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GREEN SUPPLY CHAIN MANAGEMENT PRACTICES IN SOME SECTORS

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Abstract: Green Supply Chain Management (GSCM) integrates sustainable practices throughout supply chains, addressing environmental, economic, and social concerns. This study examines the implementation of GSCM across various industries, including lumber, steel, electronics, automotive, construction, and food. It analyses key frameworks such as the triple bottom line, cradle-to-cradle, and circular economy. Industry case studies reveal common themes, such as waste reduction, eco-friendly sourcing, and process optimization. However, differences also emerge due to sector-specific challenges, including resource constraints and unique operational needs. The lessons learned emphasize the importance of stakeholder collaboration, innovative solutions, and targeted strategies to overcome barriers like high costs and limited infrastructure. These insights provide best practices for aligning GSCM with sustainability goals, fostering both economic resilience and environmental stewardship.

Keywords: *green supply chain management, cradle-to-cradle, triple bottom line, circular economy.*

Introduction

Green supply chain management (GSC) has gained significant attention recently as businesses strive to address growing environmental concerns and meet sustainability demands. GSC integrates environmentally conscious practices throughout the supply chain, from sourcing materials to production, distribution, and end-of-life disposal. As climate change, resource scarcity, and consumer awareness intensify, industries are pressured to adopt sustainable practices that minimise their environmental impact while maintaining efficiency and profitability.

This comprehensive review explores the evolution of GSCM, its underlying principles, and the unique challenges associated with its implementation. It delves into green design, operations, and logistics concepts, highlighting their relevance in diverse industries, including electronics, automotive, construction, and food. Additionally, the study examines frameworks like the triple bottom line, cradle-to-cradle design, and circular economy, which underpin the theoretical and practical aspects of GSCM.

While the growing body of literature underscores the transformative potential of GSCM, significant barriers persist, ranging from high implementation costs to regulatory and infrastructural constraints. This paper aims to synthesise key insights into these challenges, outline best practices across industries, and identify gaps in existing research. By addressing these gaps, it seeks to provide actionable directions for advancing the field of GSCM and contributing to the broader sustainability agenda.

Defining Green Supply Chain Management

Undoubtedly, a bird on the tree is not valuable compared to a bird at hand. This analogy is accurate for business enterprises where there is no value created unless the enterprise is able to not only source but transform inputs and make them available and accessible to its customers. This interplay may be summed up as a discipline: supply chain management.

Supply Chain Management (SCM) has long been understood as the coordination of processes that span from the supplier's supplier to the customer's customer, with the goal of delivering products efficiently and effectively (Kranz, 1996; Larson & Rogers, 1998). Traditionally, SCM has focused on managing the flow of goods, information, and finances across a network of entities, emphasising customer satisfaction and operational efficiency (Mentzer et al., 2001). However, as environmental concerns have grown, SCM has significantly transformed into Green Supply Chain Management (GSCM), which integrates environmental considerations into every aspect of the supply chain (Srivastava, 2007).

The transition to GSCM is characterised by a shift from focusing solely on economic factors to embracing a broader set of objectives that include environmental sustainability. This change has been driven by regulatory pressures and consumer demand for environmentally friendly products (Beamon, 1999). GSCM encompasses practices that minimise ecological impact at every stage, from product design to disposal, through green design and green operations (Srivastava, 2007). Green design involves developing products with environmental considerations, ensuring health and safety throughout their lifecycle, while green operations aim to reduce ecological defects in manufacturing processes (Srivastava, 2007).

Recent literature highlights how digital transformation, including artificial intelligence and big data, has reshaped SCM by enhancing visibility and responsiveness—key elements for implementing sustainable practices (Chopra & Meindl, 2016). Furthermore, integrating sustainability into SCM aligns with broader economic, environmental, and social goals, with studies indicating that GSCM practices significantly impact sustainability performance (Touboulic & Walker, 2015).

Government subsidies and public pressure have further accelerated this shift, with research demonstrating their influence on green practices in closed-loop supply chains (Mondal & Giri, 2022). In regions like China, external pressures have played a crucial role in the adoption of GSCM, affecting both practices and performance outcomes (Zhu & Sarkis, 2016). Similarly, in India, the implementation of GSCM faces distinct barriers that have been analysed to provide insights for overcoming these challenges (Govindan et al., 2014).

