

# *The Role and Challenges of Green Supply Chain Strategies in Reducing Carbon Footprints*

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**Abstract.** With increasing climate change risks and regulatory pressures, companies confront the challenge of lowering carbon emissions in their supply chains without losing competitiveness. As such, carbon footprint management has emerged as an important priority for sustainable supply chain transformation. This analysis investigates the nexus of carbon footprint management and green supply chain business strategy and how the incorporation of carbon reduction into strategic initiatives contributes to environmental sustainability. Through an analytical procedure that is systematic and based on the literature grounded in low-carbon manufacturing and green supply chain management theory, we provide the methodology to analyze important practices in green manufacturing, green logistics, and collaborative green procurement. The results indicate that carbon footprint management is an instrument for measuring carbon footprint and, in turn, a strategic tool to direct operational decisions towards sustainability. Good green supply chain practices can lead to substantial emissions reductions and increased resource utilization in the long term, but with the limitations of economic, coordination, and data transparency as concerns. For overall sustainability in a low-carbon economy, incorporating carbon footprint management into supply chain strategy is crucial.

**Keywords:** Green Supply Chain Management, Carbon Footprint Management, Low-Carbon Production, Green Logistics, Sustainable Supply Chain Collaboration

## **1. Introduction**

In the context of unprecedented global transformations, climate change has become one of the most critical issues of the twenty-first century [1]. Increasing levels of greenhouse gas emissions driven by transportation, energy usage, and industrial manufacturing have amplified the impacts of climate change and environmental degradation. Therefore, this has placed growing pressure on companies from governments, investors, customers, and states alike to reduce carbon emissions and enhance their environmental performance [2]. In this regard, green supply chain management has evolved into an important corporate drive for sustainable growth [3]. It encompasses all phases of the supply chain, including raw materials, manufacturing, distribution, consumption, and disposal, each of which is associated with energy consumption and carbon emissions. Consequently, supply chains are increasingly developed under the paradigm of carbon reduction. While conventional supply chain management primarily emphasizes cost, efficiency, and responsiveness, it often overlooks

environmental impacts. In contrast, a green supply chain strategy integrates environmental objectives into decision-making processes, aiming to balance economic efficiency with ecological protection. Among the key indicators for evaluating the environmental impact of supply chain activities, the carbon footprint plays a central role [4]. It quantifies the total greenhouse gas emissions generated by a product or service throughout its entire life cycle. By effectively managing carbon footprints, enterprises can identify major sources of emissions, set reduction targets, and design targeted low-carbon strategies [5]. This article investigates the extent to which carbon reduction objectives can be incorporated into the green supply chain business strategy, particularly with reference to carbon footprint management across manufacturing, logistics, and procurement activities. It reveals, based on the use of systematic literature analysis, some of the main mechanisms and challenges of carbon-oriented green supply chain practices. The study adds to the theoretical integration of sustainability with supply chain strategy and provides practical insights for firms pursuing low-carbon competitiveness.

## **2. Green supply chain strategy and carbon footprint management**

### **2.1. Green supply chain and low-carbon production**

The green supply chain strategy integrates environmental sustainability into the daily operations of a company's traditional supply chain system [2]. Unlike traditional supply chain concepts that focus on cost, efficiency, and delivery performance, the green supply chain prioritizes the simultaneous development of economic, environmental, and social goals. Through this strategy, companies focus on the environmental impact of each stage of the product lifecycle, including product design, raw material procurement, manufacturing, transportation, consumption, and waste disposal. Given that manufacturing typically produces the most carbon emissions in the supply chain, low-carbon production is central to the green supply chain strategy. Low-carbon production is all about decreasing greenhouse gas emissions at the source through optimizing energy structures and improving production processes. Companies are shifting more to the utilization of solar, wind, and hydropower renewables in place of traditional, fossil fuel energy. Such transition reduces carbon emissions, improves energy security, and lowers long-term energy costs. In addition, enterprises have equipped themselves with energy-saving equipment and optimized energy efficiency through intelligent production systems and automated monitoring platforms to reduce unnecessary energy consumption. By using real-time tracking and information systems, businesses detect energy waste and adjust production parameters accordingly. For example, clean production technologies, waste heat recovery systems, and lean manufacturing practices, have greatly improved factory resource utilization and reduced emissions [6]. Besides, low-carbon production emphasizes eco-design and circular production. For example, companies can reduce carbon emissions across the entire lifecycle by designing energy-efficient, lightweight, durable and recyclable products. In remanufacturing and recycling systems, companies recycle materials and components and obtain value through effective recycling methods. Therefore, low-carbon production is not only an operational tool, but also a strategic direction for sustainable industrial transformation [7].

