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Green Supply Chain Management in the Automotive Industry: A Path to Sustainability

Muhammad Qasim Arslan*, Tariq Bilal**
* Business and Creative Industries, University of West of the Scotland
Email: qasimsahab99@gmail.com
** Department: Business and creative industries, University of west of the scotland
Email: Tariq.bilalswl@hotmail.com

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Abstract:

The automotive industry is more and more adopting Green Supply Chain Management (GSCM) practices to mitigate environmental impact, enhance operational efficiency, and beautify financial performance. This research explores the important thing drivers, challenges, and the role of industry 4.0 technologies within the adoption of GSCM. Findings suggest that regulatory pressures, cost performance, and purchaser demand are the primary drivers, while high implementation prices, supply chain complexity, and resistance to trade stay vast boundaries. This study highlights how industry 4.0 technologies, which include Artificial Intelligence (AI), the Internet of Things (IoT), and blockchain, facilitate supply chain optimization, carbon footprint reduction, and stronger transparency. Furthermore, the studies assesses the effect of GSCM on environmental, operational, and financial overall performance, demonstrating that industry implementing sustainable practices revel in long-term profitability and aggressive benefits. The research contributes to present literature by integrating the Resource-Based View (RBV) and Institutional Theory, emphasizing the need for strategic funding and collaboration to gain sustainability goals. Despite its contributions, the study recognizes obstacles associated with facts collection and industry scope, recommending future studies on nearby versions, SME adoption, and lengthy-term financial consequences. Ultimately, the study reinforces the need for automotive corporations to include GSCM as a strategic vital for sustainability and market competitiveness.

Keywords **— Green Supply Chain Management (GSCM), Industry 4.0, Sustainability Performance, Automotive Industry, Supply Chain Optimization.**

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I. INTRODUCTION

The global automotive industry is a major contributor to environmental degradation, with its extensive supply chain activities contributing to environmental degradation [1]. Green Supply Chain Management (GSCM) is a strategy that businesses are slowly embracing to mitigate environmental effects [2]. This involves greening everything in the supply chain, from design to manufacturing processes and end product management. The automobile industry faces pressure from governments, customers, and other stakeholders to adopt sustainable practices, such as reducing waste and energy use. However, challenges such as higher costs, lack of expertise, and resistance to change can hinder successful implementation of GSCM.

The advancements in industry 4.0 technology like IoT and big data analytics can also boost GSCM by making supply lines clearer and improving business operations [3-4]. Studies show that GSCM helps with finances by making costs lower, productivity higher, and customers more loyal to the brand. Understanding key factors that help or hinder GSCM implementation in the automotive industry is crucial for maintaining sustainability and economies [5-6].

This study aims to investigate the impact of Green Supply Chain Management (GSCM) practices on sustainability performance in the automotive industry, focusing on environmental, operational, and financial outcomes. Key drivers influencing the adoption of GSCM practices include high costs, lack of technical expertise, and pushback from important players. The study also explores the mediating role

of operational and environmental performance in the relationship between GSCM practices and financial performance and provides strategic recommendations for overcoming barriers to GSCM adoption and improving sustainability in the automotive supply chain.

The study holds both theoretical and practical significance, contributing to the growing body of knowledge on GSCM and offering actionable insights for industry stakeholders. It provides useful tips for handling GSCM practices effectively and bridging the gap on struggles and using industry 4.0 technology smartly for sustainable supply chain management.

II. LITERATURE REVIEW

Green Supply Chain Management (GSCM) is a field that integrates environmental aspects into supply chain strategies, ensuring that sustainability targets are met while maintaining economic productivity [7]. It has gained popularity in industries such as the automotive, pharmaceutical, and construction sectors. GSCM focuses on integrating environmental issues into supply chain processes, including raw material sourcing, manufacturing, distribution, and end-of-life vehicle management [8]. In the automotive industry, GSCM is driven by regulatory pressures and customer demand for environmentally friendly vehicles and production techniques. Closed-loop supply chains, recycling and reuse of materials and additives in manufacturing, and the integration of digital transformation and industry 4.0 technology have significantly improved green supply chain operations [9]. Advanced information analytics and renewable energy resources are also being adopted to reduce the company's carbon footprint.

