Research on Blockchain-Enabled Green Supply Chain Implementation Pathways for Retail Enterprises from a Dual Carbon Perspective

Shuangting Zhou, Sainan Zhang*, Tong Jin, Yiting Zhong, Jiling He
School of Business Administration, University of Science and Technology Liaoning, Anshan, Liaoning, China
**Corresponding Author*

Abstract: Against the backdrop of integrating the dual carbon strategy with the digital economy, retail enterprises' green supply chains face challenges such as difficult-to-trace carbon emission data, low efficiency in low-carbon collaboration, and imperfect green supplier certification mechanisms. This study leverages blockchain technology to empower retail enterprises, advancing their supply chains toward low-carbon and green development pathways. By utilizing distributed ledgers, it enables real-time sharing and traceability of carbon data across the entire chain, addressing issues of chaotic and distorted data collection. leveraging smart contracts to predefine emission reduction rules and allocate benefits, thereby balancing divergent objectives among supply chain participants to enhance collaborative efficiency; utilizing consensus mechanisms and immutability to establish a transparent, traceable green supplier certification and dynamic oversight system, tackling certification fraud and regulatory loopholes. This provides a feasible solution for the green and low-carbon transformation of retail enterprises, supporting their journey toward sustainable development.

Keywords: Blockchain; Green Supply Chain; Dual Carbon Goals; Retail Enterprises

1. Introduction

Against the backdrop of the deep integration between the dual carbon strategy and the digital economy, leveraging digital technologies to empower enterprises in achieving their dual carbon goals has become an inevitable choice for low-carbon development[1]. In May 2024, The country promulgated the Interim Regulations on Carbon Emission Trading Management, establishing a regulatory framework for national carbon emission trading. It mandates the creation of a unified carbon emission accounting system and concurrently released the Work Plan for Accelerating the Establishment of a Dual-Control System for Carbon Emissions. This plan proposes driving green and low-carbon transformation in supply chains through a product carbon footprint management system. As pivotal hubs connecting production, supply, and consumption, retail enterprises generate relatively low carbon emissions during their operational processes. However, their supply chains encompass the entire lifecycle—from procurement and transportation to warehousing, distribution, and recycling-resulting in significant carbon intensity that cannot be overlooked[2]. In response to the dual carbon policy, numerous retail enterprises have set emission reduction targets. For instance, IKEA aims to achieve a cumulative 70% reduction in supply chain carbon emissions by 2030, yet only reached 18% by 2023. Amazon pledged to achieve net-zero carbon emissions by 2040, but its total carbon emissions surged from 64.38 million metric tons in 2023 to 68.25 million metric tons in 2024. These phenomena highlight the severe challenges facing retail enterprises in carbon emissions, underscoring the urgent need to implement reduction measures to achieve a low-carbon development path across the entire supply chain.

Blockchain technology, with its decentralized nature, traceability, and immutability of data, empowers retail enterprises to pursue innovative pathways toward low-carbon, green supply chains. Yu et al. (2025) explored the use of blockchain technology to establish a decentralized retail credit system, enabling end-to-end traceability of goods throughout the supply chain and real-time recording of transaction data[3]. Yang (2025) proposes a smart logistics business system within a blockchain environment, enabling blockchain technology to

empower smart logistics operations[4]. Emami et al. (2025) proposed a blockchain-based supply chain business model utilizing smart contracts[5]. This model employs smart contracts to securely store and dynamically evaluate supplier data, including historical performance records, environmental certifications, real-time production capacity, and carbon footprint information. Based on predefined sustainability metrics, the system automates supplier selection and order allocation. Xue (2025) found that blockchain technology applications in optimizing transportation routes, enhancing warehouse management transparency, improving cargo traceability accuracy, and automating document processing significantly reduced operational costs and time delays while increasing asset utilization and total factor productivity[6]. Yan et al. (2025) examined the structural and behavioral impacts of blockchain technology applications on supply chain alliances. Through its immutable and traceable characteristics, blockchain enhances information transparency and fulfillment credibility among alliance members. Smart contracts enable integrated order coordination, logistics tracking, and automated settlement, reducing manual intervention and communication delays[7]. Guo (2023) uses JD.com as a case study to reveal blockchain's core value in procurement internal controls by automating inspection and payment processes through smart contracts[8]. Chen (2021) designed a blockchain-based retail data sharing model that employs cryptographic authorization mechanisms and zero-knowledge proof technology to enable trusted cross-institutional data sharing while ensuring consumer privacy security[9]. Yan (2019) researched the immutable nature of blockchain technology, providing technical support for product anti-counterfeiting, supply chain transparency, and low-carbon logistics traceability[10].

