The Role of Artificial Intelligence in Green Supply Chain Management

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Abstract: As environmental concerns continue to grow, industries are compelled to implement sustainable supply chain processes. Green supply chain management (GSCM) has become a key strategy for reducing the negative effects of supply chains on the environment. It includes anything from energy-efficient logistics to environmentally friendly product design. Simultaneously, artificial intelligence (AI) is transforming supply chain management through improved decision-making, optimization, and efficiency capabilities. Businesses have a great chance to achieve sustainability objectives while preserving operational performance at the nexus of AI and GSCM. This study aims to investigate how AI applications are currently used in green supply chain management, identify possible advantages and difficulties, and offer predictions about recent advances in the field. The results show that supply chain sustainability can be significantly increased by using AI applications. More precise demand forecasting and improved waste management techniques that reduce resource use are two major advantages. AI such as machine learning and predictive analytics, enable businesses to automate labour-intensive procedures and make smart judgements instantly while monitoring environmental performance. In conclusion, AI has a lot of potential to promote environmentally friendly supply chain management approaches that also improve operational effectiveness.

Keywords: Supply chain, Sustainability, Artificial Intelligence, Eco-friendly Impact

I. Introduction

In recent times, organizations have been compelled to reconsider their supply chain operations due to the growing worldwide awareness of environmental sustainability and the need to reduce the damaging effects of industrial activity on the environment. To achieve sustainable development, green supply chain management (GSCM) incorporates eco-friendly methods into the conventional supply chain (Nozari et al., 2021).

Specifically, green supply chain management aims to reduce adverse environmental effects while increasing economic efficiency by integrating environmental considerations into all facets of the supply chain; ranging from product design to procurement, production, and distribution (Mugoni et al., 2024; Nazir et al., 2024). However, green supply chain management expands these goals to include environmental performance by promoting the use of eco-friendly products, energy-efficient procedures, and sustainable waste management techniques (Komal & Khandare 2024). Therefore, growing customer demand for sustainable products, regulatory pressures, and the realization that sustainable practices can also result in cost savings and enhanced brand reputation are the main forces behind this paradigm change.

In general, substantial number of firms now understand how crucial this integration is to developing a long-term business plan. Furthermore, a sustainable supply chain focuses, on cost containment and efficiency improvements in addition to environmental concerns. Supply chains are now the main area of concern for organizations as they strive to manage and reduce their negative environmental impact (Shekarian et al., 2022).

Transformative technologies are emerging daily in the modern world. Therefore, the manner in which business operations are conducted is greatly impacted by these technologies. Accordingly, Vaseei et al., (2024) stated that companies that do not employ digital and smart technology will not be able to get a competitive edge. Thus, supply chains and other corporate operations can be made fully sustainable with the help of these technologies. In supply chain management, artificial intelligence (AI) has become an important tool with capabilities that go beyond those of conventional analytical techniques (Hryhorak M. et al., 2023). Large-scale statistics can be analyzed by AI technologies to find trends, forecast demand, maximize inventory, and improve the robustness of the supply chain as a whole (Albayrak et al., 2023; (Seyedan & Mafakheri, 2020). Businesses may utilize AI in automate repetitive operations, lower operating expenses, and increase the accuracy of their decision-making (Huang & Rust, 2018). Applications of AI in supply chain management include predictive maintenance, route planning, demand forecasting, and inventory optimization (Dash et al., 2019). These applications not only increase productivity but also make supply chain operations more responsive and flexible, which is essential in the present industrial operations.

An important step forward in the effort to ensure sustainability is the incorporation of AI into green supply chain management. AI can support green supply chain management by offering predictive analytics for supply and demand, optimizing resource allocation, reducing waste, and minimizing energy consumption (Liu et al., 2024). For example, machine learning algorithms can

predict demand more accurately, enabling businesses to modify production schedules and inventory levels to prevent excess stock and waste (Feizabadi, 2020; Odimarha et al., 2024). Considering that supply chain activities can enable more influence and capabilities by utilizing AI technologies, this study aims to explore the role of AI in developing green supply chain management. This is by analyzing the several ways that AI technologies can be deployed to improve sustainability within supply chains. This review will examine how AI applications are currently used in green supply chain management, identify possible advantages and difficulties, and offer predictions about recent advances in the field.