### **2.2. Carbon footprint management and emission measurement**

The carbon footprint management refers to the systematic measurement, monitoring, analysis, and control of greenhouse gas emissions throughout the supply chain [1]. True emissions management relies on accurate measurement as enterprises need to identify emissions sources before they can

implement emissions reduction plans. At present, the most widely accepted international standards for carbon accounting and reporting are the Greenhouse Gas Protocol (GHG) and ISO 14064. Based on the GHG Protocol, corporate emissions can be divided into three scopes, including Scope 1, Scope 2, and Scope 3. Scope 1 refers to the direct emissions from the company's own facilities and vehicles, which mainly come from fuel combustion and industrial activities. Scope 2 is the indirect emissions released because of purchased electricity, steam, heating, and cooling. And Scope 3 provides indirect emissions in other categories along the product lifecycle, including raw material extraction, supplier manufacturing, logistics and transportation, product use, and waste disposal. It is important to highlight that Scope 3 emissions usually represent the largest share of a company's carbon footprint but measuring them is especially challenging [4]. This is because the complexity and geographical distribution of modern supply chains often rely on voluntary reports from suppliers for data collection, and these reports may be incomplete or inaccurate. To conquer this problem, companies use different accounting tools like process-based accounting, input-output analysis, or hybrid approaches. Carbon footprint management permits companies to identify carbon hotspots, establish science-based emissions reduction goals, and incorporate carbon management as part of their strategic plans [3]. In addition to everything else, carbon disclosure is essential for ESG reporting and sustainable finance. Transparency in carbon information builds investor confidence, boosts market competitiveness, and strengthens reputation [8].

### **2.3. Coordination between green strategy and carbon reduction**

In order to achieve the practical effects of a green supply chain strategy in carbon reduction, carbon management must be integrated into the daily operations of the business, rather than merely being an environmental protection measure. This requires close collaboration across all departments, such as procurement, production, logistics, finance, and sustainability. Strategic decision-making and performance evaluation systems should incorporate carbon reduction targets to ensure the entire company is working towards the same low-carbon goal. Furthermore, digital technologies are an important tool for promoting this coordination [9]. Technologies like the Internet of Things (IoT), big data analytics, artificial intelligence (AI), and digital twins are helping companies monitor energy consumption and carbon emissions in various activities in the supply chain in real time. Through intelligent optimization algorithms, companies can find a balance between production efficiency, inventory levels, and carbon reduction targets, thereby achieving more refined carbon management and resource utilization. However, internal collaboration alone is far from sufficient. Since a large amount of carbon emissions come from upstream suppliers and downstream partners, cross-enterprise collaboration is crucial [10]. Supply chain partners need to jointly develop a unified carbon management platform, set unified data standards, promote the transformation of the entire system towards low-carbon energy efficiency, and achieve system-level carbon reduction targets.

