Research on the Construction of Green Supply Chains in Manufacturing Industries

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Abstract: The development of green supply chains in manufacturing is crucial for achieving China's "dual carbon" goals (carbon peak and carbon neutrality). However, current efforts face systemic challenges including fragmented optimization, insufficient coordination, and disappointing emission reduction outcomes. Despite active promotion by both government and enterprises, supply chain carbon emissions have decreased by less than 10%, revealing fundamental issues such as inefficient resource allocation, uncoordinated technology adoption, and poor data transparency. This study provides a comprehensive analysis of key obstacles in green supply chain development from three perspectives: supply chain management, technological application, and policy environment, while proposing integrated optimization strategies. This paper findings identify three major bottlenecks: weak collaboration across supply chain tiers, inadequate digital infrastructure for carbon accounting, and misaligned policy incentives with market realities. This paper propose an "Enterprise-Technology-Policy" tripartite framework to address these challenges. Key recommendations include: establishing industry consortiums and standardized carbon accounting protocols, refining policy incentives to target critical weak points, and fostering industry-academia collaboration for talent development.

1 INTRODUCTION

In the context of global climate action and China's dual carbon objectives, building green supply chains has emerged as a strategic pathway for low-carbon industrial transformation. Worldwide, governments and corporations are actively implementing Green Supply Chain Management (GSCM) through policy interventions, technological innovation, and industry coordination.

China, as the world's manufacturing hub, has introduced a series of policies to advance environmentally sustainable supply chain systems. Academic research has developed multidimensional frameworks examining drivers of green supply chains (Zhu, 2022), digital enablement (Zhang, 2024), and policy mechanisms (Chen and Li, 2023).

However, implementation faces significant coordination challenges. While leading firms actively pursue green transformation, participation from SMEs remains limited, carbon data sharing is inadequate, and policy execution is inconsistent. The China Manufacturing Green Development Annual Report (2025) indicates that although 70% of manufacturers have adopted green supply chain systems, overall supply chain emissions have declined by less than 10%, exposing limitations of current fragmented approaches(Wang,2023).

The EU's Carbon Border Adjustment Mechanism has introduced stringent carbon disclosure requirements for global supply chains. IEA estimates suggest 25% of China's manufactured exports will be directly impacted by such environmental trade measures.

From a collaborative governance perspective (Ansell and Gash, 2018), green supply chain development represents a complex multi-stakeholder challenge. Research shows that when supply chain trust levels fall below 0.6, collaborative emission reduction efficiency drops by over 40% (Li, 2023).

This study investigates three critical dimensions. Current green supply chains exhibit structural fragmentation between proactive large enterprises and reluctant SMEs. Technological limitations: Despite blockchain applications, carbon data remains siloed across incompatible platforms; Policy gaps: Existing incentives disproportionately focus on production while neglecting logistics and recycling, resulting in sub-40% implementation rates among SMEs. By integrating supply chain theory, digital

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technology, and policy analysis, we develop an integrated framework to overcome systemic barriers in low-carbon transition.

2 CURRENT CHALLENGES ANALYSIS

The development of green supply chains in manufacturing faces multidimensional systemic constraints.

Existing studies overemphasize single-enterprise technical solutions while neglecting supply chain-wide coordination mechanisms, creating a theory-practice divide.

Technological Barriers: Blockchain applications encounter three key obstacles: 1) Prohibitive data upload costs (~$120/10,000 data entries) 2) Poor system interoperability (<30% compatibility) 3) Excessive energy demand (~1,500 kWh per carbon audit) The absence of effective digital tools prevents comprehensive carbon footprint tracking across supply chains. Current incentives primarily target production phases while overlooking logistics and recycling, imposing disproportionate compliance burdens on SMEs and maintaining sub-40% policy adoption rates.

Cross-national comparisons reveal that Germany's manufacturing sector has increased compliance rates among secondary suppliers to 75% through its "Supply Chain Due Diligence Act" (BMWi, 2024), while Toyota in Japan achieves a 58% carbon data sharing rate among its suppliers (Toyota Sustainability Report, 2025) - both significantly higher than China's average levels. Industry practices demonstrate a notable gap between policy standards and actual implementation outcomes. Although China has established multiple green supply chain management standards at the national level, excessive environmental compliance costs for SMEs have resulted in approximately 60% of environmental violations occurring among secondary and lower-tier suppliers in the electronics manufacturing sector.

Moreover, green development levels vary drastically across different supply chain tiers. While first-tier suppliers boast over 80% green certification rates, environmental violations remain prevalent among lower-tier suppliers, exposing fundamental flaws in current supply chain coordination mechanisms. Additionally, the talent cultivation system fails to meet industry needs, with significant discrepancies between the knowledge structures of university-educated green-skilled professionals and actual enterprise requirements. This mismatch further hinders effective implementation and widespread adoption of green technologies in industrial applications.

