisms, such as carbon performance indicators, carbon cost accounting, and internal carbon pricing systems. Scholars argue that these mechanisms help enterprises identify emission reduction opportunities, allocate resources toward low-carbon technologies, and embed environmental values into managerial decision-making processes[6]. As a result, carbon management is increasingly viewed as an integrated system linking measurement, governance, strategy, and performance.

Recent studies on carbon management especially emphasize its role in supporting corporate innovation. By internalizing carbon-related risks and costs, carbon management practices create incentives for firms to invest in energy efficiency, process optimization, and green technology development. For technology enterprises—characterized by rapid technological iteration and high resource intensity—carbon management serves not only as a compliance framework but also as a strategic driver of innovation capability and competitive advantage. However, existing research often treats carbon accounting and carbon management as separate constructs, lacking an integrated perspective on how carbon accounting practices contribute to the design, operation, and effectiveness of broader carbon management systems[7].

2.2 Carbon Footprint and Product Life-Cycle Carbon Management

Carbon footprint research, rooted in life-cycle assessment (LCA), has become an essential analytical approach for evaluating the environmental impact of products, services, and value-chain activities. Internationally, scholars have emphasized that carbon footprint assessment operationalizes sustainability principles by quantifying emissions across all stages of a product's life cycle—ranging from raw material extraction and manufacturing to transportation, usage, and end-of-life treatment[8]. Early studies predominantly focused on methodological refinement, including system boundary definition, emission factor selection, and allocation rules, establishing carbon footprint analysis as a standardized and scientifically grounded tool for product-level carbon quantification.

More recent research highlights the strategic implications of carbon footprint assessment in corporate environmental management. Scholars argue that carbon footprint results provide actionable insights for identifying high-emission processes, optimizing material choices, and redesigning production techniques. In manufacturing and technology-intensive industries, carbon footprint analysis enables firms to target emission hotspots and explore low-carbon

technological alternatives, such as material substitution, renewable energy integration, and digital monitoring systems. This methodological evolution has expanded the application of carbon footprint from environmental accounting to product innovation, supply-chain optimization, and sustainability-driven decision-making[9].

In the context of corporate sustainability disclosure, carbon footprint has also become a key component of firms' environmental transparency initiatives. With the rise of consumer environmental awareness and green market differentiation, enterprises increasingly rely on product carbon footprint labels and third-party certifications to signal environmental responsibility and enhance brand competitiveness[10]. Studies show that carbon footprint information improves stakeholder trust, facilitates compliance with green procurement standards, and strengthens firms' positioning in low-carbon value chains. These developments mirror the function of high-quality teaching materials described in the template article, where standardized, comprehensible, and application-oriented materials serve as instruments for bridging institutional expectations and practical implementation[11].

However, much like the challenges identified in vocational textbook construction—such as outdated content, insufficient alignment with industry needs, and uneven digitalization—carbon footprint research and application also face limitations. Several studies point out that data availability, supply-chain transparency, and methodological inconsistencies hinder accurate product-level carbon assessment. Particularly in technology enterprises, where production systems are complex and globalized, obtaining reliable upstream and downstream emission data remains difficult. Moreover, the rapid pace of technological innovation often leads to mismatches between existing carbon footprint tools and emerging production processes. As a result, many firms struggle to systematically integrate carbon footprint results into product development, procurement management, and innovation planning.

To address these challenges, scholars increasingly advocate for digitalized, dynamic, and collaborative approaches to carbon footprint management. Emerging studies highlight the role of advanced technologies—such as big data analytics, IoT-based carbon monitoring, and blockchain-enabled supply-chain traceability—in enhancing carbon footprint accuracy, improving data integration, and facilitating multi-stakeholder collaboration. These approaches mirror the template's emphasis on the integration of digital tools, contextualized resources, and continuous updating mechanisms in building “gold textbooks,” underscoring the importance of innovation, practicality, and adaptability in complex application scenarios.