Currently, while scholars have explored blockchain applications in retail such as traceability for product authenticity, internal process control, and data sharing, research on developing green supply chains for retail enterprises remains insufficient from the perspective of the “dual carbon” goals. This study aims to expand blockchain's application scenarios and provide practical reference value for the green and low-carbon development of retail enterprises.

2. Theoretical Overview

2.1 Blockchain Technology

Blockchain is a type of distributed ledger technology characterized by its decentralized architecture, traceability, and immutability of data[11]. Within a blockchain system, data is produced and stored in blocks, which are linked in a chain-like data structure according to chronological order. All nodes collectively participate in the system's validation, storage, and maintenance[12]. Blockchain technology encompasses features such as smart contracts, decentralization, immutability and traceability, and consensus mechanisms. It enables fully automated execution of end-to-end operations, comprehensive data sharing across the entire chain, authentic and trustworthy on-chain data, and consensus among multiple nodes[13]. The blockchain workflow begins with supply chain activities generating transaction data. This data is encrypted, packaged into a new block, and uploaded to full nodes. Nodes then verify the data's authenticity through consensus algorithms. Once consensus is reached, the block is linked chronologically to the main chain, forming an immutable record. Finally, predefined rules are automatically executed via smart contracts, as illustrated in Figure 1.

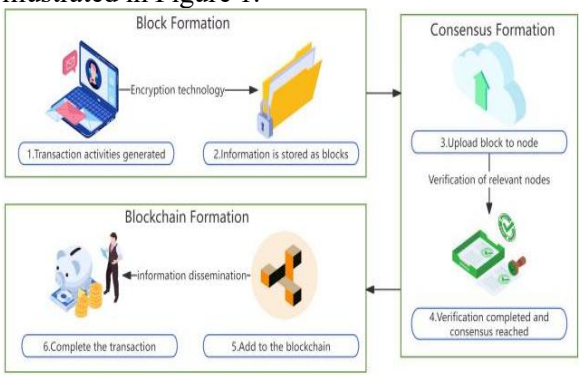

Figure 1. Blockchain Workflow Diagram

2.2 Retail Enterprises' Green Supply Chain

A green supply chain for retail enterprises is a systematic approach that deeply integrates ecological sustainability principles into the entire product lifecycle management. It requires retailers to establish environmentally friendly operational systems at every stage from source to end-user, encompassing design, raw material sourcing, manufacturing, logistics and transportation, warehousing and sales, and even recycling and disposal. By scientifically integrating upstream and downstream resources,

it achieves a dynamic equilibrium between economic activities and nature conservation[14]. From a dual-carbon perspective, the green supply chain of retail enterprises refers to a management model guided by the dual-carbon goals. It integrates zero-carbon principles throughout the entire chain—from supplier selection, procurement, warehousing, and transportation to sales and recycling—by optimizing processes, adopting low-carbon technologies, and implementing green business practices. This approach reduces carbon emissions across all supply chain stages, achieving synergistic economic and environmental benefits.