An Overview of Green Supply Chain Management

In order to maintain competitive advantage, create a greener supply chain, and maintain business profit and market share goals, it is crucial to incorporate environmental management techniques throughout the entire supply chain management process (Yang et al., 2023). As a result, Zhu et al., (2008) defined GSCM as "closing the loop," which includes integrated supply chains that start with suppliers and end with customers as well as reverse logistics. Integrating environmental thinking into supply chain management, including product design, material sourcing and selection, manufacturing process, delivery of the final product to consumers as well as end-of-life management of the product after its useful life (Chin et al., 2015).

The emergence of corporate environmental management, environmentally conscious industrial strategy, and supply chain management literature coincided with the quality revolution of the 1980s and the supply chain revolution of the 1990s, which collectively expanded the knowledge on green supply chains (Zhu & Sarkis, 2006). It is now evident that integrating environmental management with continuing operations is required by best practices (Jum'a et al., 2021). Researchers and practitioners in operations and supply chain management are becoming increasingly interested in green supply chain management (GSCM). Previous research has also demonstrated that most scholars have examined the acceptance and application of GSCM in industrialized nations including Japan, Germany, Portugal, the UK, Taiwan, and so on (Abu Seman, 2012; (Mitra & Datta, 2013). However, studies on GSCM procedures in developing nations are still limited.

II. The Green Approach to Supply Chain Management

The supervision of resources, data, and finances as they progress from supplier to manufacturer to wholesaler to retailer to customer is known as supply chain management (LeMay et al., 2017). GSCM incorporates conventional supply chain management techniques into organizational purchasing decisions and long-term supplier relationships by incorporating environmental criteria or concerns. Every phase of a supply chain's product and service development must consider the environment, according to green supply chain management (Feng et al., 2024).

Based on previous reports by Srivastava (2007), GSCM is characterized by the incorporation of environmental concerns into various aspects of supply chain management, such as product design, manufacturing process, sourcing and selection of materials, consumer delivery, and end-of-life management of the product after its intended lifespan. In this regard, important attributes of innovative sustainable supply chains encompass a focus on life cycle assessment, asset effectiveness, waste minimization, service innovation, and recycling (Shekarian et al., 2022). When properly implemented, GSCM fosters innovation in both products and services, enhances asset utilization, and strengthens customer connections and service standards by focusing on waste and cost reduction.

Table 1. Drivers of Green Supply Chain Management

Drivers	Synopsis	References
Regulatory Compliance	Strict environmental restrictions, including waste management statutes, emission limits, and requirements for sustainability reporting, have been enacted by governments across the globe. To avoid fines and legal issues, businesses must abide by these requirements.	(Zhao & Gómez Fariñas, 2022)
Cost Reduction	Long-term cost savings can result from the adoption of green supply chain techniques. Businesses may reduce operational expenses by decreasing waste, increasing energy efficiency, and optimizing resource utilization. For example, fuel usage can be decreased through effective logistics and transportation systems, which will also minimize costs and emissions.	(Kumar et al., 2021; Liu et al., 2024)
Market and Customer Demand	Consumers are choosing a growing number of goods and services that are consistent with their environmental beliefs. Businesses are encouraged to implement green practices in order to preserve market share and improve brand reputation as consumer preferences shift towards sustainability.	(Aslam et al., 2018; Wang & Pan 2022)
Competitive Advantage	Businesses can set themselves apart from rivals by incorporating sustainability into their supply chain processes. Companies can get a competitive advantage in the market and draw in environmentally sensitive consumers by projecting an image of being environmentally friendly.	(Saini et al., 2023)

