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The Role of Sustainable Supply Chain Management as a Solution to the Carbon Footprint Problem of the Global Logistics

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Abstract: Objective: This study evaluates Sustainable Supply Chain Management (SSCM) practices both for their ability to decrease carbon emissions in global logistics operations and the associated challenges along with implementation opportunities between various geographical areas. **Methodology:** The researchers employed a mixed-methods investigation approach in this research. This research obtained quantitative information through questionnaires sent to 250 worldwide logistics companies in order to measure both SSCM utilization and emission changes. The research collected qualitative information through semi-structured interviews with 25 supply chain managers and sustainability officers to determine both the promoting and obstructive elements of SSCM practice implementation. **Results/Findings:** The analysis of quantitative data showed Europe held the highest SSCM index level at 85% followed by North America at 70% but Latin America and Africa had considerably lower indices. The analysis through regression showed that SSCM practices create a positive connection to minimizing carbon footprints ($r = 0.62$, $p < 0.001$). Economic restrictions emerged as the leading barriers (15 mentions) while regulatory problems stood as the second major obstacle (10 mentions) according to the qualitative results. Green transportation together with warehouse energy efficiency operate as main pollution reduction practices yet financial constraints along with weak regulatory standards specifically in emerging regions hinder their deployment. **Conclusion/Recommendation:** The research supports governments to deliver enhanced policy backing coupled with funding programs for promoting SSCM practices. Organizations worldwide could benefit from sustainable supply chain practices because improved technological solutions would decrease implementation expenses. The implementation of improved regulations should be prioritized in developing regions since this will advance the widespread use of SSCM practices.

Keywords: Sustainability, Green Supply, Chain Management, Greenhouse Emission, Supply Chain, Global Warming, Environmentally Sustainable Practices, Logistics Sustainability.

دور إدارة سلسلة التوريد المستدامة كحل لمشكلة البصمة الكربونية في اللوجستيات العالمية

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الملخص: الهدف: تقيّم هذه الدراسة ممارسات الإدارة المستدامة لسلسلة التوريد من حيث قدرتها على خفض انبعاثات الكربون فى العمليات اللوجستية العالمية والتحديات المرتبطة بها إلى جانب فرص التنفيذ بين مختلف المناطق الجغرافية. **المنهجية:** استخدم الباحثون فى هذا البحث منهج استقصائى مختلط الأساليب. وقد حصل هذا البحث على معلومات كمية من خلال استبيانات أرسلت إلى 250 شركة لوجستية عالمية من أجل قياس كل من استخدام إدارة التعاون فيما بين بلدان الجنوب والتعاون الثلاثى وتغييرات الانبعاثات. كما جمع البحث معلومات نوعية من خلال مقابلات شبه منظمة مع 25 من مديرى سلاسل التوريد ومسؤولى الاستدامة لتحديد العناصر المعززة والمعيقة لتطبيق ممارسة إدارة سلسلة التوريد المشتركة بين الشركات. **النتائج/الاستنتاج:** أظهر تحليل البيانات الكمية أن أوروبا احتفظت بأعلى مستوى لمؤشر إدارة سلسلة التوريد المستدامة والتعاون فيما بين بلدان الجنوب بنسبة 85% تليها أمريكا الشمالية بنسبة 70% ولكن أمريكا اللاتينية وأفريقيا كانت مؤشراتهما أقل بكثير. وأظهر التحليل من خلال الانحدار أن ممارسات إدارة التعاون فيما بين بلدان الجنوب والتعاون الثلاثى تخلق علاقة إيجابية مع تقليل آثار الكربون ($r = 0.62$, $p < 0.001$) وبرزت القيود الاقتصادية باعتبارها العوائق الرئيسية (15 إشارة) فى حين جاءت المشاكل التنظيمية فى المرتبة الثانية كعائق رئيسى (10 إشارات) وفقًا للنتائج النوعية. يعمل النقل الأخضر إلى جانب كفاءة الطاقة فى المستودعات كممارسات رئيسية للحد من التلوث، إلا أن القيود المالية إلى جانب ضعف المعايير التنظيمية خاصة فى المناطق الناشئة تعيق ذلك

الكلمات المفتاحية: الاستدامة، الإمداد الأخضر، إدارة السلسلة، انبعاثات الغازات الدفيئة، سلسلة التوريد، الاحتباس الحراري، الممارسات المستدامة بيئيًا، استدامة الخدمات اللوجستية.

