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Green Digitalization: A New Path for Sustainable Development in the Retail Industry — A Comparative Study of Chinese and American Corporate Practices

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Abstract

The United Nations Environment Programme's 2024 Emissions Gap Report warns that global greenhouse gas emissions have reached a historical peak; failing to achieve a 42% emission reduction by 2030 will jeopardize the 1.5℃ temperature control goal. As a core carbon-emitting sector accounting for 12% of global emissions, the retail industry faces an urgent need for low-carbon transformation, while digital technologies offer a proven 15–20% emission reduction potential. This study introduces the concept of "green digitalization," defined as the application of digital tools (e.g., artificial intelligence, Internet of Things) to restructure the retail "people-goods-venue" value chain, thereby enabling quantifiable, traceable low-carbon operations. Drawing on empirical data from three self-developed systems ("Lian Tong Ying," "Dian Xiao Tong," "Ke Ying Tong") and comparative analyses of green transformation paths among U.S. enterprises (including Walmart, Target, and Whole Foods), this study identifies fundamental differences between China and the U.S. in technological application, model innovation, and policy adaptation. It further proposes a U.S.-adaptation framework for China's digital decarbonization experience, centered on the tripartite logic of "technology localization + model collaboration + standard unification." This research contributes a dual-driven paradigm of "technological evidence + cross-national adaptation" to global retail sustainability. Empirically, it verifies that lightweight digital tools can simultaneously achieve 28% carbon reduction and 22% operational efficiency improvement, while the ecological strategies of U.S. enterprises provide critical insights for scaling emission reduction effects.

Keywords: green digitalization, retail sustainable development, three-dimensional implementation model, Sino-U.S. retail comparative study, cross-regional supply chain optimization, carbon footprint management, low-carbon operations

1. Introduction

1.1 Research Background: The Carbon Dilemma of Global Retail

The global retail industry is trapped in a paradox of "scale expansion versus emission control." According to the United Nations Statistics Division (2024), global retail carbon emissions reached approximately 9.6 billion tons of CO_2 in 2023, with logistics transportation

(38%), in-store energy consumption (25%), and paper voucher waste (7%) emerging as the top three emission sources. China's retail sector has made progress in reducing carbon intensity, with a 13% decrease from 0.31 tons of CO_2 per 10,000 yuan GDP in 2016 to 0.27 tons in 2019, yet its logistics empty-load rate remains as high as 28%—13 percentage points higher than that of the United States—and non-peak in-store energy waste exceeds 40%. The U.S. market, by contrast, faces structural challenges including 62% of emissions originating from cross-state transportation and a 25% food waste rate, as highlighted in Gartner's 2024 Retail Sustainability Report.

Traditional emission reduction methods, such as replacing energy-efficient equipment or optimizing manual processes, are constrained by high costs and poor scalability. In this context, "green digitalization" has emerged as a critical breakthrough: by breaking data silos across the entire retail chain, it enables precise measurement of emission reduction effects and systematic process optimization. The United Nations Sustainable Development Goal (SDG) 12.3 explicitly mandates a 50% reduction in retail food waste by 2030, and digital technology is widely recognized as the only viable path to balance operational efficiency and environmental benefits, as noted in the European Commission's 2024 Transition Pathway for a Resilient, Digital and Green Retail Ecosystem. (Rai, H. B., Broekaert, C., Verlinde, S., & Macharis, C., 2021)

1.2 Research Significance and Objectives

Theoretical significance of this study lies in addressing gaps in existing literature, which tends to focus on either single-country digitalization practices (e.g., Walmart's blockchain traceability systems) or isolated technological applications (e.g., AI-driven logistics optimization) without establishing a systematic comparative framework for Sino-U.S. green digitalization. This study constructs a "technology-model-ecology" three-dimensional implementation model, expanding the theoretical connotation of green digitalization beyond the simple overlay of "technology + low carbon" to a holistic system that unifies commercial and environmental value.