2.3 Theoretical Framework for the Study

To support the analysis of how carbon accounting and carbon footprint jointly influence green innovation in technology enterprises, this study is grounded in three interrelated theoretical foundations. These theories provide conceptual guidance for understanding the mechanisms through which organizations internalize environmental information, allocate resources for innovation, and respond to institutional pressures. The selected theoretical perspectives—information asymmetry theory, resource-based view (RBV), and institutional theory—are summarized in Table 1.

Table 1 Theoretical Framework of the Study

Theory	Core Concepts	Application to This Study
Information Asymmetry Theory	Organizations and stakeholders possess unequal information; disclosure reduces uncertainty and enhances decision-making efficiency	Explains how carbon accounting and carbon footprint disclosure reduce environmental information gaps, enabling more accurate innovation decisions
Resource-Based View (RBV)	Firms gain competitive advantage by developing valuable, rare, and inimitable internal resources and capabilities	Provides a basis for viewing carbon data systems and carbon management capabilities as strategic resources that drive green innovation.
Institutional Theory	Organizations respond to regulatory, normative, and cognitive pressures by adopting legitimizing practices	Highlights how carbon accounting and carbon footprint practices evolve under regulatory and market pressures, influencing innovation strategies

The theoretical framework also serves as the foundation for constructing the study's overall analytical route. Drawing on these theoretical perspectives, this study examines how carbon accounting (organizational-level carbon governance) and carbon footprint (product-level life-cycle carbon management) interact to shape technology enterprises' innovation processes. The proposed research route integrates theoretical foundations, problem identification, mechanism analysis, and innovation pathway development—corresponding to the structural logic illustrated in the template's technical route diagram[12].

Specifically, information asymmetry theory supports the exploration of how enhanced carbon information quality improves transparency and reduces uncertainty in innovation decisions. The resource-based view provides the lens through which carbon data systems, carbon governance mechanisms, and life-cycle assessment capabilities are conceptualized as internal resources that strengthen firms' innovation capacities. Institutional theory helps explain why technology enterprises adopt carbon accounting and carbon footprint practices under external regulatory, normative, and market pressures, subsequently integrating these practices into their innovation strategies[13].

Taken together, these theories establish a coherent foundation for analyzing the synergistic role of carbon accounting and carbon footprint in promoting green innovation and guide the construction of the study's conceptual framework and analytical pathways.

This flowchart Figure 1 illustrates the complete research logic of the study, including problem identification, literature and theoretical foundation, dual-carbon mechanisms, green innovation path design, and final conclusions. Sub-nodes under each major stage clarify the analytical elements involved at each step of the research.