Corporate social responsibility (CSR)	Sustainability is considered a component of CSR by many organizations. By implementing GSCM practices, they may show stakeholders that they are committed to the environment, enhancing their reputation and fostering stakeholder confidence.	(Le, 2023)

Integration of AI and GSCM: Theoretical Aspects

Although significant changes are expected due to AI, Strohm et al., (2020) stated that implementing AI is highly complicated. However, Sharma et al., (2021) revealed that it is widely acknowledged that integrating AI in the manufacturing sector can be complicated owing to problems with data availability, data quality, cybersecurity, and worker resistance to change. The study by Sharma et al., (2021) also highlighted that workers may resist changes in their daily routines or the introduction of new technology, for example, AI and automation may be perceived as a danger to job security. Therefore, adopting AI is still crucial for this industry to be competitive in the global market despite these obstacles.

Furthermore, AI's adoption becomes essential given the substantial investment and attention it is receiving (Strohm et al., 2020). As previously noted, several AI applications have not been well received by the general public. It is debatable whether this is due to poor technological performance, organizational shortcomings, or societal factors (Frank et al., 2019). According to Boucher (2020), underutilization may be caused by a fragmented digital market since machine learning (ML) in AI depends on data, poor infrastructure, a lack of initiative, low investment, or fear of AI among the public and business community. Consequently, the reasons behind both successful and unsuccessful implementation remain obscured. Furthermore, Boucher (2020) argued that the underutilization of AI is considered a concern since it might lead to several negative outcomes, including economic stagnation, loss of comparative advantage over other regions, diminished opportunities for citizens, and failure to implement important projects. In this regard, to protect the substantial investment that a significant portion of society has made, one must ensure the catalysts behind a successful execution.

Thun et al., (2021), claimed that this demonstrates how challenging it can be to apply AI in the manufacturing sector. Nonetheless, digitalization is essential to achieve market and industry norms. It is difficult to build trust in a system, so businesses need to ensure it works with the ones they already have, resolve problems with network speed and reliability, and take care of data security issues. Similarly, Reim et al., (2020) stated that companies may also encounter difficulties with system trust, openness, analogue processes, and public misconceptions about AI. To further explain the specifics, the study revealed that if users don't understand how an AI program operates, they are less inclined to trust it. In addition to the technology itself, the corporation that created it and its information-gathering capabilities can also have an impact on trust. Furthermore, elucidating the mechanisms and decision-making procedures of AI systems is necessary to ensure their transparency. But since AI is a technology, it might be difficult to comprehend how it makes decisions. A significant obstacle is establishing openness in intelligent systems.

However, when addressing transparency in the context of AI, the idea of explainability is frequently brought up in the literature. Interpretability and system credibility are both included in explainability. Recent research by Larsson & Heintz (2020), on individuals' trust in applied AI, for example, makes the assumption that transparency needs to be evaluated taking into account how the typical person understands explanations and assesses their relationship with a service, product, or business. Analogue procedures are suggested as another difficulty. Manual or physical approaches to gathering and organizing data that are not digital are referred to as analogue procedures. For instance, tracking information with spreadsheets or by filling out paper forms. Digital procedures that facilitate the efficient gathering and storing of data must be in place for AI to be implemented successfully (Reim et al., 2020).

Despite the paucity of research on AI use in supply chain management (SCM), established ideas may still be applicable in SCM and the manufacturing sector. In order for an AI implementation in a business to be as successful as possible, Reim et al. (2020) developed a roadmap with four important insights. The roadmap is linked to the previously noted concerns, including problems with transparency, employee mistrust of AI, the usage of analogue procedures, and misconceptions about AI. The following can be used to summarize the key conclusions: developing an awareness of AI and the organizational skills necessary for digital transformation; appreciating the present business model, the possibility of business model innovation, and the function of the business ecosystem, gaining organizational acceptance and developing internal competencies; and obtaining and enhancing the capabilities required for AI application (Reim et al., 2020).