## **3. Application of green supply chain strategy in carbon footprint reduction**

### **3.1. Low-carbon production and green manufacturing**

Low-carbon production and green manufacturing constitute the main implementation mechanisms for green supply chain strategy, because in the production stage energy and material consumption constitute the largest source of carbon emissions [3]. These emissions can be tackled head-on in the supply chain by embedding carbon reduction initiatives within manufacturing activities. Enterprises employ various technology and process-oriented innovations, such as energy-efficient equipment

installations, renewable energy substitution, smart manufacturing systems, and circular product design. These methods seek to save energy, minimize material waste, and extend the life cycles of products with reuse and remanufacturing of the product. As a result, these measures reduce carbon emissions per unit of output and boost resource utilization. Meanwhile, low-carbon manufacturing promotes environmental protection and economic sustainability by saving energy costs, improving operational efficiency, and enhancing firms' resilience and competitiveness during the transition to a low-carbon economy

### **3.2. Green logistics and delivery optimization**

Logistics activities are a significant source of carbon emissions in supply chains, mainly from fuel combustion in transportation, energy use in warehousing, and packaging waste [2]. Because of the scope and heterogeneity of logistics networks, emissions produced at this point can play a major part in the total carbon footprint of supply chains. Therefore, the emission reduction of logistics has emerged as a significant target for green supply chain strategy. In addition, green logistics practices involve cleaner transportation options, intelligent route and schedule management, energy-saving warehouse systems, and advanced packaging methods. These initiatives are designed to lessen the reliance on fossil fuels, conserve energy, and reduce the consumption of unnecessary materials in logistics activities. Efficient logistics may significantly reduce carbon emission per unit output via the improvement of transportation planning, the optimization of space utilization, and minimization of energy need and energy cost of storage and handling activities. In addition to providing higher environmental value, better logistics performance contributes to improved service quality, reduced logistics costs, and greater service reliability. By adopting green logistics, supply chains become more sustainable, boosting their environmental performance and helping businesses reach long-term sustainability targets, all while staying competitive in carbon-constrained markets.

### **3.3. Supply chain collaboration and green procurement**

Given that a significant portion of carbon emissions in the supply chain originates from upstream suppliers, it follows that focal enterprises cannot drive system-level reductions by focusing solely on their internal operations. Therefore, the anticipation of these upstream emissions requires green procurement and collaborative supply chain practices moving forward. Besides, green procurement strategies combine environmental factors in supplier selection and evaluations, thus complementing more traditional indicators like price, quality, and delivery reliability [3]. Suppliers are evaluated on aspects such as carbon emissions, energy efficiency, use of renewable energy, and compliance with environmental standards, ensuring that environmental performance becomes a fundamental element of supply chain management. Beyond assessment, the focal enterprises bolster supplier capabilities through customized training, the provision of digital tools to aid in carbon accounting, and incentive plans that promote the adoption of low-carbon practices. This approach assists suppliers in adopting emission mitigation measures and catalyzes innovation in environmentally friendly technologies and supplies. In addition, when considering long-term collaborative initiatives, like co-production efforts, shared carbon management platforms, and joint green procurement projects, companies can gradually reduce Scope 3 emissions. This synergistic effort will enhance the overall environmental performance of the global supply chain, boost supply chain resilience, promote the development of green industrial ecosystems, and drive continuous investment in low-carbon technologies, thereby creating strategic value for both the focal firms and their suppliers.

## **4. Challenges and future development directions of carbon-focused green supply chain management**

### **4.1. Initial investment pressure**

The main obstacle to green supply chain transformation is the initial investment cost. In particular, companies need to make large-scale upfront investments in renewable energy, smart manufacturing, low-emission fleets, and carbon management platforms. These investments may lead to long-term savings and carbon reductions, but in the short term, they can place considerable financial strain on businesses, especially small and medium-sized enterprises. The challenges of managing initial investment pressure vary for businesses depending on their size. Large enterprises typically spread costs through long-term strategies, while Small and Medium-sized Enterprises (SMEs) often lack confidence in investing due to capital shortages, insufficient capital accumulation, and unclear market potential for low-carbon technologies. Thus, governments and relevant institutions should help businesses, especially SMEs, overcome initial investment barriers through policy support and innovative financing mechanisms, such as tax incentives, green bonds, and green credit [4].