The convergence of supply chain management (SCM) with environmental management is not only about minimising negative impacts; it also involves creating strategic business advantages. For instance, practices such as green procurement, green design, and green logistics can lead to cost savings, enhance brand reputation, and open up new markets (Hervani et al., 2005). Furthermore, green supply chain management (GSCM)

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enables organisations to build resilience, helping them navigate turbulence or unforeseen events. This resilience is largely achieved through digitisation and the use of intelligent systems. As a result, there are integrated human and IT systems that create digital twins, fostering environmental sustainability and promoting resilient business processes (Singh et al., 2024).

The journey from traditional SCM to GSCM reflects a wider societal shift towards sustainability. This evolution has been fuelled by a combination of technological advancements, regulatory frameworks, and increasing awareness among consumers and businesses regarding the environmental impact of their activities. As SCM continues to evolve, its integration with green practices will likely strengthen, driven by the need to balance profitability with planetary health.

As per Figure 1, GSCM involves a number of processes that require intricate involvement by enterprises. These processes involve green supplier selection, eco-design, green manufacturing, green inventory management, green transportation, and reverse logistics. Gurel et al. (2015) identify cost, delivery, quality, service, strategic alliance, pollution control, green product and environmental management as crucial criteria for green supplier selection.

Figure 1 Aspects in green supply chain management (Puglieri et al., 2021, p. 286)

Eco-design primarily focuses on a holistic approach towards the product life cycle and transformation process considering environmental impact, health and safety considerations. It focuses on transformation activities and how to reduce their impact on the environment. Some key dimensions of ecodesign include raw material design, where there is reduced use of hazardous or complete replacement of hazardous raw materials. Clean production, where the emphasis is on green technology, waste reduction, and environmental friendliness through reduced to no pollution. Green packaging is another dimension where reusable packaging is used through reverse logistics. Transportation and distribution design is primarily concerned with effectively improving product movement routes, reducing distance for moving products and controlling variation in transportation.

Product deployment focuses on extending the usability of products by optimising product attributes like reduced size, weight, maintenance and lower power consumption. Lastly, reverse logistics involves the activities of receiving and managing products after their usability runs out (Thamsatitdej et al., 2017).

Green manufacturing involves adopting fast, reliable and energy-efficient manufacturing processes and equipment to minimise waste and increase productivity. In mechanised processes, this involves reducing emissions, energy usage and input consumption while using eco-friendly energy sources (Afum et al., 2020). Green inventory management is characterised by the traditional economic cost focus with environmental considerations in inventory management and practices (Marklund & Berling, 2016).

Green transportation, which aims to counter high carbon emissions, has been adopted globally. Using alternative energy sources in distribution reduces the amount of carbon emissions and offers enterprises opportunities for reduced production costs where alternative energy sources are available (Saada, 2020). Lastly, reverse Logistics involves the reverse flow of goods to the enterprise. It requires planning, implementing and controlling how remnants of finished products return back to the enterprise and are reused or re-made as fresh inputs for new products or remade for consumption yet again (Agrawal et al., 2015).

Relevant concepts of green supply chain management

Green supply chain management (GSCM) is an integrative approach to designing and managing supply chain activities to minimise environmental impact while promoting economic and social sustainability. This concept reflects a growing recognition of balancing business success with environmental stewardship and social responsibility. Central to GSCM are principles like the triple bottom line, cradle-to-cradle design, and circular economy, each offering frameworks for achieving sustainability within supply chain operations. By aligning organisational practices with these principles, businesses can address critical challenges such as resource scarcity, waste management, and carbon emissions while fostering innovation and long-term profitability. This introduction highlights the interplay of economic, social, and environmental considerations as integral to modern supply chain management and lays the foundation for exploring these concepts in detail.

Triple bottom line and sustainability

Coined by Elkington in 1997, the triple bottom line looks at business success through the lens of three parameters: profit, people, and the planet. Organisations, therefore, set up their business success metrics on these three fronts. The triple bottom line is seen as a practical guide towards sustainability as organisations do not only focus on one of the three aspects but aim to maximise all three (Alhaddi, 2015).

Sustainability, on the other hand, is an overarching framework that encompasses harmony between human activity and its impact on the environment through appropriate policies and best practices and a rallying future vision that appeals to everyone, including

businesses and individual communities (Brundtland, 1987; Arowoshegbe & Emmanuel, 2016).

