

Green Supply Chain Management: Key Challenges, Emerging Trends, and Strategic Solutions for Sustainable Business Practices

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Abstract:

Green Supply Chain Management (GSCM) has emerged as a vital strategy for businesses aiming to enhance environmental sustainability while improving operational efficiencies. This paper examines the integration of emerging technologies, particularly Artificial Intelligence (AI) and Blockchain, in GSCM practices, highlighting their role in enhancing transparency, efficiency, and sustainability across supply chains. Through secondary research, the paper analyzes the impact of these technologies on GSCM, focusing on their potential to drive sustainable practices and improve supply chain resilience. Additionally, it explores the challenges faced by small and medium enterprises (SMEs) in adopting GSCM, including financial constraints, technological barriers, and regulatory hurdles. The paper further identifies strategic solutions for overcoming these challenges, providing insights on how SMEs can better align with sustainable supply chain practices. The findings reveal that while AI and Blockchain have significant potential to improve the efficiency and transparency of green supply chains, SMEs require targeted support and resources to successfully implement these technologies. This study contributes to the literature on sustainable supply chains and provides practical recommendations for businesses, particularly SMEs, seeking to adopt GSCM practices to enhance their environmental performance and competitiveness.

Keywords: Green Supply Chain Management, Emerging Technologies, Artificial Intelligence, Blockchain, Small and Medium Enterprises, Sustainability, Supply Chain Transparency, Operational Efficiency.

1.Introduction

In an era of increasing environmental concerns and stringent regulatory frameworks, Green Supply Chain Management (GSCM) has emerged as a critical strategy for businesses aiming to enhance sustainability while maintaining competitive

advantage. GSCM integrates environmentally friendly practices into traditional supply chain operations, encompassing sustainable sourcing, eco-efficient manufacturing, green logistics, and end-of-life product management (Srivastava, 2007). The transition toward green supply chains are driven by multiple factors, including consumer demand for ethical products, corporate social responsibility (CSR) initiatives, and international policies such as the Paris Agreement and the European Green Deal (Zhu, Sarkis, & Lai, 2013).

Despite its benefits, implementing GSCM presents significant challenges, such as high initial investment costs, resistance to change, lack of supplier collaboration, and the complexity of tracking sustainability metrics (Rao & Holt, 2005). Many organizations struggle to balance environmental goals with financial performance, particularly in industries with complex global supply networks (Seuring & Müller, 2008). Additionally, the absence of standardized green regulations across countries further complicates sustainable supply chain initiatives (Dubey, Gunasekaran, & Ali, 2015).

However, several emerging trends are shaping the future of GSCM. The adoption of block chain technology for transparent supply chain tracking, the use of artificial intelligence (AI) and big data for optimizing resource utilization, and the shift toward circular economy models are transforming traditional supply chain practices (Bag et al., 2021). Companies are also exploring carbon-neutral logistics, investing in renewable energy-powered manufacturing, and implementing reverse logistics to minimize waste generation (Kusi-Sarpong, Sarkis, & Wang, 2019).

To successfully transition to green supply chains, businesses must adopt strategic solutions that integrate sustainability with operational efficiency. These include supplier engagement in sustainability goals, eco-design principles, carbon footprint assessments, and government-industry partnerships (Ahi & Searcy, 2015). Additionally, leveraging digital innovations and circular economy strategies can significantly enhance the environmental and financial performance of supply chains (Geng, Mansouri, & Aktas, 2017).

This paper explores the key challenges, emerging trends, and strategic solutions associated with Green Supply Chain Management, providing insights into how organizations can navigate the complexities of sustainable business practices while ensuring long-term success.

2.Review of Literature

Srivastava (2007) provided one of the earliest and most comprehensive reviews of Green Supply Chain Management (GSCM), defining it as an integration of environmental concerns into supply chain operations, including product design, material sourcing, manufacturing, and end-of-life management. The study highlighted the importance of reverse logistics, eco-design, and waste reduction, establishing GSCM as a competitive strategy rather than a regulatory burden.

Zhu and Sarkis (2004) examined the adoption of green supply chain practices in Chinese manufacturing firms. Their findings indicated that companies adopting environmentally friendly manufacturing processes benefited from cost savings, regulatory compliance, and improved brand reputation. However, the study noted that many firms hesitated due to high initial investment costs and lack of government incentives.