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Introduction

International logistics has a very significant importance in the world economy since they are in charge of transporting goods between different territories. But this sector is one of the leading causes of the environmental pollution; especially through emission of carbon. Logistics or moving of goods in supply chain networks contributes approximately $8-10\%$ of the global greenhouse gases (Stern, 2007). This has been compounded by the rising e-commerce whereby there is higher demand for delivery in the shortest time possibly makes the number of logistics operations more frequent and energy consuming (McKinnon et al., 2015). Due to the increasing concerns on the adverse effects of climate change industrial sectors are under pressure to embrace environmentally friendly practices. Sustainable Supply Chain Management (SSCM) has been established as a potential solution in the context of supply chain considering the need for environmental aspect to be incorporated with supply chain operation in order to achieve improved ecological and economic performance (Seuring & Müller, 2008). SSCM therefore involves the minimization of carbon emission, increased efficiency in energy utilization as well as the use of cleaner technologies in the procurement of raw materials to the distribution of the final product.

Despite the growing number of industries that have integrated SSCM principles into their supply chain strategies, global logistics is a rather problematic issue because of the large supply chains and the rather worrisome focus on fossil fuel-based transportation. The study focuses on the following research question; this article seeks to establish the use of SSCM to solve the carbon footprint challenge in the global logistics. It will focus on significant SSCM approaches, their efficacy, and the difficulties faced in their implementation with appropriate suggestions towards the minimization of carbon emissions while ensuring non-negotiable operational effectiveness and cost optimisation in the course of logistics solutions.

Literature Review

Global logistics being a major driver of carbon footprint has evolved to becoming one of the biggest environmental issues of the 21st century with its impacts on climate issues. These logistics involve transport, storage, and packaging among others and are a source of global emissions which are mainly carbon dioxide (CO_2). The IPCC (2014) claims that transportation sector contributes to about 23% of the global energy related CO_2 emissions. As a result of globalization there is more transport of goods across borders and hence increasing the carbon footprint of the transport sector (Carter & Rogers, 2008). This growing burden requires- new solutions- such as Sustainable Supply Chain Management (SSCM) that ensures that sustainability becomes a way of life in supply chains and dealing with logistics and the adverse effects on the environment.

Important of Sustainable Supply Chain Management

According to Elkington (1998), SSCM is an approach of managing the material, information and capital flows of a given organization with regards to environmental impacts, social effects and economic returns in supply chain management. Considerable number of the traditional supply chain thinking and the concept of supply chain management is primarily based on cost, speed and time. The SSCM approach on the other hand acknowledges sustainable practices in the reduction of negative impacts on the environment and at the same time acknowledges the need to have sustainable economic benefits (Seuring & Müller, 2008). The concept of SSCM is grounded in the "triple bottom line" (TBL) framework, which argues that businesses must balance three critical dimensions: called triple bottom line, from people, planet and profit as proposed by Elkington in 1998. This presents a framework that requires organisations to act in a manner that is profitable in terms of dollars and cents but at the same time, have the least impact on the environment and the society. In logistics, SSCM includes the following; Green transportation, Energy efficient warehousing and Sustainable sourcing.

The increasing demand of SSCM is also well linked to the global move towards the achievement of the Sustainable Development Goals. SDG 12 is on sustainable consumption and production patterns, thus leading to change towards responsible supply chain management practices as identified by Sarkis et al., 2011. In other words, SSCM may play an important role in the vision and implementation of global objectives that aim at reducing wastes, inefficient resource consumptions and greenhouse gas emissions. Kleindorfer et al., (2005) have noted that, for the logistics companies, the primary purpose of SSCM is to decrease the organization's impact on global climate without compromising with competitive operations.