3. Challenges in Developing Green Supply Chains for Retail Enterprises from a Dual Carbon Perspective

3.1 Carbon Emissions Data is Difficult to Trace

Retail enterprises face challenges in carbon emissions data collection due to inconsistent standards, inaccurate recording, and distorted information transmission, leading to difficulties in tracing emissions across the entire supply chain. At the data collection stage, the retail supply chain involves multiple entities including suppliers, manufacturers, logistics providers, and retail stores. Carbon emission data from these entities is scattered across different systems, lacking unified data collection templates and standards. Differences in data formats and dimensions lead to inconsistent statistical criteria. During data recording, manual reporting of retail store energy consumption remains common, making it prone to omissions, errors, and other forms of data distortion. The multi-party nature and complexity of retail supply chains create multiple layers of information transmission with slow speeds, often leading to distorted or inaccurate data. Yet carbon emission verification typically relies on post-event audits, making it difficult to detect anomalies in real time. This risk of data distortion hinders end-to-end carbon traceability, prevents precise identification of high-emission segments, and undermines the effective implementation of carbon reduction measures.

3.2 Low Efficiency in Low-Carbon Collaboration across the Supply Chain

Retail enterprises and upstream/downstream entities exhibit divergent perceptions regarding low-carbon objectives. Inefficient information sharing results in high costs for collaborative emissions reduction and unfair distribution of benefits, hindering the formation of a cohesive force for low-carbon development. Regarding emissions reduction targets and cost allocation, retail enterprises primarily focus on long-term green and low-carbon strategies, aiming to achieve carbon reduction and sustainable development through optimization across the entire supply chain. Suppliers, however, prioritize short-term cost control and order fulfillment. The additional expenses associated with upgrading environmental equipment and low-carbon technologies dampen their enthusiasm for implementing such measures. Furthermore, the absence of transparent information-sharing mechanisms often leads to barriers in key areas like carbon emissions data, reduction investments, and low-carbon technology adoption, as upstream and downstream entities guard commercial secrets. Information opacity or delays can lead to unfair distribution of emission reduction benefits among stakeholders, undermining their willingness to sustain collaborative efforts. This “information silo” phenomenon also prevents retailers from accurately assessing actual carbon emissions across the entire chain, making it difficult to quantify the tangible benefits of driving low-carbon transformation within their supply chains.

3.3 Inadequate Green Supplier Certification Mechanism

For retail enterprises to achieve low-carbon development in their green supply chains, a green supplier certification mechanism is the core component. The retail supply chain encompasses multiple stages including raw material procurement, production processing, warehousing and transportation, and end-point sales. The carbon emissions from these stages often exceed those generated by the retail enterprises' own operations. As the central entities in the supply chain, retail enterprises must accurately identify suppliers practicing low-carbon production. Currently, retailers rely on third-party reports or self-certification from suppliers for green qualification reviews, leading to issues such as opaque certification processes and susceptible results to falsification. Retailers lack objective criteria when screening green suppliers, making it difficult to effectively verify

suppliers' green credit certifications. Relying on paper materials such as environmental certification certificates and annual carbon emission reports provided by suppliers can lead to information tampering or compromised credibility of third-party certification results due to conflicts of interest. This allows "pseudo-green" suppliers to infiltrate retail supply chains. Furthermore, the lack of dynamic monitoring of suppliers' green and low-carbon performance means some companies relax their low-carbon management after obtaining certification, making it difficult for retailers to achieve a closed-loop, full-chain low-carbon management system.