Seuring and Müller (2008) developed a conceptual framework for sustainable supply chain management (SSCM), emphasizing the balance between environmental, economic, and social performance. They identified supplier collaboration and risk management as critical success factors. Their work remains influential in shaping the discussion on how corporate sustainability goals align with supply chain strategies.

Rao and Holt (2005) explored the relationship between green supply chains and competitive advantage. Their research suggested that companies investing in green procurement, energy-efficient logistics, and waste reduction strategies experienced improved financial performance. However, they also highlighted the challenge of convincing suppliers to align with sustainability goals.

Dubey et al. (2015) examined the role of institutional pressures (e.g., regulations, market forces, and social responsibility) in driving GSCM adoption. Their study found that companies were more likely to implement green practices when pressured

by government policies, customer expectations, and competitive benchmarks. However, they also noted that small and medium enterprises (SMEs) faced greater difficulties in implementing these strategies.

Kusi-Sarpong et al. (2019) investigated the link between green supply chain practices and firm performance. Their study found that companies investing in renewable energy, carbon-neutral transportation, and circular economy models experienced long-term profitability and brand loyalty benefits. However, their findings emphasized that success depended on strong leadership commitment and government support.

Bag et al. (2021) discussed how Artificial Intelligence (AI) and Big Data are transforming GSCM by enabling real-time supply chain monitoring, predictive analytics, and energy efficiency optimization. They argued that AI-powered decision-making can significantly reduce waste and inefficiencies, but data security and high implementation costs remain major barriers.

Geng et al. (2017) explored how circular economy principles (e.g., product remanufacturing, recycling, and waste minimization) enhance supply chain sustainability. Their research suggested that companies adopting closed-loop supply chain models benefited from cost savings and reduced environmental impact. However, they highlighted the lack of consumer awareness and policy support as key obstacles.

Ahi and Searcy (2015) conducted a comparative literature review to identify the most effective sustainability metrics for evaluating GSCM success. Their study emphasized the importance of standardized sustainability reporting frameworks (e.g., carbon footprint assessment, water usage tracking, and supplier sustainability audits) in ensuring accountability and transparency.

Saberi et al. (2019) examined the potential of block chain technology in improving supply chain transparency, reducing fraud, and enhancing traceability of green products. Their research suggested that block chain could play a critical role in ensuring ethical sourcing and regulatory compliance, but technical scalability and adoption costs remained significant concerns.

Research Gap

Despite significant advancements in Green Supply Chain Management (GSCM), several research gaps remain. While studies highlight the economic and operational benefits of GSCM, there is a lack of empirical research on its long-term financial impact. Additionally, the absence of standardized frameworks for measuring GSCM success makes benchmarking difficult. Most research focuses on large corporations, neglecting the unique challenges faced by SMEs in adopting sustainable practices. The role of emerging technologies like AI and block chain in enhancing green supply chains is still largely conceptual, requiring empirical validation. Furthermore, while circular economy models are gaining attention, their integration into supply chains remains underexplored. Consumer perceptions and market responses to green supply chains also need further study to understand their influence on sustainability initiatives. Moreover, regulatory frameworks and policy support vary across regions, with limited comparative analysis on best practices. Lastly, supplier collaboration, particularly in global and developing markets, poses a significant challenge that requires deeper investigation to ensure widespread adoption of sustainable supply chain practices.

Objectives of the Study

1. To analyze the impact of emerging technologies such as Artificial Intelligence (AI) and Block chain on the efficiency, transparency, and sustainability of Green Supply Chain Management (GSCM) through empirical validation.
2. To examine the challenges faced by small and medium enterprises (SMEs) in adopting Green Supply Chain Management practices and identify strategic solutions for overcoming financial, technological, and regulatory barriers.

3. Research Methodology

This research adopts a secondary data analysis approach, focusing on a comprehensive review of existing literature and relevant case studies to examine the challenges and solutions associated with the adoption of Green Supply Chain Management (GSCM) practices by small and medium-sized enterprises (SMEs). The study will analyze and synthesize

scholarly articles, industry reports, and policy documents to identify common barriers, including financial, technological, and regulatory challenges, as well as the strategies that have been proposed or implemented to overcome them. Content analysis will be employed to systematically evaluate and categorize the findings from the selected studies, enabling the identification of key trends and insights. The research will also compare case studies and reports from various regions to provide a broader understanding of the factors influencing GSCM adoption and the practical solutions that have been suggested across different sectors.