However, we must add that Corporate Social Responsibility (CSR) and Environmental Social and Governance (ESG) concepts are very close to the triple bottom-line framework. Corporate social responsibility gives businesses, particularly corporations, an extended aim of maximising profit and generating benefits for different stakeholders and related communities. The main dimensions of CSR in businesses are economic considerations, legal considerations, and legal and discretionary responsibilities, which The Organisation of Economic Cooperation and Development considers 'making a positive contribution to economic, environmental and social progress' which in extension are at the core of the triple bottom line perspective (Bansal, 2005: Mendes et al, 2021).

Environmental, social, and governance (ESG) factors, which are seen as businesses' contributions to environmental and societal concerns, stem from the need to promote greater good and benefits to stakeholders while striving towards profitability. ESG factors are seen as crucial for businesses considering their roles in environmental pollution. They are seen as a compliance exercise and a strategic decision essential for long-term success, especially with the need to reduce carbon emissions globally (Suzan et al., 2024).

CSR and ESG are largely interrelated but distinct. CSR, which focuses on activities an enterprise engages in, closely relates to social obligations resulting from its use of natural resources and affects how it interacts with external and internal environments. In contrast, ESG is more quantitative and measures an enterprise's CSR activities and initiatives (Lew et al., 2024).

Automation of large-scale production by manufacturers like Coca-Cola has reduced production, reducing production costs. Integrated real-time monitoring and visual inspection technologies allow the manufacturer to trace defective output. These, among other process improvements, have resulted in increased profits for the beverage manufacturer. Further inclusivity programs have created a harmonious working environment for not just disabled employees and women; inclusivity networks link different communities around the globe in their areas of operation and leverage ideas generated from these networks into business practices. From the planet perspective, Coca-Cola has proactively reduced waste with innovative technologies like paper bottles and planet bottles, among others (Jia & Ma, 2022).

Cradle to Cradle and sustainability

Motivated by scarce resources, engineers strive to reduce the impact of lifecycles and their wastages by utilising the fewest resources while maximising output. Braungart and McDonough introduced the cradle-to-cradle concept in their 2002 book as an ideological shift from 'less bad' to 'more good' by reducing eco-footprint and damage.

The cradle-to-cradle concept relies on three tenets that enterprises need to strive towards: waste equals food, where wastes from one process are treated as inputs for the next process; use of current solar income or sustainable energy sources is applied in

production; and thirdly, diversity is celebrated to reduce reliance on one criterion in production (Toxopeus et al., 2015).

McDonough et al. (2003) stipulate that the C2C approach focuses on what to do and not necessarily how to make the approach. As such, they suggest 12 principles that provide a guiding compass to employ the C2C approach in the business model. This approach is, however, not foolproof as it requires a completely closed-loop recycling system, whereas organisational activities rely on externalities like external energy sources and waste management infrastructure (Bjørn & Strandesen, 2011).

These principles include the use of non-hazardous inputs and outputs, prevention of waste production, minimising energy consumption, efficiency in terms of products, processes and systems, an output pull use of energy and materials, embedded entropy, targeted durability in design goals, utilisation of excess capacity and capabilities, reduction of material diversity for value retention, interconnectivity with available energy sources.

A compostable diaper manufactured by Diapers is a case of Cradle to Cradle in practice. With their eco-friendly diapers, the use of more than 75% cellulose material is more compostable than the industry standard of polypropylene or polyethene plastics, as they break down within 3 months of disposal. They are also considered user-friendly, especially for babies, as alternative diapers impact babies' health, limiting breathability and causing diaper rash. Its manufacturer is also credited for using 100% renewable energy (Lumsden, 2014)

Circular economics

Seen as a comprehensive multidimensional approach, circular economy falls into 6 main theories; economic and environmental theory, theory of resource efficiency, waste hierarchy theory, environmental impact theory, green growth theory and sustainable development theory. What is common about these theories is their emphasis on keeping materials and products in a closed cycle as long as it can take and making recyclable material flow efficiently through the loop. Economic and environmental theories emphasise trading in recycled raw materials and keeping them in a closed loop. Resource efficiency theories place emphasis on recycling infrastructure and technologies; waste hierarchies theory also places hierarchy on waste management strategies by focusing on the best solution for waste prevention and reduction coupled with appropriate management and recycling and reuse strategies; environmental impact theory focuses on impact to the environment and giving priority to reducing the unfavourable impact of economic activity on the environment; green growth strategies state environmentally friendly practices can achieve sustainable growth; lastly, sustainable development combines social, economic and environmental goals through sustainable practices (Lingaitiene & Burinskiene, 2024).