### **4.2. Inconsistent carbon standards**

The lack of common carbon accounting and reporting systems is a major bottleneck for effective supply chain carbon management. Besides, it is noteworthy that carbon reporting systems available so far differ markedly between countries and industries, due to differences in regulatory standards, reporting models, and practices among industries. Furthermore, lack of agreement regarding data boundaries, calculation approaches, and emission scopes also makes it difficult to compare carbon information between companies and regions. Such disparities increase administrative burdens on firms to collect, reconcile, and verify their data, while also hindering cross-border cooperation in supply chains, where reliable and consistent carbon information is crucial for effective reduction efforts. Given the growing interconnectivity within global supply chains, the absence of shared standards hinders entities' ability to collaborate on low-carbon policies, assess supplier behavior, and measure environmental performance. Consequently, the development and implementation of common carbon accounting standards and reporting guidelines worldwide are essential in building data credibility, promoting global collaboration, and establishing a more systematic supply chain carbon reduction strategy [3].

### **4.3. Supply chain complexity**

The increasing complexity of contemporary supply chains, which are multi-tiered, geographically dispersed, and highly heterogeneous, combined with large differences in technical and managerial capabilities, presents major challenges for coordinating carbon controls. Most supply chains in the upstream sector, especially small and medium-sized enterprises, do not have the financial resources, technical knowledge, and experience needed to effectively manage carbon reduction. Moreover, some suppliers may be reluctant to disclose carbon data due to regulatory compliance pressures or concerns over business confidentiality. These shortcomings can markedly diminish the success of collaborative carbon mitigation efforts as incomplete or non-uniform data limits focal enterprises' capability to monitor, benchmark, and support supplier performance. To address these challenges, enterprises should reinforce their supplier engagement within specific training programs, technical assistance, incentive mechanisms, and improved transparency mechanisms. These measures boost



suppliers' carbon management capabilities and make emission reduction efforts more coordinated and manageable from source to destination [9].

#### 4.4. Data and technology limitations

For effective carbon footprint management, real-time, reliable, and traceable data are critical, yet data inconsistency and technological limitations remain major challenges for many enterprises. A substantial proportion of firms currently work with manual data collection and siloed information systems, leading to widespread mistakes, delays, and inconsistencies that eventually compromise the accuracy and credibility of carbon reporting. Some emerging technologies, such as blockchain and artificial intelligence, also provide an exciting set of solutions by enabling secure, automated, and transparent data management. However, implementation costs, cybersecurity risks, and lack of skilled personnel have posed significant obstacles to their widespread adoption. Firms must invest in technological innovation to remove these barriers, standardizing data collection and reporting methods, and training talent for advanced digital management to overcome them [6]. These efforts are crucial for generating accurate, timely, and actionable carbon data, which in turn supports more effective supply chain-wide emission reduction strategies.

#### 5. Conclusion

This study reveals that green supply chain business development and carbon footprint management are essential to organizational sustainability, acting as both legal and strategic imperatives towards sustainable competitive advantage. Specifically, carbon reduction is mainly realized through three key strategies: low-carbon production, green logistics, as well as collaborative green procurement. Low-carbon manufacturing lowers emissions by adopting energy-saving technologies, sustainable production processes, and eco-friendly materials. Besides, green logistics optimizes transportation efficiency, integrates reverse logistics, and helps to minimize environmental impact. In addition, collaborative green procurement inspires suppliers to practice sustainability in their supply chains. Effective carbon footprint management enables companies to identify emission sources, streamline operations, cut waste, enhance energy efficiency, improve ESG performance, and strengthen their corporate reputation. Nonetheless, there are several problems that enterprises confront as they strive to fulfill high upfront costs, inconsistent emission standards, limited supplier cooperation, and a lack of technical expertise. Overcoming these barriers will demand harmonized carbon accounting standards, robust digital infrastructures, and improved supply chain collaboration. At the heart of the situation, green supply chain strategies are crucial for driving low-carbon transformation and boosting competitiveness in the sector, while playing a key role in supporting sustainable economic growth through stronger climate policies and the current trends in digital innovation.

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