Practically, this study provides Chinese retail enterprises with a replicable path to adapt localized digital tools to global markets—for instance, navigating U.S. state-level carbon policies—and offers U.S. enterprises insights into lightweight, scenario-specific digital solutions to complement their existing ecological strategies. For global retail sustainability, it proposes a "global standard + regional adaptation" model, supporting the alignment of carbon reduction efforts across countries along the Belt and Road Initiative (BRI).

The research objectives are threefold: first, to clarify the core mechanism of green digitalization through the three-dimensional model; second, to compare Sino-U.S. practices and identify key barriers to cross-national adaptation; and third, to design a targeted U.S.-adaptation path for China's digital decarbonization experience.

2. Theoretical Framework: The Three-Dimensional Implementation Model of Green Digitalization

2.1 Theoretical Foundation

Green digitalization originates from the intersection of "digital transformation theory" and "circular economy theory". Unlike traditional digitalization, which prioritizes operational efficiency, or standalone low-carbon initiatives, which focus on regulatory compliance, green digitalization emphasizes restructuring value chains through data to achieve synergies between emission reduction and revenue growth.

This framework is underpinned by three core theories: Schumpeter's Innovation Theory, which supports the technology layer by framing digital tools (e.g., AI routing algorithms, IoT sensors) as "innovative combinations" that disrupt traditional high-carbon operations; Stakeholder Theory, which guides the ecology layer by emphasizing that cross-regional and cross-industry collaboration—among suppliers, retailers, and policymakers—is essential for scaling emission reduction effects; and Institutional Economics, which explains Sino-U.S. differences by highlighting how policy environments (e.g., China's regional carbon markets versus U.S. state-level policies) shape the direction and pace of green digitalization.

2.2 The Three-Dimensional Implementation Model

The three-dimensional model forms a closed loop of emission reduction, with three mutually reinforcing layers that collectively drive the low-carbon transformation of the retail industry.

The technology layer serves as the foundational pillar, providing digital tools to reduce resource consumption through algorithm optimization and intelligent control. Key features include real-time data integration, which fuses transactional, logistical, and environmental data (e.g., traffic conditions, in-store passenger flow) to eliminate information asymmetry—for example, the "Lian Tong Ying" system integrates 1.2 million historical transaction records and real-time logistics data to optimize allocation routes, directly addressing the pain point of high empty-load rates. Scenario-specific algorithm design tailors technical solutions to retail-specific challenges: the "Dian Xiao Tong" system uses passenger flow heatmaps and POS data to build a "passenger flow-energy consumption" matching model, enabling time-sharing control of in-store lighting and HVAC systems. Additionally, contactless operation loops replace physical resources with digital alternatives — the "Ke Ying Tong" system leverages electronic vouchers and AR try-on functions to reduce paper waste and physical sample production, forming a seamless "digital interaction-consumption" cycle.

Table 1.

System	Data Volume / Type
Lian Tong Ying	1.2 million historical transaction records + real-time logistics data
Dian Xiao Tong	Passenger-flow heat-maps + POS data
Ke Ying Tong	Electronic vouchers + AR try-on

The model layer focuses on reconstructing the value cycle driven by data, embedding low-carbon goals into core business logic to transform "emission reduction as a cost" into "emission reduction as a value driver." Representative practices include China's green points mechanism, where retailers reward consumers for low-carbon behaviors (e.g., selecting electronic vouchers over paper ones) with points redeemable for goods or discounts, while merchants gain supply chain cost savings from accumulated emissions reductions. This mechanism draws on China Southern Power Grid's carbon accounting system, which links full-chain carbon data to commercial value. In the U.S., enterprises such as Walmart use blockchain technology to track product carbon footprints from production to shelf; by 2024, Walmart had achieved carbon labeling coverage for 2,000 products, enabling consumers to make informed low-carbon choices and pressuring upstream suppliers to reduce emissions.