From a circular economic perspective, Paghal et al. (2024) identify several barriers to adopting and implementing green practices like green logistics. For example, a lack of commitment by management translates to poor adoption of green logistics activities. Lower-level management may also fail to cooperate among departments, coupled with a lack of understanding or adequate training in green logistics practices.

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Battery production plays a vital role in the circular economy through Battery Second Use (B2U) systems, which repurpose batteries from Battery Electric Vehicles (BEVs) for stationary energy storage applications, such as grid storage and home energy optimization. This approach significantly lowers the environmental impact, saving approximately 100 kg of CO2 per kWh and delaying energy-intensive recycling processes, in line with the principles of reduce, reuse, and recycle, as well as EU Battery Regulations.

Second-life batteries are also economically advantageous, offering savings of 8-25% compared to new batteries. Successful implementation of B2U systems requires modular designs, thorough safety testing, and innovative business models, including leasing or pay-per-use options, to foster customer trust. In summary, B2U systems represent a sustainable strategy for advancing a circular economy (Meyer et al., 2024).

Summary of relevant models and frameworks

As Figure 2 shows various models and theories relate the term of green supply chain management. The similarities and differences between the triple bottom line, CSR and ESG models have been explained above. These models focus on the management vision and the success factors. The Cradle to Cradle and Circular economics approaches share a complex vision, i.e. they look at the whole supply chain. Of course, both the implementation of modern management and the analysis and development of the supply chain as a whole are necessary; thus, neither model is mutually exclusive, but rather complementary.

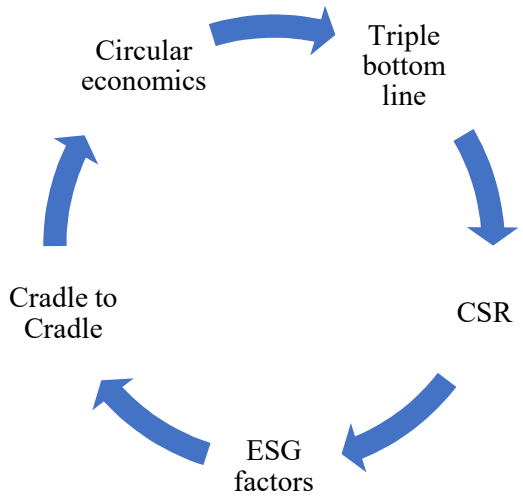

Figure 2 Some models and frameworks concerning green supply chain management

Source: Own editing based on literature

Barriers to implementing green supply chain management solutions

So far, we have seen the multi-faceted nature of the green supply chain. Enterprises may recognise the importance and competitive advantage GSCM offers but may fail to implement it into their processes. It is important to recognise these barriers to develop appropriate implementation strategies. Dhull & Narwal (2016) categorise these barriers and may fall into one of the following categories: internal, external, customers, competition, society, suppliers and uniquely industry-specific barriers (Table 1).

Category	Examples of barriers	Impact
Internal	High investment costs, lack of expertise, organisational inertia, inappropriate business models	High investment costs, lack of expertise, organisational inertia, inappropriate business models
External	Limited infrastructure, regulatory constraints, minimal government support, low public awareness	Impedes the broader ecosystem needed for GSCM success
Customer	Price sensitivity, lack of demand and awareness of green products	Discourages market adoption and demand for green initiatives
Competition	Undercutting on costs, reluctance to adopt long-term sustainability goals	Discourages collaborative approaches to sustainable practices
Supplier	Lack of knowledge, commitment, or resources to implement green initiatives	Disrupts alignment within the supply chain
Industry-specific	Manufacturing: energy costs; Food: sustainable packaging, perishability; Logistics: green infrastructure	Creates unique challenges that require tailored strategies for green practice adoption

Table 1 Barriers to implementation of green supply chain practices (own edit)

Among internal barriers include factors like high investment costs required to implement green practices from design, transformation of inputs, logistical costs etc., organisational deficiency in understanding green practices and associated benefits, inappropriate business models and business structure hindering implementation, a lack of commitment to implementation, inaccessibility of green technology due to associated costs or a reluctance to implement, nature of industry and its complexity among others.