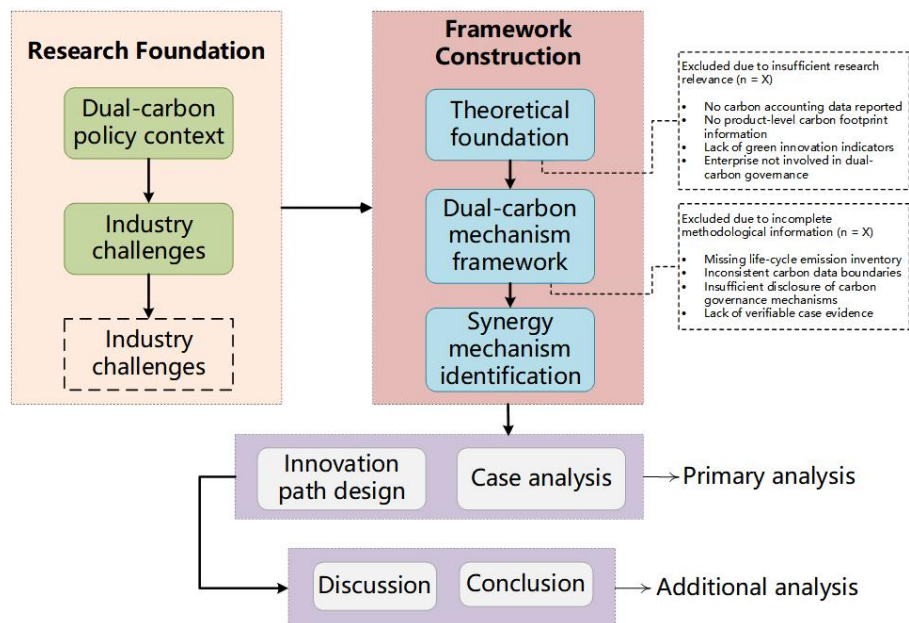


Figure 1 Technical Route of the Study

3 PATHWAYS OF DUAL-CARBON MANAGEMENT TO GREEN INNOVATION

3.1 The Role of Carbon Accounting in Enhancing Green Innovation

The foundation of dual-carbon management in technology enterprises lies in the establishment of a comprehensive and measurable carbon accounting system that reflects organizational-level carbon governance needs. Unlike traditional environmental accounting, which tends to focus on cost recognition or regulatory compliance, carbon accounting emphasizes the systematic identification, quantification, and reporting of greenhouse gas emissions across operational boundaries. For technology enterprises—whose operations involve energy-intensive data centers, complex manufacturing processes, and globalized supply chains—carbon accounting serves as a critical tool for understanding emission structures and managing environmental performance.

In recent years, the increasing stringency of national carbon regulations and the growing importance of green competitiveness have intensified the need for technology enterprises to develop accurate and standardized carbon accounting systems[1]. These systems not only document emission levels but also articulate carbon governance objectives that align with corporate strategies and societal expectations. Carbon accounting must integrate three core dimensions: carbon information accuracy, carbon governance capability, and carbon strategic integration[7]. Together, these dimensions determine whether carbon accounting can effectively support decision-making processes related to green innovation.

To illustrate this relationship more clearly, Table 2 summarizes the core dimensions of carbon accounting in technology enterprises and their implications for green innovation.

Table 2 Core Dimensions of Carbon Accounting and Their Implications for Green Innovation

Dimension	Definition	Relevance to Green Innovation
Carbon Information Accuracy	Precise measurement and reporting of Scope 1–3 emissions using standardized methods	Helps identify emission hotspots and guides targeted technological improvements
Carbon Governance Capability	Internal systems for carbon control, performance assessment, and compliance monitoring	Embeds carbon-reduction responsibilities into management processes, motivating internal innovation
Carbon Strategic Integration	Incorporation of carbon metrics into corporate strategy, investment, and R&D planning	Shapes long-term innovation priorities, supporting low-carbon technology development and deployment

As Table 2 indicates, carbon accounting forms the informational and organizational basis for supporting innovation-oriented environmental actions. When enterprises accurately identify the sources, intensity, and distribution of emissions across organizational units, they are better positioned to recognize areas requiring technological upgrading or process redesign.

Moreover, carbon accounting contributes to internal governance by embedding carbon performance metrics into management systems. Technology enterprises often operate within dynamic and data-driven environments; thus, the integration of carbon information into internal evaluation mechanisms enhances accountability and promotes innovation-oriented behavioral change. Through internal carbon pricing, carbon budgeting, and cross-departmental carbon performance assessments, enterprises convert carbon constraints into innovation incentives—particularly in areas such as energy-efficient computing, low-carbon materials, smart manufacturing, and circular product design.

Finally, carbon accounting plays a strategic role by linking carbon-related risks and opportunities with corporate development planning. As technology enterprises pursue competitiveness in global markets that increasingly value low-carbon products and green supply chains, the incorporation of carbon data into strategic decision-making helps firms allocate resources toward forward-looking innovation initiatives. These strategic initiatives may include R&D in alternative materials, green data-center technologies, product redesign for recyclability, or the adoption of new digital tools for carbon monitoring.

3.2 The Role of Carbon Footprint in Guiding Product and Technology Innovation

Carbon footprint analysis functions as a key component of product-level carbon management, enabling technology enterprises to examine the environmental impact of their products and processes throughout the entire life cycle. By quantifying emissions from raw material extraction, component manufacturing, assembly, distribution, use, and end-of-life treatment, carbon footprint provides a comprehensive perspective that connects low-carbon objectives with concrete technological and design decisions. This life-cycle approach is particularly important for technology enterprises, where complex supply chains, advanced materials, and energy-intensive operations contribute to diverse and distributed sources of carbon emissions.