Carbon footprint of Supply Chain

This implies that the major driver of carbon footprint in the international globe is transportation, which is mostly petroleum based. Research also points that logistics process especially long-distance transport by road, sea or air contributes to the emission of significant levels of CO_2 and other GHGs. McKinnon et al. (2015) estimate that the global logistics generate 8-10% of total CO_2 emissions with transportation being the major emitter. Specifically, because logistics involves the transportation of goods over large distances with energy-intensive transport means, it is one of the most difficult industries to green.

Carbon intensity of logistics operations also has other sub factors such as the mode of transport used in the process. Piecyk & McKinnon (2010) made a comparison of several modes of transport and its carbon footprint and noticed that air freight had the highest carbon footprint with approximately 500g CO_2 per tonne-kilometre (/t-km). However, sea freight that takes relatively longer, it is more environmentally friendly, discharging 15 grams of CO_2 per tonne-kilometre. Road transportation can be considered to be in between these two extremes, though the emission rates are comparatively high because of increased reliance on diesel vehicles in the form of trucks. In light of these challenges several measures that businesses and policymakers have undertaken to achieve the goal of lowering carbon footprint of logistics include: there is need to enhance the efficiency of transportation as a way of lowering emissions (Linton et al., 2007). This can be done through the reduction of the distance travelled by vehicles, using vehicles with better fuel Economy, and replacing traditional engines with low emission ones e.g. electric or hybrid engines on the trucks. Bio fuels and solar energy transport systems are also identified by Sánchez-Rodríguez et al. (2010) as approaches capable of eliminating carbon in logistics networks.

SSCM Strategy

Martin sweat has targeted a 15% absolute reduction in organisational carbon footprint. SSCM brings the concepts that can be used as a hub for a successful logistically-sound carbon-reducing approach. To this end, the following strategies can be utilized to achieve this; the strategy may involve green transportation, reverse logistics and so on. Many of these strategies do not only deal with minimizing the negative effects of the firm on the environment but also enhance the effectiveness of the supply chain process.

Green Transportation: Another significant approach suggested by Tieman et al, (2011) towards lowering the logistics

emission is the greening transportation whereby the use of electric, hybrid or any type of low-emission vehicles is encouraged instead of the piston engine ones. (Al Kurdi et al. 2024) emphasize that enhancing customer experence motivates businesses to adopt green transportation and sustinable practices. Another aspect of green transportation is the choice of transportation corridors to reduce fuel consumed and exhausted. Companies can use superior logistics software and Business Intelligence (BI) that will help the companies to devise delivery plans that would require less transport and distance covered through traffic-prone areas. (Alshaketheep et al. 2024) demonstrate the role of digital marketing in raising awareness about sustainable practices aiding businesses in aligning with SDG 2030 goals. Some of the companies have gone in advance by applying environmentally friendly transportation strategies. (Mansour et al. 2024) highlight how green marketing and consumer behavior drive businesses to adopt sustainable sourcing and eco-friendly practices. For instance, UPS has lately launched an integrated type of vehicles that utilizes alternative fuel and advanced technology such as electric, hybrid and natural gas. This has gone quite a long way in ensuring that much of the carbon impacts from UPS delivery fleet are minimized (UPS, 2018). On the other hand, DHL has joined the campaign and vowed to ensure it eliminates all emissions associated with logistics by 2050 but through the use of electric vehicles, carbon offset and through renewable energy sources (DHL, 2017).

Energy-Efficient Warehousing: The other subcategory of SSCM that is considered as essential is the energy-efficient warehousing. Businesses use a lot of electricity on lighting, heating, cooling and other processes that take place inside the warehouses. Therefore, the use of efficient technologies like LED lights, smart system ventilation heating and air conditioning systems, and utilizing of renewable energy for instance solar power system can help companies cut down on energy use and carbon dioxide emissions in their warehouses (Zhu et al., 2013). Energy management system (EMSs) can also be used for improving the efficiency of energy use in warehousing business. EMS makes energy usage measurement and management possible in real-time, thus it is easier to detect areas that require intervention. EMS is now implemented in Amazon's international distribution centres resulting in the company's energy consumption decreasing by a quarter (Amazon, 2020). In addition, the management noted that improved building designs such as insulation and natural lighting of the facilities will cut down energy use, especially in cold storage centres.