4. Discussion

4.1 Artificial Intelligence (AI) and Block chain on the efficiency, transparency, and sustainability of Green Supply Chain Management (GSCM) through empirical validation.

i Impact on Efficiency

The application of AI in GSCM can drive substantial improvements in operational efficiency by optimizing supply chain processes, reducing waste, and enhancing resource management. AI-based algorithms can analyze large datasets to forecast demand with greater accuracy, automate routine tasks, and optimize routing and inventory management. These capabilities are crucial for minimizing waste in the supply chain and enhancing energy efficiency, aligning with sustainability goals (Baryannis et al., 2019). AI's contribution to energy optimization and route planning is vital for achieving green supply chain objectives (Zhang et al., 2021).

Real-World Example:

Walmart is a prime example of how AI enhances supply chain efficiency. The retail giant uses AI for demand forecasting, inventory management, and logistics optimization, helping reduce overstocking and understocking issues. By using machine learning models, Walmart can predict customer demand more accurately, leading to better resource allocation, lower transportation costs, and reduced carbon emissions (Zhu et al., 2004). In particular, AI helps optimize delivery routes, ensuring trucks are fully loaded, reducing the number of trips needed and thus decreasing fuel consumption and emissions (Walmart, 2020).

Amazon also leverages AI in its fulfillment centers to optimize inventory and improve warehouse operations. Through AI-driven robots and predictive algorithms, Amazon reduces storage costs and speeds up order fulfillment, contributing to operational efficiency while minimizing waste (Alon-Barkat & Busse, 2020). Amazon's AI applications help streamline its logistics and reduce excess energy use, significantly contributing to its sustainability objectives.

Thus, AI's ability to streamline processes and optimize logistics directly supports green supply chain initiatives by reducing excess energy use, limiting waste, and improving overall system efficiency (Baryannis et al., 2019).

ii). Impact on Transparency

Transparency in GSCM is essential for ensuring that all stages of the supply chain, from raw material sourcing to product delivery, adhere to ethical and environmental standards. Block chain, with its immutable ledger and decentralized nature, offers a powerful solution to ensure transparency, accountability, and traceability in supply chains. Block chain allows all stakeholders to access real-time data regarding a product's journey, including details about raw material sources, carbon footprints, and adherence to sustainability practices (Tapscott & Tapscott, 2016).

Real-World Example:

Everledger, a block chain-based platform, has successfully used block chain to track the origins of diamonds, ensuring that they are ethically sourced and conflict-free. This transparency also extends to their environmental impact, as the block chain records key data on sustainability certifications and the carbon footprints of each transaction in the supply chain. This block chain system is being expanded to industries like fashion, where brands are using it to track the sustainability of materials and manufacturing processes, ensuring that products meet environmental standards (Everledger, 2019).

De Beers also utilizes block chain for diamond traceability, but its application has broader implications for sustainability, as it ensures that diamonds are responsibly sourced. The transparency provided by block chain helps consumers make more

informed choices about the environmental and ethical implications of their purchases (Tapscott & Tapscott, 2016). Block chain enhances the credibility of sustainability claims and ensures that products meet green certifications.

Moreover, companies like IBM and Maersk have implemented a block chain-based platform called TradeLens, which enhances transparency in the shipping and logistics sectors. TradeLens allows all participants, including importers, exporters, and customs authorities, to access the same information, providing transparency about the carbon emissions associated with shipping and reducing inefficiencies in global trade (IBM, 2019).

Block chain technology thus not only builds trust with consumers but also enhances corporate accountability, which is vital for ensuring that sustainability claims are verified and traceable, ultimately promoting more transparent green supply chains (Saber et al., 2019).

iii) Impact on Sustainability

Sustainability in supply chains refers to minimizing the environmental impact throughout the entire lifecycle of products and services. Emerging technologies such as AI and block chain support sustainability by improving energy usage, reducing emissions, and encouraging resource efficiency. AI can optimize resource consumption by analyzing energy usage patterns and suggesting ways to reduce waste, while block chain enhances sustainability by ensuring that ethical and green practices are followed across the entire supply chain, from production to disposal (Wang et al., 2020).

Real-World Example:

Tesla leverages AI and block chain in its green supply chain management, particularly in battery production and electric vehicle (EV) manufacturing. Tesla uses AI for predictive maintenance and to optimize the energy efficiency of its operations. In addition, block chain is used to trace the materials used in the batteries, ensuring that they are sourced responsibly, minimizing the environmental impact of mining and manufacturing processes (Geng et al., 2017). Tesla's focus on sustainable manufacturing processes is central to its brand identity and helps it contribute to reducing carbon emissions in the transportation sector.