However, implementing GSCM in the automotive industry faces challenges such as high costs, lack of coordination among stakeholders, and limited regulatory enforcement. Collaboration among supply chain partners is crucial for enhancing GSCM effectiveness [10]. Companies that efficiently implement GSCM strategies stand to gain long-term benefits in terms of cost savings, regulatory compliance, and improved brand recognition. Key drivers and challenges of GSCM adoption include regulatory pressures, market competitiveness, cost performance, and environmental consciousness. Global companies and governments have placed significant emphasis on sustainability, leading to the adoption of GSCM practices in various industries [11]. Regulatory frameworks play a crucial role in shaping sustainable supply chain techniques, as companies must comply with environmental requirements, emissions management, waste management, and sustainable sourcing. Policies like the European Union's Circular Economy Action Plan and the Paris Agreement encourage companies to incorporate sustainable initiatives into their operations.

Green Supply Chain Management (GSCM) is driven by cost efficiency, waste reduction, and electricity efficiency [12]. However, implementing green projects can be challenging due to high initial costs, supply chain complexity, stakeholder resistance, and technological limitations. SMEs often struggle with the economic burden of transitioning to green practices, while global supply chains are complex and inconsistencies in environmental guidelines complicate the process.

Technological and understanding limitations also play a role in limiting the adoption of GSCM. The combination of virtual solutions, IoT-enabled tracking systems, AI-driven analytics, and secure digital transactions for supply chain transparency requires specialized information and infrastructure funding [13]. Companies must continuously update their strategies to match rising sustainability trends, which requires ongoing research and improvement efforts. Industry 4.0 has significantly transformed conventional supply chain management through the integration of advanced virtual technologies, such as the Internet of Things (IoT), artificial intelligence (AI), large data analytics, blockchain, and cyber-body systems. These technologies contribute to

improved environmental performance and resource efficiency in supply chain operations, leading to decreased waste, carbon footprints, and more sustainable practices [14].

IoT-enabled smart sensors and real-time tracking structures provide visibility into supply chains, enabling predictive maintenance and inventory optimization. Big data analytics enable actionable insights that help companies reduce raw material usage, optimize transportation routes, and anticipate fluctuations, leading to increased aid efficiency and reduced emissions [15-16]. Blockchain technology enhances transparency and duty in green supply chains by providing a decentralized and tamper-evidence digital ledger that tracks each transaction within the supply chain. This improved transparency fosters trust among stakeholders and allows companies to implement more sustainable procurement techniques.

Industry 4.0 technology plays a transformative role in enhancing Green Supply Chain Management (GSCM) by enhancing efficiency, transparency, and sustainability across supply chain operations [17-18]. It includes the Internet of Things (IoT), artificial intelligence (AI), large data analytics, secure digital transactions, and cyber-body systems, all of which contribute to improved environmental performance and useful tool efficiency in supply chain operations. One of the most impactful contributions of industry 4.0 to GSCM is the use of IoT-enabled smart sensors and real-time tracking structures [19-20]. These technologies provide agencies with more visibility into their supply chains through continuously tracking electricity consumption, emissions, and aid usage at various stages of manufacturing and distribution. IoT applications also beautify inventory management by optimizing stock levels and decreasing overproduction, contributing to waste reduction and reducing environmental impact.

Green Supply Chain Management (GSCM) is driven by various theoretical perspectives, including the Resource-Based View (RBV) Theory, Institutional Theory, and the Triple Bottom Line (TBL) Model. RBV theory suggests that companies with valuable, unique, inimitable, and non-substitutable (VRIN) assets can gain a competitive advantage through green practices [20-21]. However, it also highlights challenges for small and medium-sized businesses (SMEs) who may lack the necessary resources to implement green practices.