The analysis above reveals three prominent structural contradictions in current green supply chain development.

First, a severe input-output imbalance exists. While core enterprises continue increasing environmental investments, SMEs' green transformation lags significantly, creating a "green divide." For instance, an automotive parts manufacturer spends approximately 1.2 million yuan annually to meet environmental standards but receives less than 300,000 yuan in government subsidies. This disproportionate cost-benefit ratio directly undermines sustainable development incentives.

Second, digital technology applications for carbon tracking face coordination challenges. Despite blockchain adoption rates exceeding 50% in supply chain carbon management, the lack of unified data standards results in substantial carbon accounting errors averaging 35%, severely compromising accuracy and reliability.

Third, ineffective data sharing mechanisms persist across supply chains. While core enterprises control over 90% of carbon-related data, interoperability rates among upstream and downstream partners remain low. This data monopoly obstructs comprehensive lifecycle carbon monitoring and ultimately impedes supply chain greening.

3 KEY OBSTACLES IN MANUFACTURING GREEN SUPPLY CHAIN DEVELOPMENT

The fundamental contradiction stems from systemic coordination failures compounded by localized optimization inefficiencies. A three-dimensional analysis (supply chain management, technology application, and policy environment) reveals deeper issues.

3.1 Fragmented Greening Due to Lack of Supply Chain Coordination Mechanisms

Current supply chains exhibit a "core enterprise-dominant, SME-lagging" dual structure. While first-tier suppliers achieve 82% green certification rates, environmental violation rates among lower-tier suppliers remain as high as 38% (Greenpeace, 2025).

3.1.1 Imbalanced Cost Transfer

Core enterprises frequently shift emission reduction responsibilities upstream through contractual terms without providing commensurate financial or technical support. An automotive parts manufacturer's case shows 1.2 million yuan in annual environmental compliance costs but only 300,000 yuan in subsidies, bearing 75% of decarbonization costs. This creates an SME dilemma: rejecting requirements risks losing orders while acceptance erodes profits. Limited financing channels further force SMEs to sacrifice R&D and operational funds for compliance, creating a "compliance equals losses" cycle. Solutions require cost-sharing mechanisms like corporate environmental escrow accounts and increased government subsidies.

3.1.2 Inequitable Benefit Distribution

Green supply chain value-added benefits (e.g., brand premiums, market share growth) are disproportionately allocated. Core enterprises capture 15%-20% of green premiums through pricing power and branding, while upstream SMEs struggle to recoup investments. A textile supplier's wastewater treatment system requires 3.5 years for ROI versus the industry's 2-year standard. Remedy options include green premium profit-sharing based on environmental investments or supply chain financing tools to accelerate SME returns.

3.1.3 Standard Implementation Gaps

Green standard enforcement deteriorates across supply chain tiers. Secondary suppliers achieve only 60% compliance due to limited testing equipment and technical staff. An electronics case shows an ISO14001-certified PCB manufacturer's overall green rating dropped 30% because its coating supplier lacked heavy metal detection capabilities. This "strict-upfront, lax-downstream" pattern causes substantive green supply chain fractures and may trigger "race-to-the-bottom" effects. Solutions involve core enterprises implementing technical assistance programs (shared testing platforms, engineer dispatches) and establishing tiered compliance timelines for SMEs (ISO,2024).

3.2 Insufficient Digital Technology Application Undermines Carbon Credibility

3.2.1 Contradiction Between Technology Adoption and Coordination Failure

Although blockchain and other digital technologies have achieved a 53% adoption rate in carbon tracking(China Federation of Logistics and Purchasing, 2025), data fragmentation across supply chain segments prevents comprehensive carbon emission monitoring. This contradiction manifests in three dimensions.

First, inconsistent accounting standards cause data inaccuracies. Enterprises adopt different frameworks (GHG Protocol, 2023), resulting in up to 35% variance in Scope 3 emissions calculations②. For instance, in a photovoltaic supply chain, silicon material suppliers using PAS 2050 standards and cell manufacturers applying ISO 14067 caused 28% statistical overlap in final assembly's carbon footprint aggregation.

Second, data monopolies exacerbate information asymmetry. While core enterprises control 90% of critical carbon data (e.g., raw material transportation, processing energy consumption), less than 12% is shared with suppliers(China Federation of Logistics and Purchasing, 2025), preventing downstream firms from obtaining complete data for product carbon labeling.

Most critically, technology costs create new barriers. SMEs require annual investments of 500,000 CNY(Zhang, 2024) (8%-10% of net profits) for carbon management systems, forcing many to rely on manual reporting. Resolving this requires a tripartite "standardization-sharing-cost reduction" solution: mandatory industry carbon data interoperability protocols, tiered data interface requirements for core enterprises, and SaaS models to lower SME digitalization thresholds.