Compared with organizational-level carbon accounting, which emphasizes overall emission inventories, carbon footprint offers detailed and location-specific insights. These granular measurements highlight emission hotspots across different stages of the product life cycle. This allows enterprises to identify which materials, processes, or suppliers contribute disproportionately to total emissions, thereby revealing opportunities for technological improvement and eco-design. As a result, carbon footprint acts both as a measurement tool and as an innovation guide, directing attention to the most impactful areas where low-carbon interventions can be effectively implemented[13].

The logical relationship between carbon footprint analysis and innovation can be described through a progression from life-cycle information to product redesign, process optimization, and evaluation-based decision-making. First, carbon footprint transforms abstract sustainability goals into concrete design requirements by identifying critical points where emissions are concentrated. Second, insights derived from life-cycle data stimulate technological improvements, such as adopting cleaner production methods, optimizing energy use, or integrating low-carbon materials. Third, carbon footprint metrics can be embedded into supplier selection, product benchmarking, and R&D evaluation systems to ensure that innovation aligns with long-term carbon reduction objectives[2,4,9].

These relationships can be summarized as follows in Table 3.

Table 3 Logical Relationship Between Carbon Footprint Analysis and Product/Technology Innovation

Relationship	Life-Cycle Carbon Insights	Innovation-Oriented Response
From Life-Cycle Goals to Design Choices	Identifies critical stages and emission hotspots in the product life cycle	Supports material substitution, low-carbon component selection, and eco-design integration
From Process Insights to Technological Upgrading	Reveals high-emission processes and operational inefficiencies	Encourages cleaner production, digital monitoring, and energy-efficient manufacturing
From Life-Cycle Metrics to Evaluation Systems	Provides measurable indicators for product and supplier assessment	Guides carbon-based procurement, supplier evaluation, and R&D performance management

As illustrated in Table 3, carbon footprint analysis connects environmental information with practical innovation mechanisms. When life-cycle carbon data are incorporated into the early stages of product development, enterprises can embed low-carbon considerations into design concepts, material selection, and structural decisions. This reduces the need for costly redesign later and supports the creation of inherently low-carbon products.

At the technological level, carbon footprint findings highlight opportunities for upgrading manufacturing processes. These improvements may involve more efficient energy systems, advanced automation, intelligent monitoring technologies, or redesigned workflows that minimize carbon-intensive inputs. Such process innovations not only reduce emissions but also enhance production efficiency, thereby improving overall competitiveness.

At the managerial level, carbon footprint metrics can be integrated into suppliers' carbon performance assessments, enabling enterprises to construct low-carbon supply chains. The availability of comparable, quantifiable data supports procurement decisions aligned with carbon reduction objectives, encouraging suppliers to adopt cleaner technologies and improve transparency.

3.3 Integration of Carbon Accounting and Carbon Footprint

The integration of carbon accounting and carbon footprint represents the core of a dual-level carbon management system that connects organizational governance with product life-cycle assessment. While carbon accounting provides an overall inventory of emissions at the enterprise level, carbon footprint supplies granular insights into carbon distribution along the value chain. When combined, these two mechanisms form a comprehensive structure that links carbon information, managerial control, and innovation-oriented actions in technology enterprises[3,14,15].

At the organizational level, carbon accounting establishes standardized procedures for measuring and reporting greenhouse gas emissions. This ensures that enterprises maintain an accurate understanding of carbon performance across business units, facilities, and operational boundaries. At the product and process level, carbon footprint analysis enables the identification of emission hotspots, revealing opportunities for material innovation, process optimization, and supply chain improvements. The integration of the two systems enables a more complete and dynamic representation of carbon emissions, reducing information fragmentation and enhancing the coherence of carbon management activities[12,13].