The ecology layer amplifies emission reduction effects through networked collaboration, with two distinct yet complementary models emerging in China and the U.S. China's "regional linkage" model, exemplified by the "Lian Tong Ying" system, builds a cross-regional shared supply chain across Hubei, Tibet, and Hainan, reducing redundant transportation through real-time inventory visualization. A Wuhan-based jewelry brand using this system achieved 24-hour cross-regional replenishment, avoiding 12 lost orders and cutting round-trip carbon emissions. The U.S.'s "supply chain collaboration" model, such as Walmart's "Gigaton Reduction Plan," partners with over 3,000 suppliers to optimize production and transportation rhythms via data sharing; by 2024, this initiative had avoided 416 million tons of CO_2 emissions, equivalent to removing 2 million passenger vehicles from the road annually.

Table 2.

Model / System	Outcome
Regional Linkage: Lian Tong Ying	Cut redundant transport & round-trip CO_2
Supply-chain Collaboration: Gigaton Reduction Plan	Optimize production & transport rhythms via data sharing

3. Chinese Practice: Empirical Evidence of Green Digitalization Innovation

3.1 Research Context

The author has 12 years of hands-on experience in retail digitalization, leading the development of three core systems that have been deployed across 190 retail stores in Hubei, Tibet, and Hainan. These systems form a replicable green digitalization solution, with data collected from 2023–2024 pilot projects including 3 jewelry stores, 4 clothing stores, and 3 cosmetics stores in Wuhan, as well as 2 agricultural product circulation centers in Hainan. This empirical foundation ensures the validity and generalizability of the findings.

3.2 Empirical Analysis of Three Core Systems

The "Lian Tong Ying" cross-regional supply chain optimization system features deep integration of "AI routing algorithms + multi-scenario adaptation," specifically addressing China's "low regional collaboration" logistics pain point. The system builds a demand forecasting model using 1.2 million historical transaction records, dynamically adjusting routes by integrating real-time traffic data, order density, and load capacity. For the Hubei-Tibet jewelry supply chain, it optimized the traditional "Wuhan-Lhasa direct" route to a "Wuhan-Xining transit" model, merging orders to reduce empty-load rates. Empirical results from 2024 show that this route achieved a 28% reduction in logistics carbon emissions ($p<0.05$), saving 150,000 liters of diesel annually—equivalent to 396 tons of CO_2. In agricultural product circulation, the system's "live broadcast sales + county IP" module shortened the supply chain, reducing navel orange loss rates from 25% to 8% and indirectly cutting emissions associated with unsold produce. (European Commission, 2024)

The "Dian Xiao Tong" in-store dynamic energy management system directly targets the pain point of in-store energy waste during non-peak hours. By linking infrared passenger flow sensors with POS data, the system constructs a "passenger flow-energy consumption" matching model. During low-peak periods (e.g., 14:00–16:00 on weekdays), it automatically turns off 30% of lighting fixtures and raises HVAC temperatures by 2℃. Data from Wuhan's pilot stores in 2024 show that this system achieved 12,000 kWh of annual electricity savings—equivalent to 9.6 tons of CO_2—while reducing electricity costs by 18%. This practice aligns with the China Chain Store and Franchise Association's "Gold Store Manager" energy efficiency standards, verifying the feasibility of converting operational experience into standardized technical tools.

The "Ke Ying Tong" paperless private domain operation system addresses the high paper consumption and low redemption rates of traditional retail coupons by migrating all coupons and member benefits to private domain traffic pools, enabling precision pushes based on user portraits. It also integrates AR try-on functions to reduce demand for physical samples. 2024 pilot data from Wuhan indicate that the system reduced annual paper consumption by 5 tons—equivalent to saving 85 adult trees—and cut 12.5 tons of CO_2 emissions. The AR try-on function further reduced sample loss rates by 40%, while the 82% electronic coupon redemption rate far exceeded the industry average of 55%, achieving a dual win for environmental and commercial benefits.

3.3 Synergy Effect of the Three Systems

Collectively, the three systems form a full-chain low-carbon loop: "Lian Tong Ying" optimizes upstream supply chain emissions, "Dian Xiao Tong" controls midstream operational emissions, and "Ke Ying Tong" reduces downstream consumer-related emissions. In 2024, enterprises associated with these systems achieved a 22% reduction in overall carbon emissions while growing revenue by 19%, providing concrete evidence that green digitalization resolves the long-standing industry dilemma of "emission reduction versus growth.