4. Blockchain-Enabled Green Supply Chain Implementation Pathways for Retail Enterprises from a Dual Carbon Perspective

4.1 Establish a Full-Chain Carbon Footprint Traceability System for Retail Enterprises

The synergistic functions of blockchain smart contracts, distributed ledgers, and consensus mechanisms can establish a trustworthy carbon footprint traceability system. Retail enterprises utilize smart contract functionality to predefine unified carbon emission accounting rules and data format templates across the supply chain. All nodes—including suppliers and logistics providers—collect and upload data to the blockchain using standardized metrics. Leveraging distributed ledgers enables real-time, automated recording of energy consumption data on the chain, eliminating errors and omissions from manual reporting. Encrypted storage and blockchain integration ensure the authenticity and immutability of carbon emission data. Simultaneously, the distributed ledger enables real-time access and sharing of recorded carbon emission data, eliminating hierarchical delays inherent in traditional supply chain information transmission. Leveraging consensus mechanisms, all on-chain participants can conduct real-time, parallel mutual oversight. Any node can instantly detect anomalous data and trigger verification processes, with the option to integrate third-party audit nodes for validation. Simultaneously, smart contracts establish carbon emission thresholds. By precisely locating high-carbon segments through comprehensive on-chain data records, the system automatically triggers high-carbon threshold alerts. It then conducts in-depth analysis of specific causes for anomalies in high-carbon segments based on on-chain data, notifying responsible parties to implement corrective actions. The results of these corrective measures must be uploaded to the chain in real time and undergo supervision, ultimately achieving a traceable carbon footprint system across the entire supply chain.

4.2 Enhancing Low-Carbon Collaborative Efficiency in Retail Supply Chains

Retail enterprises, as the chain leaders, can leverage blockchain technology to effectively incentivize and balance the differing objectives of various supply chain participants, break down information barriers, and establish a fair profit-sharing mechanism. Smart contracts predefine reward and penalty rules, offering priority settlement and shorter payment terms to suppliers meeting emission reduction targets, thereby encouraging active participation in the retail entity's emission reduction strategy. Retail enterprises can establish incentive measures through smart contracts, automatically triggering cost rebates, priority settlements, and shorter payment cycles for suppliers who actively adopt shared technology solutions and meet targets. To achieve low-carbon collaborative development across the supply chain, distributed ledgers break down information barriers by enabling real-time on-chain recording of carbon emissions data and low-carbon technology solutions. Concurrently, permission management safeguards participants' commercial confidentiality. Blockchain's information-sharing capabilities establish low-carbon collaboration channels among all stakeholders across the retail supply chain. Furthermore, consensus mechanisms verify and quantify each entity's actual carbon reduction contributions, automatically distributing overall carbon reduction benefits proportionally on-chain. This ensures fairer profit allocation among participants, thereby enhancing the efficiency of low-carbon collaboration within the retail supply chain.

4.3 Green and Low-Carbon Supplier Certification and Dynamic Oversight

Blockchain technology requires the recording of suppliers' green qualification audit information—including environmental certification documents and carbon emission data—on the blockchain for permanent storage. The immutable nature of blockchain eliminates information falsification. No single party can

alter the data, and all operational records are traceable, ensuring full transparency and auditability throughout the certification process. This eliminates reliance on third-party reports or self-declared green credentials from enterprises. Simultaneously, smart contracts establish dynamic monitoring nodes to capture real-time carbon emission data across multiple supplier operations—including production, logistics, and store operations—for on-chain storage. This enables continuous tracking of suppliers' green and low-carbon performance, preventing post-certification laxity. It forms a closed-loop chain from qualification review to dynamic oversight, empowering retailers to accurately identify green suppliers. Should carbon emissions data deviate from standards, blockchain smart contracts automatically trigger alert mechanisms. Tiered alerts are pushed to retailers and suppliers, detailing the category of non-compliant data, deviation magnitude, and potential impacts. This ensures stakeholders immediately grasp core carbon emission issues. Based on predefined clauses, subsequent actions—such as supplier reassessment or mandated rectification within specified timeframes—are automatically executed. Blockchain technology will further enable dynamic certification and routine monitoring of green, low-carbon suppliers for retailers, safeguarding low-carbon sustainability across the entire supply chain.