Institutional theory explains how businesses adopt sustainable practices in response to regulatory requirements, societal expectations, and industry norms [22]. It identifies three key forces: coercive, mimetic, and normative pressures. Coercive pressures come from regulatory bodies, such as the EU's carbon emissions guidelines, which force companies to adhere to strict emissions targets and waste reduction guidelines. Mimetic pressures arise from companies imitating industry leaders' practices to remain competitive and enhance their reputation.

Normative pressures stem from professional businesses, industry institutions, and customer advocacy organizations that promote sustainable business practices [23-25]. Companies that align their practices with globally recognized sustainability frameworks, such as ISO 14001, gain credibility and enhance their corporate social responsibility (CSR) reputation. Partnerships with NGOs and green certification bodies also encourage environmentally responsible practices [26]. The Triple Bottom Line (TBL) model, introduced by Elkington (1997), provides a comprehensive framework for comparing sustainability performance based on environmental, financial, and social dimensions [27]. It emphasizes the interconnectedness of corporate responsibility, resource efficiency, and social well-being. In GSCM, the environmental dimension focuses on reducing carbon emissions, optimizing electricity use, and minimizing business waste. The social dimension focuses on fair work practices, place of business protection, and community engagement within supply chains.

III. METHODOLOGY

This study methodology chapter outlines the research philosophy, studies method, and methods used to analyze data in the context of Green Supply Chain Management (GSCM). The Systematic Literature Review (SLR) method was used to synthesize current research and identify key trends, gaps, and contributions within the area. The SLR process involved searching through various educational databases, obtaining 110,000 information through key-word searches, and removing duplicates. To maintain the high-quality and relevance of the research, further screening was conducted, excluding studies that did not meet predefined inclusion criteria.

The research philosophy, Pragmatism, was followed, allowing for flexibility in integrating both qualitative and quantitative strategies to address complex sustainability-related problems in GSCM. The studies approach used in this study followed a deductive reasoning framework, based on existing theories such as the Resource-Based View (RBV), Institutional Theory, and the Triple Bottom Line (TBL) model. The systematic literature review allowed for an intensive examination of previous studies, taking into account pattern identification, understanding synthesis, and theoretical validation.

The SLR method ensures a transparent, replicable, and comprehensive system that minimizes bias and enhances the reliability of findings. The study gained insights into how corporations implement GSCM practices, the role of emerging technologies, and the challenges and benefits associated with sustainable supply chain management.

Systematic Literature Review (SLR) is a systematic method that provides a structured, transparent, and replicable approach for synthesizing understanding. It helps consolidate dispersed findings and identify patterns across multiple studies on Green Supply Chain Management (GSCM). SLR also helps detect gaps in existing research, providing a roadmap for future investigations into sustainability, performance, and technological advancements within GSCM.

The research design follows a systematic, step-by-step framework, including identification, screening, eligibility evaluation, inclusion, and synthesis. The framework includes five key ranges: identification, screening, eligibility evaluation, inclusion, and synthesis. The inclusion criteria require studies to be published in peer-reviewed journals or conferences, written in English, published within the last 10 years, and directly relevant to GSCM. The exclusion criteria remove articles that are more than 10 years old, not in English, not directly related to GSCM, or lacking methodological rigor or empirical data.

The final stage involves extracting key findings from the selected articles using a structured template, which records author(s) and publication year, research objectives, methodology, key findings and contributions to GSCM, and identified gaps and future research directions. The extracted data is then categorized under technological advancements, regulatory impacts, economic benefits, and sustainability performance, providing holistic insights into the field of green supply chain management.