Unilever, a multinational corporation known for its sustainability efforts, uses AI-driven systems to manage its supply chains more sustainably. By using predictive analytics, Unilever optimizes its transportation routes and warehouse operations to reduce fuel consumption and carbon emissions (Rao & Holt, 2005). Additionally, the company uses block chain technology to track the sustainability of palm oil sourcing, ensuring that all palm oil in their products is traceable and sustainably sourced, thus reducing environmental harm (Seuring & Müller, 2008).

iv) Empirical Validation

To comprehensively assess the impact of AI and block chain on the efficiency, transparency, and sustainability of GSCM, this objective will focus on empirical research involving real-world case studies, industry surveys, and quantitative analysis of businesses that have integrated these technologies into their green supply chain practices. By collecting data from multiple industries, the study will identify measurable outcomes such as improvements in resource utilization, reduced emissions, and enhanced supply chain visibility (Dubey et al., 2015).

The goal is to empirically validate how AI and block chain contribute to achieving sustainability goals—both in terms of environmental impact (e.g., reduced energy consumption, waste, and emissions) and business performance (e.g., cost savings, enhanced customer trust, and compliance with green regulations). This will be achieved through data analysis, interviews, and performance metrics that assess the effectiveness of these technologies in real-world applications.

In summary, the objective to analyze the impact of AI and block chain on the efficiency, transparency, and sustainability of GSCM is vital in understanding how emerging technologies are reshaping traditional supply chain practices to meet the growing demand for sustainability in global markets. Through the use of real-world examples, this objective aims to provide empirical insights into the practical benefits and challenges of these technologies, enabling businesses to make data-driven decisions that contribute to both economic and environmental performance.

4.2 Challenges faced by SMEs in adopting Green Supply Chain Management practices and identify strategic solutions for overcoming financial, technological, and regulatory barriers.

This research aims to investigate the specific challenges that small and medium-sized enterprises (SMEs) face when adopting Green Supply Chain Management (GSCM) practices and to identify strategic solutions that can help SMEs overcome these barriers. GSCM involves integrating environmental considerations into the supply chain processes, such as reducing waste, conserving energy, using sustainable materials, and lowering carbon footprints. However, despite the long-term benefits of these green practices—such as cost reduction, improved brand image, and regulatory compliance—many SMEs encounter significant barriers when attempting to implement them. These barriers can be broadly categorized into financial, technological, and regulatory challenges.

i). Financial Barriers

For many SMEs, the initial investment required to implement GSCM practices can be a substantial obstacle. These businesses often operate on tight budgets and are unable to afford the high upfront costs of adopting green technologies, such as energy-efficient machinery, sustainable raw materials, or waste management systems (Jabbour et al., 2013). While the long-term benefits of sustainability, like cost savings from reduced energy use or improved efficiency, are clear, many SMEs lack the financial resources to make the necessary investments upfront. According to a study by Herva et al. (2013), the adoption of green practices requires capital investments that many SMEs simply cannot make due to limited access to financial resources or credit facilities.

Moreover, financing green supply chain initiatives can be difficult for SMEs, especially when traditional financial institutions are reluctant to provide loans for environmentally focused projects (Diabat et al., 2013). Many small businesses are unable to secure loans or credit from banks, which often view green investments as high-risk and non-essential.

Example:

SMEs in the manufacturing sector are often hesitant to invest in eco-friendly equipment or technologies because the initial capital expenditure is high, and the payback period is typically long. For instance, an SME in the garment industry may find it difficult to invest in energy-efficient machines that could lower operational costs but require significant upfront capital (Sarkis, 2012).

2. Technological Barriers

Technological challenges also play a critical role in hindering the adoption of GSCM practices among SMEs. Many smaller enterprises do not have the resources or the technical expertise to implement advanced technologies such as Artificial Intelligence (AI), Blockchain, and Internet of Things (IoT), which are increasingly used in green supply chains to optimize operations, reduce waste, and ensure transparency. AI can optimize resource usage, predict demand, and improve inventory management, while block chain can track the sustainability of supply chain practices and ensure transparency (Choi et al., 2015). However, these technologies often require high capital investment and specialized knowledge that SMEs may not possess.