External drivers outside the enterprise's scope range from the high cost of acquiring green inputs to a lack of infrastructure to support green practices, as discussed earlier. Some practices involve the whole value chain and not individual players. There are cases of limited manpower with appropriate expertise, heavy regulation minimal government support, and a general lack of environmental concern, ethical support, and CSR.

Customer drivers include, but are not limited to, pressure to have competitive prices. In cases where green practices are expensive, the high costs translate to high practices, which may be seen as unattractive to price-sensitive markets. A lack of demand

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and awareness about green products and practices may limit the support organisations with green practices get from customers.

Competition barriers may hinder green practice adoption through unnecessary competition where companies undercut each other to dominate or acquire market share. This may not be feasible to maintain, especially where green practices involve a high cost of acquiring green inputs and a high cost of transformation.

Supplier commitment or lack thereof, has a direct impact on the extent of the adoption of green practices. A lack of knowledge or understanding of green practices may also hinder the adoption of green supply chain management.

Some barriers are also industry-specific and may fall in any implementation stage due to either failing to have green design, green inputs due to the nature of operations, or infrastructural limitations in distribution.

To overcome these barriers, as tabulated but not limited to in Table 1, enterprises and policymakers must collaborate to create enabling environments through incentives, awareness campaigns, capacity-building initiatives, and supportive infrastructure. Solutions must be industry-specific, addressing each sector's unique challenges while fostering alignment across the supply chain. Through such targeted approaches, businesses can successfully navigate these barriers and fully realise the potential of green supply chain management.

Green supply chain management in some sectors

Understanding how green supply chain management practices emanate in different industries is important, as each industry offers unique challenges. Distinct challenges in value chains require a level of ingenuity and engineering, which usually results in new ways and business models. Though inconclusive, Let us explore how green supply chain practices in a few industries.

Lumber Industry

The implementation of a green supply chain in the lumber industry emphasizes sustainability by integrating economic, environmental, and social dimensions at every stage, from forests to lumber production and distribution. Sustainable forest management practices focus on optimizing resource use and minimizing environmental impacts through techniques like life cycle assessment, carbon sequestration analysis, and multi-objective programming. These methods aim to balance profitability with ecological objectives, such as reducing greenhouse gas emissions and preserving biodiversity. For example, decision-support systems, such as GIS-based tools and dynamic programming models, are used to optimize harvesting and transportation logistics, leading to lower costs and reduced emissions.

In sawmill operations, green supply chains benefit from innovations in manufacturing systems, material flow analysis, and sustainable procurement models. Techniques like mixed-integer programming and discrete event simulation are employed to improve production efficiency, minimize waste, and enhance resource circularity.

Additionally, social metrics are applied to ensure fair labour practices and community involvement. These approaches represent a shift towards a low-impact, high-value system in the lumber industry, promoting environmental stewardship and economic resilience while addressing societal expectations for sustainability (Jorge et al., 2024).

Steel Industry

The steel and iron manufacturing industry has numerous specific issues to address, from greenhouse gas emissions to various pollutants, as it is a sector that consumes a significant amount of energy and resources. Hunan province in China, which is predominantly dominated by this industry, faces considerable environmental challenges.

Pang et al. (2011) propose two strategies for establishing a green supply chain in the steel and iron industry: forward supply chain and reverse supply chain. The forward supply chain focuses on green purchasing, strengthening cooperation with suppliers. For instance, Xiang Gang factory fully implemented green purchasing by establishing qualified supplier files and conducting annual assessments of suppliers to evaluate quality, pricing, delivery times, and, importantly, environmental protection considerations.

In terms of green production, Xiang Gang has optimised its processes by implementing ERP information technologies, enhancing production efficiency. Hunan Valin Xiangtan Iron and Steel Ltd has adopted green production methods using Six Sigma management and optimised Total Productive Maintenance (TPM).

Green marketing is directed at downstream industries and customers through marketing networks that incorporate centralised distribution, resource consumption control, and route optimisation. Additionally, green product marketing involves collaboration between the manufacturer, Xiang Gang, and its customers to develop new products that meet emerging needs.

Finally, the reverse supply chain has been implemented to create a closed-loop system in the steel industry by recycling waste products. Xiang Gang constructed a recycling centre and waste gas disposal facility to address environmental issues effectively.

Electronics manufacturers

In their definition of green procurement, Ninlawan et al. (2010) describe it as purchase activities that aim at reducing, reusing, and recycling inputs. They found that supplier selection has strict adherence to environmental quality and standards requiring suppliers to meet certain thresholds and certifications, creating “green partnerships” or “green partners.”