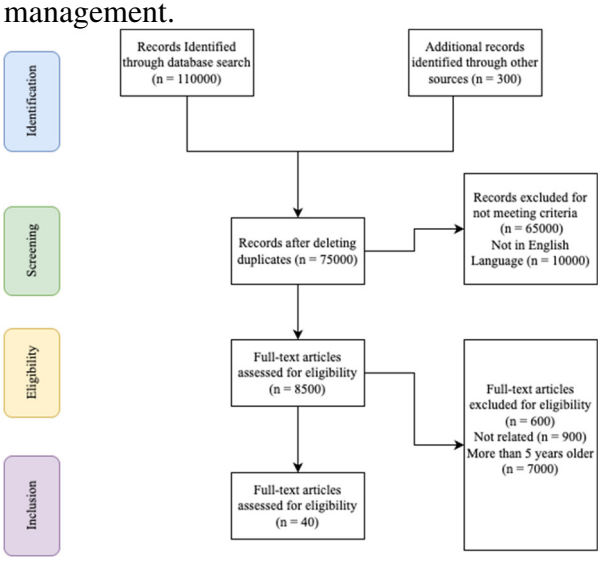

Figure 1 Systematic Literature Review process for this research

Data analysis techniques used in the study include qualitative strategies, thematic analysis, and content analysis. These methods ensure a complete synthesis of findings associated with GSCM, identifying unusual topics, tendencies, and gaps within the current knowledge frame. Validity and reliability are crucial for this research, as they ensure the accuracy and relevance of the study's findings. .

IV. RESULTS

Overview of the Selected Studies

The literature on Green Supply Chain Management (GSCM) emphasizes the importance of integrating sustainability into supply chain operations through frameworks and theoretical models. Key drivers include regulatory pressures, stakeholder expectations, and environmental responsibility [28-30]. However, GSCM faces challenges such as technological readiness and resistance to change. The automotive industry is a prime example, with disruptions impacting sustainability goals. The intersection of industry 4.0 and GSCM is also explored, with virtual transformation enhancing sustainability performance. Supply chain collaboration is also a key theme, with studies highlighting the benefits of environmental collaboration and financial performance..

Thematic Analysis of GSCM Practices inside the automotive industry

The literature on Green Supply Chain Management (GSCM) emphasizes the importance of integrating sustainability into supply chain operations. Key drivers include regulatory pressures, stakeholder expectations, and company environmental responsibility. [31-32]. However, GSCM faces challenges such as lack of technological readiness and resistance to change. The DEMATEL method evaluates elements influencing GSCM implementation, highlighting the role of top management dedication and supplier collaboration [33]. The automotive industry has seen the impact of the COVID-19 pandemic on green Closed-Loop supply chains, leading to a reconsideration of supply chain resilience strategies. The role of supply chain collaboration is also a key theme, with studies highlighting the benefits of environmental collaboration and the role of industry 4.0 technology [34]. The automotive industry is under immense pressure to adopt green practices, reduce environmental impact, and improve sustainability.

The adoption of Green Supply Chain Management (GSCM) in the automotive industry is driven by regulatory pressures, corporate social responsibility (CSR), market competitiveness, and financial advantages. Governments have implemented strict environmental rules, such as the European Union's Emission Trading System (ETS) and the Corporate Average Fuel Economy (CAFE), which mandate automobile companies to reduce their carbon footprint and enhance sustainability. Consumers are increasingly favoring environmentally responsible brands, prompting automakers to adopt GSCM practices such as inexperienced sourcing, recycling, and strength-in-experienced manufacturing [35].

Financial performance and rate reduction are also key drivers, with GSCM adoption often leading to cost savings through waste reduction, power performance, and optimized resource utilization. Technological advancements and business innovation have provided automobile groups with new equipment to enforce inexperienced supply chain practices efficiently [36]. However, the automotive industry faces several challenges and barriers in implementation, including high initial investment costs, lack of dealer collaboration and coordination, technological barriers, regulatory challenges, inconsistent global environmental regulations, lack of consumer awareness and demand for green products, and supply chain disruptions due to geopolitical issues, pandemics, and weather trade.

The integration of Industry 4.0 technologies, such as artificial intelligence (AI), Internet of Things (IoT), blockchain, massive data analytics, and automation, has emerged as a transformative force in improving GSCM practices in the automotive

industry [37]. These technologies include real-time tracking and predictive analytics, smart logistics and direction optimization systems, blockchain generation, 3-D printing and advanced manufacturing techniques, big data analytics, and the rise of self-sufficient and electric vehicles (EVs).