The relationship between carbon accounting and carbon footprint can be understood through their complementary roles in data governance, operational decision-making, and innovation management. Carbon accounting aggregates emission data from various activities and processes, forming a macro-level picture of corporate carbon performance. Carbon footprint, by contrast, offers micro-level evidence that can be traced to specific product components, processes, or suppliers. When integrated, macro-level data support strategic planning and resource allocation, while micro-level data guide technology choices and product development. This dual perspective creates a feedback loop in which organizational carbon information shapes product strategies and product-level findings inform corporate carbon governance.

The integrated functioning of carbon accounting and carbon footprint can be summarized as shown in Table 4.

Table 4 Integration of Carbon Accounting and Carbon Footprint

Integration Dimension	Role of Carbon Accounting	Role of Carbon Footprint	Expected Educational Outcomes
Data Complementarity	Provides enterprise-wide emission inventories	Offers detailed life-cycle emission data	Enhances accuracy of innovation decisions and prioritizes high-impact areas
Governance Alignment	Establishes internal carbon targets, budgeting, and oversight	Identifies product-level improvement opportunities	Strengthens consistency between strategic goals and technological innovation
Strategic Synergy	Incorporates carbon metrics into organizational planning	Guides low-carbon product redesign and technology choices	Enables alignment of long-term innovation roadmaps with carbon reduction goals
Value-Chain Integration	Supports carbon disclosure and supplier management	Traces emissions across upstream and downstream activities	Promotes collaborative green innovation across supply-chain partners

As shown in Table 4, the integration of carbon accounting and carbon footprint creates a multi-layered carbon management architecture that simultaneously supports strategic, managerial, and technological innovation. At the strategic level, decision-makers can allocate resources toward low-carbon technologies with greater precision. At the managerial level, internal governance structures become more responsive to product-level environmental data, reinforcing accountability and performance evaluation. At the operational level, engineers and designers obtain actionable insights to improve materials, processes, and components[12].

The combined application of these two mechanisms also promotes cross-departmental collaboration within technology enterprises. Carbon accounting often involves departments such as finance, operations, and corporate governance, whereas carbon footprint analysis engages product design, engineering, and supply-chain management. Their integration fosters interdepartmental communication and knowledge exchange, enabling firms to embed carbon considerations into all stages of technological development[8].

4 STRATEGIES FOR DEVELOPING DUAL-CARBON-BASED GREEN INNOVATION PATHS

4.1 Principles for Constructing Dual-Carbon-Based Green Innovation Paths

The development of effective green innovation paths in technology enterprises requires a systematic approach that integrates environmental objectives, organizational capabilities, and technological resources within a unified dual-

carbon management framework. To ensure that carbon accounting and carbon footprint jointly support innovation-driven carbon reduction, several guiding principles must be established. These principles serve as the foundation for translating carbon data into innovation actions and for constructing long-term mechanisms that align enterprise development with low-carbon transformation.

4.1.1 Data integrity and traceability

Green innovation relies on accurate, consistent, and traceable carbon information. Technology enterprises typically operate complex production systems and multi-tier supply chains, making comprehensive carbon data essential for identifying emission sources and designing targeted innovations. Ensuring high-quality data requires the establishment of standardized measurement protocols, transparent data flows, and digital tools that integrate organizational carbon accounting with product-level carbon footprint analysis. Through robust data governance, enterprises can identify key emission hotspots, uncover innovation opportunities, and support evidence-based decision-making.

4.1.2 Integration of organizational and product-level carbon management

A second principle is the alignment of organizational carbon governance with product-level life-cycle carbon management. Organizational carbon accounting offers a strategic perspective, while product-level carbon footprint analysis provides detailed insights into materials, processes, and supply-chain impacts. Integrating these two dimensions ensures coherence between corporate carbon reduction goals and specific innovation activities. This integration also helps enterprises embed carbon considerations across departments—including design, engineering, procurement, and operations—thus supporting cross-functional collaboration and reducing the risk of fragmented or inconsistent innovation efforts.