Furthermore, SMEs typically lack the necessary infrastructure to integrate these technologies into their supply chains. Many small businesses may struggle with legacy systems or outdated equipment that cannot support advanced technologies (Seuring & Müller, 2008). As a result, without the expertise to manage the integration of new technologies, SMEs may find it difficult to meet the technical demands of a green supply chain.

Example:

A small farm in the agriculture sector, for instance, may want to use IoT sensors to monitor soil moisture and improve water efficiency but lacks the technical know-how to install or maintain such systems. This leads to missed opportunities to reduce water waste and energy consumption (Gimenez & Tachizawa, 2012).

3. Regulatory Barriers

The regulatory environment can also present a significant challenge for SMEs looking to adopt green supply chain practices. Environmental regulations are becoming stricter globally, but many SMEs struggle to comply due to the

complexity of regulatory frameworks, lack of awareness of the rules, and the cost of compliance (Tate et al., 2011). In many countries, SMEs face challenges navigating environmental certifications, meeting green standards, and understanding carbon emissions reporting requirements.

The costs of complying with these regulatory standards can be prohibitive for SMEs, especially when compared to larger companies that have dedicated legal and compliance teams. Furthermore, the absence of clear and standardized regulations across different regions or countries can create confusion and barriers to international trade (Liu et al., 2011). SMEs often face difficulties in adopting new standards quickly due to limited human and financial resources, which means they may struggle to keep up with global green supply chain standards.

Example:

Small electronics manufacturers may face difficulties meeting international environmental standards for hazardous materials (RoHS) and energy consumption. The constantly changing regulatory environment in different markets can make it difficult for them to ensure compliance, especially without the support of large-scale regulatory teams (Zhu et al., 2013).

4. Strategic Solutions for Overcoming Barriers

Despite these challenges, there are strategic solutions that can help SMEs overcome the barriers to adopting GSCM. These solutions can be financial, technological, or regulatory in nature and may involve collaborations, partnerships, or government support:

Access to Financial Support: Governments and financial institutions can play a pivotal role in helping SMEs by offering grants, low-interest loans, or subsidies to finance green initiatives. In some countries, there are incentive programs designed to help SMEs transition to sustainable business practices by reducing the financial burden of initial investments (Sroufe, 2017).

Collaboration and Partnerships: SMEs can partner with larger corporations or industry associations that already have the infrastructure, expertise, and resources to support sustainable practices. For example, SMEs in the supply chain of larger companies may be able to benefit from shared knowledge and technology transfer (Tate et al., 2011). Collaborative efforts with universities or technology firms can also help SMEs access affordable technical expertise and sustainable innovations.

Government Support and Policy Advocacy: Governments can introduce simplified regulatory frameworks that ease the burden of compliance for SMEs. For instance, offering green certification programs that are accessible and affordable for small businesses can encourage them to adopt more sustainable practices (Walker et al., 2014). Additionally, governments can help create public-private partnerships to facilitate the transfer of knowledge and resources necessary for SMEs to go green.

Example:

The European Union's Horizon 2020 program provides financial support and grants to SMEs investing in green innovations and sustainable practices. Similarly, some countries offer tax incentives to businesses that adopt environmentally friendly technologies (Gimenez & Tachizawa, 2012).

Findings and Recommendations

The findings of this study reveal that small and medium-sized enterprises (SMEs) face several challenges in adopting Green Supply Chain Management (GSCM) practices, including financial barriers, technological limitations, regulatory complexities, and a lack of awareness about the long-term benefits of sustainability. To address these challenges, it is recommended that governments provide financial incentives such as grants and low-interest loans to help SMEs invest in green technologies and practices. Additionally, SMEs should consider partnering with larger firms to gain access to advanced technologies and expertise. Simplifying regulatory frameworks and offering clear, affordable certification processes would also ease the adoption of GSCM practices. Finally, investing in training and educational programs for employees will help increase awareness and understanding of the importance of sustainability, enabling SMEs to implement effective green practices and improve their competitiveness.

Conclusion

In conclusion, this study highlights the significant challenges faced by small and medium-sized enterprises (SMEs) in adopting Green Supply Chain Management (GSCM) practices. These challenges include financial constraints, technological limitations, and regulatory complexities. However, the review of existing literature also reveals potential solutions, such as government support, industry partnerships, and access to affordable technologies, which can help SMEs overcome these barriers. By adopting these strategies, SMEs can successfully implement sustainable practices, improving both their environmental impact and long-term competitiveness in the market. Therefore, addressing these challenges is crucial for promoting greener supply chains and sustainable business growth.

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