3.3 Dual Constraints of Policy Incentives and Talent Supply

Green supply chain development faces twin constraints of inadequate policy support and talent shortages, severely impeding progress. Policy gaps are particularly acute for SMEs. While SME green standard compliance is only 39%(Ministry of Education, 2025), fewer than 15% qualify for specialized tax incentives, undermining transformation motivation. Crucially, weak end-market demand—with consumers willing to pay just

7%-9% premiums for green products(Greenpeace, 2025).—fails to create sustainable business models. This "government enthusiasm vs. market indifference" dilemma stalls progress.

Concurrently, structural talent shortages worsen. Effective green supply chain operations require combined expertise in environmental management, digital technology, and supply chain optimization. Yet SMEs average under 4 hours of annual green training per employee versus the 40-hour industry standard. This capability gap hinders carbon footprint tracking and circular logistics implementation. Blockchain traceability and carbon accounting face acute specialist shortages.

Solutions require coordinated policy-talent mechanisms: market-driven incentives linking subsidies to emission reductions, coupled with consumer education to cultivate green markets. Simultaneously, industry-academia partnerships should develop modular training programs emphasizing digital-environmental cross-competencies. Only synergistic policy-leverage and talent development can provide sustainable momentum.

4 RECOMMENDATIONS

To address these multidimensional challenges, we propose systematic improvements.

First, establish green supply chain symbiosis ecosystems. Industry leaders should initiate green alliances, sharing carbon management SaaS platforms to enable technology diffusion. Implement equitable cost-sharing (suggested 1:0.7 ratio between core enterprises and SMEs) to reduce SME burdens and incentivize participation.

Second, create unified carbon data governance. Government-led "Unified Supply Chain Carbon Accounting Standards" and industry carbon data banks are essential. Legislate minimum 40% data disclosure requirements for core enterprises to dismantle silos and enable full-chain emission visibility.

For digital transformation, adopt a phased approach.

Short-term (1-2 years): Build foundational data infrastructure for direct and energy-related indirect emissions. Standardize collection formats and reporting protocols to ensure comparability and traceability, complemented by data quality audits.

Medium-term (3-5 years): Develop AI-powered smart accounting systems integrating IoT monitoring and big data analytics to reduce calculation errors below 15%. Prioritize lightweight solutions for SME accessibility.

Long-term (5+ years): Enable international carbon market integration through cross-border carbon credit infrastructure, supported by financial services for carbon asset management.

Policy enhancements should increase logistics/recycling subsidies to 30% of total budgets under MOF's Revised Green Manufacturing Fund Management. Launch dedicated 5-billion-CNY annual SME green transition funds to alleviate financial pressures

Finally, deepening the reform of industry-education integration in talent cultivation is imperative. It is recommended to incorporate cross-disciplinary courses on green supply chain management into the "Emerging Engineering Education" initiative in universities, making cutting-edge technologies such as blockchain and carbon accounting mandatory components. Drawing inspiration from Germany's dual education system, leading enterprises should collaborate with academic institutions to establish practical training bases, cultivating interdisciplinary professionals proficient in both environmental technologies and supply chain management. Through industry-academia collaborative education mechanisms, we can fundamentally address the current shortage of green-skilled talent.

5 CONCLUSION

This study systematically reveals the core contradictions in building green supply chains in manufacturing: despite progress in individual enterprises' green transformation under the "dual carbon" goals, insufficient systemic coordination across supply chains has resulted in suboptimal overall emission reduction outcomes. Through a three-dimensional analysis of supply chain management, technological application, and policy environment, the study identifies four key obstacles: (1) fragmented greening due to lack of supply chain coordination mechanisms, (2) compromised carbon credibility from inadequate digital technology adoption, (3) structural misalignment between policy incentives and market demand, and (4) severe disconnection between talent cultivation and industry needs. These findings provide new theoretical perspectives for understanding the deep-seated challenges in manufacturing's green transition.

The academic and practical significance of this study manifests in three aspects. Theoretically, it constructs an "enterprise-technology-policy" collaborative framework, overcoming the limitations of existing research focused on isolated optimizations.

Practically, proposed solutions—such as establishing green symbiosis ecosystems and carbon data banks—offer actionable approaches to address industry pain points. olicy-wise, recommendations on subsidy optimization and talent development provide valuable references for governmental support policies.

Looking ahead, green supply chain development will exhibit three core trends.

Deep integration of digital technologies will enable real-time, precise carbon accounting, significantly enhancing full-chain transparency.

Policy systems will evolve toward full lifecycle coverage, with strengthened support for SMEs and recycling processes.

Innovative industry collaboration models will emerge through technology sharing and balanced benefit mechanisms to achieve holistic green development.

Realizing this transformation requires a synergistic system integrating technological application, institutional innovation, and talent cultivation, advancing green supply chains from fragmented breakthroughs to systemic optimization. The key to future development lies in establishing a sustainable ecosystem that balances efficiency and equity.

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