4.1.3 Innovation-oriented carbon governance

For technology enterprises, carbon management should not be limited to compliance or reporting but should serve as a catalyst for innovation. Embedding carbon-related indicators into project evaluation, resource allocation, and internal performance assessment creates incentives for breakthrough technological solutions. This principle emphasizes the need to view carbon constraints as an opportunity for value creation rather than a limitation. By incorporating carbon metrics into strategic planning and R&D management, enterprises can establish forward-looking innovation pipelines aligned with environmental objectives.

4.1.4 Life-cycle perspective and systemic thinking

Green innovation requires moving beyond isolated technological improvements toward a comprehensive understanding of environmental impacts across the entire product life cycle. A life-cycle perspective encourages enterprises to consider upstream raw materials, manufacturing processes, logistics patterns, product use, and end-of-life disposal when designing low-carbon solutions. This systemic view helps avoid problem shifting—for instance, reducing emissions in one stage while unintentionally increasing them in another—and supports the development of balanced and sustainable innovation strategies.

4.1.5 Collaborative and value-chain-based development

Technology enterprises rarely operate independently; their innovation performance is shaped by suppliers, manufacturing partners, logistics providers, and end-users. Accordingly, effective green innovation paths must incorporate collaboration across the value chain. This includes sharing carbon data, aligning carbon reduction targets, and jointly developing low-carbon technologies or materials. Building a collaborative ecosystem promotes coordinated emission reductions and enhances the overall low-carbon competitiveness of the enterprise and its partners.

4.1.6 Dynamic improvement and adaptive adjustment

Given the rapid evolution of technologies, regulatory environments, and market expectations, green innovation paths must remain adaptable. Continuous monitoring, evaluation, and feedback mechanisms enable enterprises to refine carbon management practices and adjust innovation strategies. This principle supports dynamic improvement rather than static adherence to pre-established plans. Through iterative learning, enterprises can adapt to emerging challenges, integrate new technologies, and maintain alignment with long-term sustainability goals.

4.2 Framework and Key Characteristics of Dual-Carbon-Based Innovation Strategies

Building green innovation paths in technology enterprises requires not only a set of guiding principles but also a structured framework that links carbon management practices with innovation-oriented actions. A dual-carbon-based innovation framework integrates organizational-level carbon governance, product-level life-cycle carbon assessment, and value-chain collaboration into a coherent system that supports low-carbon technological advancement. This framework emphasizes the complementary roles of carbon accounting and carbon footprint analysis, positioning them as mutually reinforcing components that enhance strategic planning, operational transformation, and green technology development.

The framework consists of three interconnected layers:

1. Strategic Layer – embedding carbon objectives into enterprise-level strategies and long-term innovation planning;
2. Operational Layer – incorporating carbon data into processes, design activities, and managerial systems;
3. Collaborative Layer – extending carbon-oriented innovation across the supply chain and external partnerships.

These layers collectively enable enterprises to align environmental goals with technical capabilities and market demands. The key characteristics of dual-carbon-based innovation strategies are summarized in Table 5.

Table 5 Key Characteristics of Dual-Carbon-Based Innovation Strategies

Standard Dimension	Core Characteristics	Practical Approaches	Expected Impact
Strategic Integration	Incorporation of carbon goals into long-term innovation and development plans	Linking carbon metrics with corporate strategy, prioritizing low-carbon R&D agendas	Strengthened alignment between innovation direction and carbon reduction objectives
Data-Driven Transformation	Use of organizational and life-cycle carbon data to guide innovation	Integrating carbon accounting with carbon footprint insights; enabling digital carbon management platforms	More precise identification of innovation opportunities and emission hotspots
Process and Technology Enhancement	Continuous optimization of production processes and adoption of cleaner technologies	Implementing energy-efficient systems, advanced manufacturing, and digital monitoring tools	Reduced carbon intensity in operations and improved technological competitiveness
Product-Level Low-Carbon Design	Embedding carbon considerations into product design and material selection	Eco-design, low-carbon materials, modular structures, recyclable components	Development of low-carbon products with improved environmental performance
Supply-Chain Collaboration	Coordination with suppliers and partners to develop shared carbon reduction mechanisms	Carbon-based procurement systems, supplier carbon audits, co-development of low-carbon materials	Integrated emission reduction across the value chain and enhanced supply-chain resilience
Dynamic Evaluation and Adjustment	Continuous assessment of innovation progress and carbon performance	Establishing evaluation indicators, feedback loops, and iterative optimization mechanisms	Improved adaptability and consistency of innovation strategies over time