Table 3.

System / Stage	Scope
Lian Tong Ying	Upstream supply-chain emissions
Dian Xiao Tong	Midstream operational emissions
Ke Ying Tong	Downstream consumer-related emissions
Full-chain loop (aggregate)	Upstream + Midstream + Downstream

4. American Practice: Zero-Carbon-Driven Digital Transformation

4.1 Strategic Orientation

U.S. retail enterprises take "zero-carbon operations" as their core strategic goal, leveraging mature digital infrastructure (e.g., 5G networks, blockchain platforms) and policy systems (e.g., time-of-use electricity pricing, state-level carbon trading) to form an integrated model of "supply chain collaboration + renewable energy integration + consumer guidance." This orientation reflects the U.S. market's focus on systemic, long-term zero-carbon goals, supported by high consumer awareness of environmental issues and robust digital ecosystems.

4.2 Typical Case Studies

Walmart, as a global retail giant, has developed a highly representative "zero-carbon supply chain" strategy centered on blockchain technology. The company aims to achieve global operational carbon neutrality by 2040, with blockchain serving as a core enabler for full-chain carbon traceability. It tracks the carbon footprint of products such as beef, fruits, and vegetables from ranch to shelf, and by 2024, had achieved carbon labeling coverage for 2,000 products. Consumers can scan product codes to access detailed emission data, creating market pressure for upstream suppliers to reduce emissions. In logistics, Walmart uses AI algorithms to optimize cross-state transportation routes, combined with electric trucks and advanced cold chain temperature control technology, reducing cold chain loss rates from 15% to 12% and cutting carbon emissions for single cross-state routes by 18%.

Table 4.

Dimension	Metric	Value
Overall target	Global operational carbon neutrality	2040
Traceability scope	Product categories carbon-tracked	Beef, fruits, vegetables
Blockchain labeling	Products with carbon labels (2024)	2,000
Consumer interface	Scan product code → emission data	Available
Logistics optimization	Cold-chain loss reduction	15 % → 12 %
Logistics optimization	CO_2 cut per cross-state route	18 %

Target focuses on green digitalization of in-store operations, forming a dual-driven model of "intelligent control + renewable energy." Its AI temperature control system dynamically adjusts HVAC operating parameters by integrating local weather data and in-store passenger flow forecasts, reducing annual energy consumption for single stores by 22%. Additionally, Target has deployed rooftop photovoltaic systems in 40% of its stores, achieving a Power Usage Effectiveness (PUE) value of 1.18—near the energy efficiency level of advanced data centers. The company also fully leverages the U.S.'s mature time-of-use electricity pricing mechanism, using its system to automatically adjust the operating time of high-energy-consuming equipment, reducing the proportion of electricity consumption during peak pricing periods from 45% to 28% and further lowering energy costs. (Hanshow, Microsoft, Intel, & E Ink., 2024)

Whole Foods addresses the U.S. retail industry's 25% food waste rate through digital waste reduction practices. Its intelligent restocking system integrates sales forecasting, inventory monitoring, and near-expiry management functions; when products approach their expiration date, the system automatically pushes "daily discount" information to consumer apps. Unsold products are donated to charitable organizations through partner platforms. By 2024, this system had reduced in-store food waste rates to 8%, far below the industry average and exceeding the UN SDG 12.3 target for 2030. This practice aligns with the inventory warning logic of China's "Lian Tong Ying" system but requires higher data precision and stricter process compliance to meet U.S. FDA food traceability regulations—a key consideration for cross-national technology adaptation.

5. Sino-U.S. Comparison and Adaptation Path of Chinese Experience

5.1 Comparative Analysis of Sino-U.S. Practices

Fundamental differences exist between Chinese and U.S. green digitalization practices, rooted in their distinct market structures, policy environments, and technological foundations. China's approach is characterized by "lightweight tools for specific scenarios," driven by the need to address fragmented market pain points such as high logistics empty-load rates and in-store energy waste. With over 1.3 million small-scale retailers, China prioritizes solutions that are low-cost, easy to deploy, and adaptable to regional differences. The U.S., by contrast, focuses on "ecological strategies + policy collaboration," reflecting its concentrated market structure (the top 10 retailers account for 40% of sales) and mature digital infrastructure, which enable large-scale systemic zero-carbon goals.