The roadmap for digital transformation involves understanding AI and organizational capabilities, creating a conceptual framework, understanding the current business model, and acquiring and improving necessary capabilities (Reim et al., 2020). Successful implementation depends on data acquisition and infrastructure, understanding how the business creates, captures, and delivers value to customers, and how technology can be used to exceed expectations. Acquiring and improving capabilities requires understanding the current business model, internal and external capabilities, and customer needs. Firms can be the first developers or followers in these transformations, and benchmarking activities can inspire the development of technical and strategic solutions. Achieving organizational acceptance and building internal competencies is crucial, and collaboration with partners is essential. Feedback and evaluation are also crucial for successful AI implementation. Unstructured planning and monitoring can restrain implementation and lead to risk, exceeding budget, and postponing schedules. By planning and

monitoring the implementation process more thoroughly, companies can assess success and save time and costs (Strohm et al., 2020; Sun & Medaglia, 2019).

Applications of AI in Green Supply Chain Management

Wireless sensor networks, and other tools and intelligent equipment are used by the AI mechanism technology. In order to overcome the difficulties of automated detection devices, it makes use of web-based software platforms that depend on cloud computing, which generates a lot of data (Dirican, 2015). In cloud computing and the Internet of Things, artificial intelligence technology builds a virtual infrastructure. Customer delivery, analytics tools, visualization platforms, and monitoring and storing procedures are made possible by this integration capabilities (Nahr et al., 2021). Consequently, IoT is one of the important AI strategies utilized in the field of sustainability in GSCM by fostering increased interpersonal communication to raise awareness and foster interaction, which leads to the creation of successful communication.

Cloud computing made a substantial contribution to GSCM by assisting decision-makers in lowering uncertainty in the three most crucial supply chain management areas: supply, demand, and process (Khasawneh, 2019). Through the use of the Internet, this technology offers a service that is represented by software, a platform, and infrastructure. By providing on-demand information about product flow or information flow from the management of suppliers to the management of customers in both forward and reverse flows, this service helps managers monitor the flow of products and information in both forward and reverse flows. This technique uses software known as "Software As A Service" (SAAS) to manage uncertainty (Nozari et al., 2019). As a result, supply chain management tasks including forecasting, planning, warehouse management system, logistics system, and procurement are greatly aided by cloud computing connected with SAAS (Min, 2010).

Big Data Analysis (BDA) is essential for improving decision-making in green supply chains (GSCs). Research has shown that BDA increases the availability of important information while also improving visibility and integration in GSCs (Benzidia et al., 2021). Furthermore, as a hybrid technology, BDA-AI supports SCM companies by handling the data required to make decisions about the green supply chain both internally and externally, thereby enhancing environmental performance (Dauvergne, 2020). In light of this, Sun et al., (2019) reported that AI-BDA has been used to integrate environmental strategies in both internal and external supply chains, which has reduced waste and air pollution. However, Benzidia et al., (2021), suggested that BDA-AI enhanced internal GSC operations and supplier cooperation, and may lower environmental risk by cutting down on waste and carbon emissions.

The right supplier selection in SCM has a significant impact on Supply Chain performance. The study by Liu (2021) stated that this hybrid technology is a computational tool that have been applied in GSCM to solve variety of problems in pattern recognition, prediction, and optimization. Data Environment Analysis–Artificial Neural Network (DEA-ANN) is a combined technology used for supplier selection and green supplier selection. Therefore, environmental performance of the suppliers is predicted and calculated in large part by this technique. A method used in green manufacturing to offer green products through both online and offline channels is called a dual-channel green supply chain (DGSC) (Benzidia et al., 2021). In the context of dual supply chains, DGSC technology offered a thorough decision support system to help determine critical decisions such as pricing, differentiation price, and inventory in the face of risk. Kumar et al., (2021) and Liu (2021) summarily suggested that adopting DGCS is a preferable choice for businesses looking to cut costs, acquire new clients, and safeguard the environment.