Despite these challenges, the adoption of GSCM is crucial for the automotive industry to adapt and achieve a sustainable supply chain..

Impact of GSCM on sustainability Performance

Green Supply Chain Management (GSCM) is a strategic approach within the automotive industry that aims to enhance sustainability performance while maintaining competitiveness [38]. It integrates environmentally friendly practices throughout the supply chain, from raw material sourcing to manufacturing, logistics, and waste management. The impact of GSCM on sustainability performance can be analyzed through three key dimensions: environmental performance, operational performance, and financial performance.

Energy performance is a key goal of GSCM, as it reduces carbon emissions, minimizes waste, and enhances power efficiency [39]. Implementing green practices, such as fuel-efficient transportation methods, electric vehicle fleets, and path optimization strategies, significantly reduces environmental risk. Sustainable procurement rules ensure suppliers adhere to environmental regulations and adopt green practices. Companies like Toyota and Tesla have integrated renewable electricity sources, biodegradable substances, and water recycling systems into their manufacturing processes to promote sustainability.

Operational performance is enhanced by integrating green practices in production, stock management, and logistics, leading to better resource efficiency, reduced waste, and optimal resource usage [40]. Sustainable manufacturing strategies, such as lean production, JIT stock systems, and 3D printing, help reduce raw fabric wastage and strength consumption. Supply chain resilience and risk management are also crucial issues, as GSCM reduces dependency on non-renewable resources and supports business continuity during the COVID-19 pandemic.

Financial performance is significantly impacted by GSCM adoption. It reduces prices, increases profitability, and enhances brand price. Companies with strong sustainability rules attract more investment and reap better financial performance. Compliance with environmental policies and tax incentives contributes to financial savings. Supplychain risk reduction is vital for financial sustainability, as companies that implement GSCM techniques are better prepared to deal with market fluctuations, supply chain disruptions, and regulatory changes.

V. CONCLUSIONS

This paper discusses the adoption of Green Supply Chain Management (GSCM) in the automotive industry, focusing on key drivers, challenges, and the role of industry 4.0 technology. The study highlights that regulatory compliance, economic benefits, and environmental issues are the most important drivers of GSCM adoption in the automotive industry. However, the integration of industry 4.0 technologies, such as AI, IoT, and blockchain, has been identified as a key enabler of green and transparent supply chains.

Theoretical contributions from this study include the Resource-Based View (RBV) principle, which suggests that companies adopting green practices gain a competitive advantage through support performance, waste reduction, and innovation. The study also contributes to Institutional Theory, demonstrating that technological advancements can mitigate institutional pressures, allowing industry to satisfy sustainability regulations and customer expectations more effectively.

Practical implications for the automotive industry include strategic investment in industry 4.0 technologies, overcoming cost and implementation barriers, enhancing supply chain collaboration and transparency, building a sustainability-oriented

organizational culture, and strengthening regulatory compliance and competitive advantage. The findings affirm that GSCM adoption is vital for automotive companies to achieve sustainability desires while maintaining profitability and competitiveness.

The study on Green Supply Chain Management (GSCM) within the automotive industry has limitations, including reliance on secondary information sources and literature overview-based analysis, a focus on the automotive industry, and a geographical scope that may limit its generalizability. It also does not consider regional variations in GSCM implementation and differences between developed and developing nations. The study also highlights the role of industry 4.0 technologies (AI, IoT, and blockchain) in improving GSCM but does not explore the implementation challenges faced by small and medium-sized enterprises (SMEs).

Future research should include empirical research with primary data, industry-wide comparisons, exploring regional and cultural influences on GSCM, investigating the role of industry 4.0 in GSCM implementation, examining the long-term financial impact of GSCM adoption, and assessing the role of SMEs in sustainable supply chains.

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