The framework emphasizes the interplay between strategic direction, technological execution, and value-chain engagement. At the strategic level, enterprises define long-term innovation trajectories informed by carbon reduction commitments. At the operational level, integrated carbon data systems guide the redesign of products, processes, and technologies. At the collaborative level, suppliers and partners are incorporated into shared carbon goals, ensuring that innovation does not remain siloed within the enterprise but extends to the broader ecosystem.

By incorporating these dimensions, the framework supports technology enterprises in achieving sustained green innovation that is both environmentally responsible and economically competitive. It highlights the need for coordination across organizational functions and emphasizes that effective carbon management requires simultaneous consideration of strategy, operations, and collaboration.

4.3 Case Analysis: A Representative Practice of Dual-Carbon-Based Innovation in a Technology Enterprise

To illustrate how the dual-carbon framework can be applied in practice, this section presents a representative example of how a technology enterprise integrates carbon accounting and carbon footprint analysis to support green innovation. Although the case is conceptualized rather than tied to a specific company, it reflects common practices observed in leading technology firms undergoing low-carbon transformation. The example demonstrates how enterprises can operationalize the principles and strategies described earlier and provides insight into the mechanisms through which dual-carbon management guides innovation activities.

4.3.1 Background of the enterprise

The case focuses on a medium-to-large technology enterprise engaged in smart device manufacturing, digital infrastructure, and component production. The company operates multiple production bases, maintains complex global supply chains, and invests heavily in research and development. As national regulations on carbon disclosure and carbon reduction became more stringent, the enterprise recognized the need to integrate environmental objectives with innovation strategies. To respond effectively, it established a dual-carbon management system consisting of organizational-level carbon accounting and product-level carbon footprint assessment.

4.3.2 Implementation practices

The enterprise initiated a multi-stage reform process that included data system development, internal governance restructuring, and product innovation driven by life-cycle insights. Key practices include:

4.3.2.1 Establishing a Digital Carbon Accounting System

The enterprise developed a unified digital platform to collect and manage carbon data across production facilities. The system standardized emission boundaries, automated data collection through IoT sensors, and consolidated Scope 1 to Scope 3 emission information. This centralized carbon inventory allowed managers to accurately identify major emission sources and set internal carbon targets aligned with the overall innovation strategy.

4.3.2.2 Conducting Life-Cycle Carbon Footprint Assessments

Parallel to organizational accounting, the enterprise launched a life-cycle carbon footprint project for its flagship hardware products. Through collaboration with suppliers, it gathered detailed material and process data covering upstream raw materials, manufacturing stages, logistics routes, product usage scenarios, and recycling processes. The results revealed that certain components—such as semiconductor modules and specialized composite materials—accounted for a disproportionate share of total emissions.

4.3.2.3 Linking Carbon Data with Innovation and R&D Planning

Findings from both accounting streams were integrated into the company's R&D decision-making system. The engineering division incorporated carbon footprint results into material selection and structural design reviews. At the same time, management used carbon accounting insights to prioritize investments in cleaner production technologies, including energy-efficient equipment, low-carbon surface treatment processes, and intelligent energy management systems.

4.3.2.4 Promoting Supplier Collaboration for Low-Carbon Materials

Recognizing the importance of upstream emissions, the enterprise worked closely with key suppliers to co-develop alternative materials with lower carbon intensities. Joint innovation initiatives focused on recyclable alloys, bio-based polymers, and high-efficiency electronic components. Supplier performance evaluations were updated to include carbon indicators, encouraging alignment across the supply chain.

4.3.2.5 Integrating Carbon Metrics into Product Evaluation and Market Strategy

To ensure consistency and accountability, the enterprise incorporated carbon indicators into product quality assessment, procurement rules, and internal performance reviews. Low-carbon product lines were highlighted in marketing strategies to strengthen brand competitiveness and meet customer expectations for environmentally responsible products.