The Thai electrical manufacturing green supply chain is defined as the use of inputs with a low environmental impact during the production process and tends towards little to no waste or pollution. With this, manufacturers replace the use of chemicals with water to allow re-use while cleaning parts. There are also energy efficiency measures in place ensuring the use of fewer resources to produce output, the use of bio-based plastic components and hence an elevated level of fire resistance.

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Green distribution, which involves efficient packaging and logistics, has seen manufacturers optimise space in warehousing and shipping through packaging characteristics like the use of unique sizes and correcting typing mistakes! shapes, and materials. This has resulted in better arrangement of load patterns, reduced packaging material usage, and use of space. Therefore, transporting has been optimised by carrying more finished output and using alternative energy sources, and an increase in returnable packaging methods has been adopted just as much.

Automobile manufacturers

Initially, the industry was mostly focused on the domestic market, but there have been instances of partnerships with external players and car brands. This has resulted in both the assembly of global household car brands in China and the export of Chinese car brands to other markets. Such expansion has economic and environmental influences on the Chinese automotive supply chain.

The rapid growth in automotive manufacture has had an impact affecting not just environmental sustainability but also resource shortages. Air pollution is a grim reality in big cities with automotive manufacturing being one of the major culprits. Such environmental burdens influence how players in the industry do business; hence, there have been attempts at having more environmentally friendly supply chains and products through eco-design practices by learning with and learning through supply chain partners.

Construction Industry

Green construction has been embraced by construction firms as a means of environmental consciousness, and it entails ensuring quality, safety, and other scientific management practices in engineering construction to maximize resource conservation and reduce unnecessary activities that result in wastage.

The dimensions involved in GSCM and construction practices include green initiation and green design, where firms come up with eco-friendly designs that are in harmony with the environment; green material management, which involves such processes as raw material planning, storage, handling, green material selection and sourcing and compliance to government regulations and legislations on environmentally friendly construction practices; green construction and green operation and maintenance which focus on transportation, onsite management and environmental safety and green building practices; reverse logistics which pushes for recycling and reuse of residual resources on other related projects (Wibowo & Handayani, 2018).

These industry examples highlight both the diversity of GSC implementation and common themes, such as waste reduction and eco-friendly sourcing, underscoring the adaptability of GSC principles across sectors.

Food Sector

Though ambiguous on its parameters, sustainable agriculture has gained considerable traction as an environmentally conscious approach to food production. It may

be seen as an approach allowing the production of high-quality produce while protecting resources; this heavily relies on the use and re-use of the farms' own resources instead of purchasing fertilisers or other purchased materials (Reganold et al., 1990; Velten et al., 2015).

With ICT solutions comes the need for intensive capital employment as these technologies do not become cheap. This may be too expensive for small unit farms. These technologies require technical know-how or the employment of experts, which is just as expensive. This may limit the benefits of smart and precision farming to small-time players. Precision agriculture, a form of sustainable farming, is increasingly used to minimise environmental impact through targeted input applications, enhancing productivity and resource use efficiency.

The competitive nature of the food industry, coupled with the need for competitive advantage, is pushing businesses to employ novel strategies like green procurement to remain not just afloat but competitive. Adopting green procurement differentiates businesses with this strategy from those with normal procurement practices without environmental considerations (Beleya et al, 2019).

Other than regulatory requirements, Hauschildt & Schulze-Ehlers (2014) study shows that green procurement is not only driven by moral and legal considerations but also a source of competitive advantage. Dynamic capabilities refer to a firm’s ability to use both external and internal competencies to address emerging environmental changes. Thus, firms may choose green supply chain practices to gain a competitive advantage or first-mover advantage, hoping their customers will take note of their green practices.

Challenges to Implementation of Green Supply Chain Management across various Industries

In the lumber industry, the high initial investment required for technologies like life cycle assessments and decision-support systems poses a significant financial obstacle to adopting sustainable forest management practices. The complexity of multi-objective programming, which requires balancing economic profitability with ecological goals, can lead to indecision and slow adoption rates. Additionally, there may be resistance to change due to entrenched traditional practices and scepticism about the economic viability of green methods (Jorge et al., 2024).