5. Conclusion

This study centers on the fundamental challenges that retail enterprises encounter when constructing green supply chains within the dual-carbon policy framework. By capitalizing on the distinctive features of blockchain technology, the research investigates potential pathways through which retailers and their associated supply chain partners can attain environmentally sustainable and low-carbon development objectives. Distributed ledger technology effectively addresses critical issues related to the traceability and verification of carbon emission data, thereby enhancing transparency and accountability across the supply network. Meanwhile, smart contracts facilitate and incentivize active participation among supply chain stakeholders, encouraging collective efforts to establish robust mechanisms for building green trust and distributing benefits equitably. Through the use of consensus algorithms and the inherent immutability of records, blockchain enables end-to-end green certification processes and comprehensive monitoring of low-carbon activities. This integrated approach outlines a clear trajectory for retail businesses shifting toward green and low-carbon supply chain models—progressing from reliable carbon emission data acquisition to collaborative operational efficiency and finally to verifiable certification—thereby closely aligning the capabilities of blockchain with the sustainability requirements of the retail industry. The successful implementation of blockchain technology necessitates coordinated efforts among multiple actors, including enhanced policy support and guidance from governmental bodies, strengthened cooperation between enterprises, and continuous technological refinement. Future research should prioritize the exploration of diverse blockchain deployment strategies and further refine the collaborative frameworks involving governments, businesses, and technology providers. Such a dual-engine strategy, combining technological innovation and institutional transformation, will accelerate the high-quality development of green supply chains in retail, thereby contributing valuable sector-specific insights to support China’s ambitious dual-carbon goals.

Acknowledgments

This work is supported by research project on “economic and social development of Liaoning provincial federation of social sciences” (No. 2025lslqnwzzkt-072), “Liaoning association for science and technology innovation think tank project” (No. LNKX2025QN11), and college student innovation and entrepreneurship project (Research on Blockchain-Enabled Implementation Pathways for Green Supply Chains in Retail Enterprises from a Dual Carbon Perspective)

References

[1] Zhu HB, Wu LM. Research on Digital Technology Empowering Green Transformation of Shaoxing Textile Enterprises Under the “Dual Carbon” Goals. Business & Economy, 2024(9):119-122127.

[2] Zeng FB. Research on Green and Low-Carbon Development Pathways for Retail Enterprises from a Supply Chain Perspective. The Light & Textile Industries of Fujian, 2024, (05): 6-9.

[3] Yu X, Chen WH, Fu SL. Blockchain-Empowered Reconstruction of Retail Credit Systems: Practical Exploration of Digital-Physical Integration and Industry-City Synergy. Industry & City, 2025, (03): 72-75.
[4] Yang Zhihua. Research on Blockchain Technology and Its Application in Smart Logistics. Logistics Sci-Tech, 2025, 48(3): 73-76.
[5] Emami A, Eifbarghy M, Bbas E A, et al. A blockchain-driven business model for supplier selection and order allocation leveraging smart contracts in supply chains. Digital Business, 2025, 5(2):100128-100128.
[6] Xue T. Research on the Impact of Blockchain Application on the Operational Efficiency of Logistics Enterprises: An Empirical Analysis Based on DEA Data. Journal of Aussie-Sino Studies, 2025, 11(2): 1.
[7] Yan J, Gui Q, Jiang S, et al. How does blockchain application impact on supply chain alliance? Technovation, 2025, 143103199-103199.
[8] Guo BH. Research on Internal Control of Purchase Business of JD. Com Inc. under the Background of Blockchain. Zhongnan University of Economics and Law, 2023.
[9] Chen Y. Blockchain-based retail data privacy protection and sharing model. Jiangxi University of Science and Technology, 2021.
[10] Yan XH. Changes and Development Paths of New Retail Formats Driven by Block Chain Technology. Journal of Technical Economics & Management, 2019, (01): 10-15.
[11] Moosavi N, Taherdoost H, Mohamed N, et al. Blockchain Technology, Structure, and Applications: A Survey. Procedia Computer Science, 2024, 237645-658.
[12] Guo Y, C JH. Research on Application Approaches for Blockchain Embedded in Supply Chain Carbon Auditing. Times of Economy & Trade, 2025, 22(06): 67-69.
[13] Wang P. Design of a Blockchain-Based Transparency Management System for Electromechanical Product Supply Chains. Development & Innovation of Machinery & Electrical Products, 2025, 38(2): 175-177.
[14] Lu SY. Research on Enterprise Cost Control Based on Green Supply Chain. China Circulation Economy, 2025, (09): 145-148.