5 DISCUSSION AND CONCLUSION

5.1 Discussion

This study investigates how carbon accounting and carbon footprint jointly contribute to the development of green innovation in technology enterprises. The findings presented in earlier chapters reveal that the integration of these two carbon management mechanisms forms a multidimensional framework that supports innovation at strategic, operational, and collaborative levels. The analysis highlights several theoretical and practical implications.

First, the study underscores the importance of integrating organizational and product-level carbon information. While carbon accounting provides a macro-level overview of enterprise emissions, carbon footprint offers micro-level, life-cycle-based insights. Their combination enables enterprises to develop a more accurate understanding of emission sources, revealing opportunities for technological upgrading, material substitution, and supply-chain optimization. This dual perspective strengthens decision-making by bridging corporate environmental objectives with actionable innovation strategies.

Second, the discussion emphasizes the central role of data governance in enabling effective dual-carbon management. High-quality carbon data allow enterprises to justify innovation investments, identify high-impact intervention points, and evaluate the effectiveness of technological improvements. The reliance on digital systems, such as carbon data platforms, IoT monitoring devices, and life-cycle databases, suggests that digitalization is not merely a supporting element but a fundamental driver of carbon-informed innovation.

Third, the analysis reveals how carbon governance mechanisms can act as internal sources of innovation incentives. By embedding carbon metrics into performance evaluations, budget allocation processes, and R&D planning, enterprises convert environmental constraints into opportunities for technological progress. This governance-driven innovation logic demonstrates that carbon management is not limited to compliance but can operate as a catalyst for organizational transformation and capability development.

Fourth, the study highlights the significance of value-chain collaboration in achieving systemic carbon reduction. Innovation activities that depend solely on internal processes may fail to capture upstream and downstream emission drivers. Effective dual-carbon management requires suppliers, partners, and customers to participate in coordinated innovation. The case analysis illustrates how supplier engagement in low-carbon materials development and carbon-based procurement standards can expand the scope and depth of innovation outcomes.

Finally, the study offers theoretical contributions by synthesizing insights from information asymmetry theory, resource-based view, and institutional theory. These theoretical perspectives help explain why enterprises invest in carbon information systems, how carbon management becomes a strategic resource, and under what institutional pressures enterprises adopt low-carbon innovation actions. The integration of these theories enriches understanding of dual-carbon-based innovation and provides an analytical foundation for future research.

5.2 Conclusion

This study explores the pathways through which carbon accounting and carbon footprint jointly drive green innovation in technology enterprises, proposing a dual-carbon framework that integrates organizational carbon governance with life-cycle carbon analysis. The findings indicate that:

1. Carbon accounting enhances innovation by providing enterprise-wide carbon inventories, strengthening internal governance, and embedding carbon considerations into strategic planning.
2. Carbon footprint analysis guides innovation by identifying life-cycle emission hotspots, informing eco-design, and supporting low-carbon process improvements.
3. The integration of carbon accounting and carbon footprint creates a comprehensive carbon management system that supports green innovation across strategic, operational, and collaborative dimensions.

4. A dual-carbon-based innovation pathway requires alignment of data integrity, carbon governance, technological upgrading, value-chain cooperation, and adaptive evaluation.

Taken together, these insights demonstrate that dual-carbon management is not merely a compliance mechanism but a powerful driver of long-term, capability-based environmental innovation. For technology enterprises, the adoption of integrated carbon management practices can strengthen competitiveness, support sustainability commitments, and accelerate the transition toward low-carbon development.

Future research may explore additional mechanisms, such as the role of carbon auditing, digital twin technologies, or industry-specific carbon innovation models, to further expand the theoretical and practical understanding of dual-carbon-driven innovation. As carbon regulation intensifies and markets increasingly value environmental performance, the strategic integration of carbon accounting and carbon footprint will become an essential pathway for technology enterprises seeking sustainable growth.

COMPETING INTERESTS

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