Table 2. Benefits of AI in Green Supply Chain

Advantages	Description	References
Enhanced effectiveness of warehouse	AI can help warehouses become more efficient by assisting with layout design and racking organization. Models of machine learning can provide floor plans that optimize the amount of material moved through warehouse lanes and reduce the time it takes to access inventory, from reception to racks to packing and shipping locations. AI may design the best pathways for employees and robots to move inventory more quickly, which will increase fulfilment rates even more. AI-enabled forecasting tools assist producers in balancing inventory against carrying costs, further optimizing warehouse capacity, by analyzing demand signals from marketing, production line, and point-of-sale systems.	(Oluwademilade et al., 2024)
Decreased operating cost	Repetitive operations, including counting, tracking, and documenting inventory, can be accomplished with more accuracy and less labour because of AI's capacity to understand complicated behaviours and operate in unpredictable environments. AI has the potential to save operational costs in complicated supply chains by spotting inefficiencies and learning from recurring actions. AI can also save costs for distribution managers and manufacturers by minimizing equipment downtime, detecting malfunctions and breakdowns in their early stages or	(Rege, 2023; Albayrak et al., 2023)

	anticipating them before they occur.	
Reduce errors and waste	AI can identify abnormal behaviour in both humans and robots far sooner than people can. For this reason, producers, warehouse managers, and shipping firms are teaching algorithms to identify inefficiencies in their processes, mistakes made by employees, and shortcomings in their products. Time and material waste can be prevented as the system can identify errors made by employees and machines before items are reassembled or shipped to the incorrect location.	(Sodiya et al., 2024; Allahham et al., 2023)
Enhanced sustainability of the supply chain	AI has the potential to improve supply networks' sustainability and reduce their negative environmental effects by increasing operational efficiencies. By optimizing truckloads and delivery routes to ensure that trucks burn less gasoline while delivering supplies, ML-trained models can assist organizations in reducing energy use. AI is also utilized to provide insights that support a circular economy one in which resources are recycled and reused by analyzing the lifecycles of completed goods. AI-enabled supply chain planning and sourcing tools can also assist suppliers become more transparent and allow them to follow social and environmental sustainability guidelines.	(Kumar et al., 2021)

AI in Green Supply Chain Management (GSCM) presents a game-changing chance for companies looking to improve their sustainability initiatives without sacrificing profitability and operational effectiveness. AI makes it possible to solve environmental difficulties with higher precision, speed, and adaptability by automating and streamlining activities that have historically been done manually. By offering real-time data on energy use, emissions, and environmental performance, AI can help improve sustainability monitoring and compliance. This aids organizations in monitoring their advancement towards sustainability objectives, pinpointing areas in need of development, and guaranteeing regulatory compliance. Therefore, to balance environmental and economic goals throughout modern supply chains, decision-makers must be able to swiftly and accurately interpret enormous amounts of data.

III. Conclusion

Despite the potential advantages, integrating AI into GSCM comes with difficulties. These include expensive upfront expenses, concerns about data security, a dearth of technical know-how, and the challenge of incorporating AI technology into supply chain infrastructures that are already in place. In addition, the environmental effects of AI systems must be taken into account, especially with regard to the energy required for data processing and storage. Businesses must adopt a balanced approach when implementing AI to ensure that the wider environmental objectives are not outweighed by the technology advantages.

The study has also revealed gaps in the literature and practice of the present day, especially with regard to the scalability of AI-driven solutions and the long-term effects of AI on sustainable supply chains. To address these gaps and improve sustainability even further, future research should concentrate on figuring out how AI might work well with other cutting-edge technologies like blockchain, the Internet of Things (IoT), and renewable energy sources. Furthermore, longitudinal research is required to assess the long-term effects of AI on supply chain efficiency and environmental performance.

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