In the steel industry, the primary challenges arise from the sector's high energy consumption and pollution levels. Transitioning to greener practices necessitates substantial technological upgrades and investments, which can be both costly and disruptive. Green purchasing also presents difficulties, as ensuring supplier compliance with environmental standards across a vast network can be logistically complex and expensive. Integrating Enterprise Resource Planning (ERP) systems for green production adds further complexity, requiring workforce retraining and potentially causing operational disruptions during implementation (Pang et al., 2011).

For electronics manufacturers, establishing "green partnerships" hinges on supplier certification and compliance with environmental standards, which can be a significant barrier due to the associated costs and time required for audits. Replacing traditional

materials with eco-friendly alternatives, such as bio-based plastics, may affect product performance or increase costs. Moreover, optimizing green distribution involves revamping packaging and logistics, which may encounter resistance due to existing systems and networks (Ninlawan et al., 2010).

The automobile industry faces barriers related to the complexity of managing a global supply chain while aligning it with green practices. Rapid industrial growth exacerbates resource scarcity and environmental impacts, particularly regarding air pollution, making the shift to sustainable practices more challenging. Implementing eco-design necessitates extensive collaboration with supply chain partners, which can be complicated by competitive or proprietary concerns (Zhu & Sarkis, 2007).

In the construction industry, complying with diverse and changing environmental regulations presents significant hurdles, potentially leading to project delays and increased costs. Green material management requires more expensive and less accessible eco-friendly materials, affecting budgets and timelines. Additionally, effective reverse logistics for recycling construction materials faces challenges due to a lack of infrastructure and economic viability (Wibowo & Handayani, 2018).

In the food sector, the adoption of Information and Communication Technology (ICT) solutions for sustainable agriculture is often hindered by high costs, making it less feasible for small to medium-sized farms. There is also a shortage of technical skills required for precision agriculture, which limits its implementation. Although there is a push for green procurement to gain a competitive advantage, market readiness to pay a premium for sustainably produced goods remains uncertain, impacting the return on investment for green practices (Reganold et al., 1990; Velten et al., 2015; Beleya et al., 2019).

These barriers underscore the need for industry-specific strategies, financial incentives, and educational programs to facilitate the transition to GSCM across these diverse sectors.

Conclusions

The discussed industrial practices exhibit several commonalities in their approaches to green supply chain management (GSCM). A key focus across sectors is waste reduction, which is achieved through practices such as eco-design, green manufacturing, and recycling. Another important aspect is supply chain optimization, where industries utilize green logistics, route optimization, and efficient inventory management to minimize their carbon footprints. Sustainable sourcing is also a shared priority, with green procurement practices emphasizing environmentally friendly materials and careful supplier selection. Furthermore, there is a strong emphasis on lifecycle management across industries. Techniques like reverse logistics and cradle-to-cradle approaches ensure that materials remain within the supply chain loop, thereby minimizing waste and reducing environmental impact.

Despite their similarities, different industries encounter unique challenges that influence their green supply chain management (GSCM) practices. Operational challenges

can vary significantly; for example, manufacturing sectors like steel and automotive deal with issues related to high energy consumption and pollution, while the food industry faces the challenges of perishability and resource-intensive farming. The level of technological integration also differs amongst industries. Advanced sectors like electronics often embrace cutting-edge green manufacturing technologies, whereas industries such as construction and agriculture tend to rely on simpler, resource-efficient practices. Regulatory impacts further distinguish these industries. For instance, steel and automotive sectors adapt their green practices to comply with stringent environmental laws, while the food industry is more swayed by consumer-driven demands for sustainability. Finally, the nature of the outputs produced contributes to variations in GSCM practices. Industries that produce raw materials, such as steel and lumber, emphasize efficient processes to minimize waste. In contrast, sectors like food and electronics prioritize innovations in packaging and distribution.

In conclusion, although industries share foundational GSCM principles, their unique challenges and outputs emphasize the necessity for innovative, collaborative, and sector-specific strategies to achieve sustainability.

Limitations of the study include its scope, which focusses on specific industries in specific geographic areas. While these provide insight into green supply chain management, many areas of application of GSCM with shared and unique challenges and opportunities need examining. The study has limited quantitative analysis, as it relies on existing literature. To ascertain generalisability, empirical analysis and statistical validation are required to prove and disprove the findings across industries and geographical locations.

These limitations offer an opportunity for future research focus and cross-industry studies. Just as important are geographical and cultural cross-examinations. Behavioural and consumer behavioural studies are also needed to gain insights into consumer behaviour and GSCM in different geographical locations across industries.

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