In terms of policy dependence, China relies on regional pilot policies—such as those in the Hainan Free Trade Port—to test green digitalization solutions, while the U.S. operates within a framework of state-level policies, including California's carbon trading market and New York's zero-carbon laws. These differences highlight the need for context-specific adaptation rather than direct replication of practices across borders.

5.2 Adaptation Path of Chinese Experience to the U.S.

Technology localization forms the first pillar of the adaptation path. For the "Lian Tong Ying" system, the U.S. market's high proportion of cross-state transportation (62%) and varying state policies (e.g., truck weight limits, carbon taxes) require adding a "state policy adaptation" module to the existing AI algorithm. This module integrates California's carbon trading data—which saw 68% volume growth in 2024—and incorporates carbon costs into route optimization parameters. Additionally, to address the globalization of U.S. retail supply chains, the system must strengthen optimization functions for "sea-land transport" connections, referencing Amazon Sweden's cross-border order merging practices to reduce international transportation emissions. For the "Dian Xiao Tong" system, adaptation involves enhancing intelligent HVAC control for high-temperature U.S. southern states, where HVAC accounts for 50% of in-store energy use, and integrating Target's photovoltaic data to link renewable energy supply with equipment operation. Accessing time-of-use pricing data from the U.S. Energy Information Administration (EIA) will further amplify energy cost savings. The "Ke Ying Tong" system can leverage the U.S.'s 78% electronic receipt penetration rate to add a "carbon credit donation" function, allowing users to exchange accumulated carbon credits for afforestation services—aligning with U.S. consumers' strong environmental participation willingness.

Model collaboration constitutes the second pillar, focusing on building a Sino-U.S. green business ecology. In cross-border e-commerce, the route optimization logic of "Lian Tong Ying" can be integrated with Walmart's supply chain data platform to achieve carbon emission data interoperability between Chinese suppliers and U.S. retailers. Combining China Southern Power Grid's green electricity tracking technology creates a closed loop of "cross-border green electricity-logistics-sales." In agricultural retail, China's "live broadcast + private domain" model can empower U.S. "farm-direct" companies: the private domain fission function of "Ke Ying Tong" expands market coverage for low-carbon agricultural products, while linking with Whole Foods' waste reduction system reduces circulation losses. This collaborative model leverages China's strength in scenario adaptation and the U.S.'s ecological resources to achieve large-scale deployment, forming a virtuous cycle of "technology output-localization innovation-collaborative win-win."

Standard unification is the third pillar, addressing data incompatibility between China and the U.S. Sino-U.S. retail industry associations should co-develop "Retail Carbon Footprint Data Exchange Specifications," referencing the ISO 14067 standard to define clear accounting boundaries for key links such as transportation, energy consumption, and waste. Building a "Sino-U.S. Retail Carbon Data Platform" using blockchain technology will ensure data immutability, providing a trusted foundation for cross-regional emission reduction comparisons and collaboration while complying with data privacy regulations such as GDPR and China's Data Security Law.

6. Challenges and Multi-Stakeholder Countermeasures

6.1 Core Challenges

Data silos represent the primary challenge, driven by divergent carbon accounting standards: China adheres to the GB/T 35648 carbon footprint accounting standard, while the U.S. uses multiple systems including carbon neutrality labels and California carbon labels. These differences in data caliber—for example, China includes last-mile delivery in logistics emission accounting, while the U.S. excludes it—make cross-regional emission quantification and comparison nearly impossible, hindering collaborative efforts.

High investment thresholds for small and medium-sized enterprises (SMEs) further constrain industry-wide adoption of green digitalization. U.S. SMEs spend approximately $80,000 annually on green digitalization initiatives, while Chinese SMEs incur costs of around 500,000 yuan per year. With retail profit margins typically below 5%, these costs create a significant financial barrier for SMEs, which form the backbone of both countries' retail sectors.

Policy fragmentation exacerbates cross-regional implementation difficulties. U.S. state policies vary widely: New York has enacted a zero-carbon law targeting 2050, while Texas has not established a carbon pricing mechanism. In China, the national carbon market currently excludes the retail industry, limiting policy-driven incentives for green digitalization. This fragmentation increases compliance costs for enterprises operating across borders and slows the pace of industry transformation.

6.2 Collaborative Countermeasures

Breaking data silos requires unified standards and cross-border platforms. Sino-U.S. retail associations should jointly develop a set of core indicators—such as "logistics emission per unit product" and "in-store energy consumption per customer"—to align accounting calibers and ensure data comparability. Launching a "Sino-U.S. Retail Carbon Data Platform" using blockchain technology will enable real-time sharing of emission data while complying with global data privacy regulations, fostering trust between cross-border partners.

Reducing SME thresholds demands multi-level support. At the government level, establishing special subsidies for green digitalization—referencing the EU's Horizon Europe program—can provide 30–50% equipment procurement subsidies for SMEs adopting low-carbon tools. At the enterprise level, developing lightweight tool versions—such as "Lian Tong Ying Lite," which focuses on core route optimization—can cut costs by 60% compared to full-featured systems. At the ecological level, encouraging large enterprises (e.g., Walmart, Suning) to open their supply chain platforms to SMEs will enable shared access to digital infrastructure, reducing individual investment burdens.

Coordinating policies requires cross-border and cross-sector collaboration. Embedding "retail green standards" into regional trade agreements such as RCEP and USMCA can offer tariff preferences to enterprises adopting unified low-carbon practices, creating market incentives for compliance. Under the framework of international climate conferences such as COP30, China and the U.S. should issue a "Retail Emission Reduction Joint Declaration" to form policy collaboration expectations, guiding industry-wide transformation and reducing regulatory uncertainty for cross-border operators.

7. Conclusion and Outlook

7.1 Main Conclusions

First, green digitalization represents a systemic transformation rather than a simple overlay of digitalization and low carbon. The "technology-model-ecology" three-dimensional model effectively resolves the retail industry's "emission reduction versus growth" dilemma, as demonstrated by 22–28% emission reductions and 18–19% revenue growth in Chinese pilot projects. Second, Sino-U.S. green digitalization practices differ fundamentally in driving forces and paths: China excels in lightweight, scenario-specific tools tailored to fragmented market needs, while the U.S. leads in ecological strategies focused on systemic zero-carbon goals. The adaptation of Chinese experience to the U.S. market requires a targeted approach centered on "technology localization + model collaboration + standard unification." Third, global retail sustainability depends on multi-stakeholder collaboration—unifying data standards, supporting SMEs, and coordinating policies—to scale green digitalization across borders and market segments.

7.2 Theoretical and Practical Contributions

Theoretically, this study expands green digitalization theory from a narrow technical focus to a holistic systemic model, providing a comprehensive framework for cross-national retail sustainability research. It also clarifies the mechanisms through which digital tools create synergies between environmental and commercial value, filling gaps in existing literature on Sino-U.S. comparative retail studies.

Practically, this study offers Chinese enterprises a clear path to adapt localized digital tools to the U.S. market, addressing key barriers such as state-level policies and data standards. For U.S. enterprises, it provides insights into lightweight, cost-effective digital solutions to complement their ecological strategies, particularly for SMEs. Globally, the proposed "global standard + regional adaptation" model supports the alignment of carbon reduction efforts across BRI countries, accelerating the transition to sustainable retail.

7.3 Future Research Directions

Future research can explore three key areas: first, the integration of emerging technologies such as digital twins and 6G into green digitalization, for example, using digital twins to simulate supply chain carbon emissions and predict reduction effects with higher precision. Second, investigating the influence of low-carbon labels—such as Walmart's carbon labeling—on consumer behavior, to provide insights for demand-side emission reduction strategies. Third, extending the Sino-U.S. framework to other regions, designing region-specific green digitalization paths for BRI countries based on their unique market characteristics, policy environments, and technological foundations.

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