Sustainable Sourcing: Another strategy widely used in the framework of SSCM is the concept of sustainable sourcing which aims at diminishing the amount of harm the logistics activities cause to the environment. This requires purchasing materials and products from the supply chain which are eco-friendly and non-conducive to unethical behaviours (Pagell & Wu, 2009). Sustainable procurement reduces procurement associated environmental impacts by specifying suppliers who meet several sustainable material and supply chain requirements. (Mansour et al. 2025) highlight the role of electronic systems in enhancing sustainable sourcing and promoting eco-friendly practices. Asfa et al. (2022) using the SCOR model, how effective supply chain practices enhance operational performance and sustainability in industrial companies A good example for sustainable sourcing in logistics is the outdoor clothing company called Patagonia, which has set up the goal to use only recycled or renewable materials in the company's supply chain. Such commitment has assisted Patagonia in minimizing its carbon emulsion while at the same time inspiring other apparel industry stakeholders to do the same (Patagonia, 2021).

Reverse Logistics: Remanufacturing the product and getting it back from the consumers to the manufacturer is what reverse logistics also referred to as closed-loop supply chains. This strategy does not only ensure that there is a cut on the amounts of wastes being disposed of but also does reduce the amount of carbon being emitted in the atmosphere. As this paper has illustrated, organisations can leverage reverse logistics processes to recover value from return products and, at the same time, decrease the effect on the environment. IKEA has also come up with a unique reverse logistics management policy whereby customers can return old equipment and these will be recycled or sold as second hand. This programme has a positive impact both on the environment and the society, since it diminishes the amount of waste and emissions incurred by disposal of old equipment, also it is in accordance with the principles of circular flow (IKEA, 2020). Likewise, Apple has a well-structured reverse logistics management which allows them to recycle their old gadgets to recover metals including aluminium and rare earth metals for reuse in the production of new products (Apple, 2019).

Challenges in Implementing SSCM in Global Logistics

Though there are a number of advantages of employing SSCM, its application in global logistics industry consists of certain issues. Such difficulties involve issues of finance, technology, and policy, which tend to provide quarters in the broad implementation of sustainable solutions.

Financial Constraints: Another major challenge influencing the inability to adopt SSCM is the expense of eradicating the conventional practices in favour of sustainable ones. Khaled et al. (2021) highlight how disruptions like COVID-19 exacerbate financial challenges on retail markets, emphasizing the need for resilient & adaptable supply chain strategies. Chakraborty & Chuan (2013) also observed that most organisations including the SMEs have financial constraints that do not allow them to afford the infrastructural, technological and personnel resource that can support SSCM. (Kamel and Abdelkader 2015) the role of financial sector development in addressing funding challenges for sustainable practices, particularly in resource constrained regions. For instance, when expanding the use of electric cars or upgrading a warehouse to incorporate efficient energy equipment, the first-time costs are very high, especially for organizations that run relatively small profit margins. Additionally, adopting SSCM strategies may entail additional costs of operations in the short run a fact that may discourage organizations from practicing sustainability. Conversely, some literature reveals that SSCM has the potential to deliver sustainable cost advantages in the organization through efficient consumption, low energy usage and optimal costs of waste disposal (Zhu et al., 2013).

Technological Limitations: The last problem that is relevant to the implementation of SSCM is the inadequate availability of high technologies necessary for sustainable transporting and delivering services. Govindan et al., (2014) have opined that although big companies particularly the multinational are capable of investing in innovative advanced technologies, the small companies are financially and technically constrained in their incorporation of sustainability in the supply chain. For instance, electric vehicles and solar-energy systems continue to be costly and highly-integrated, meaning that they cannot be readily adopted by the various actors in the logistics chain. Besides, the uses of big data, artificial intelligence (AI), and Internet of Things (IoT) in supply chain networks can enhance sustainability by reducing emissions, enhancing the selection of efficient routes, and efficiently managing energy. However, these are costly technologies both in terms of

purchasing and requiring expertise in order to implement and manage them effectively; this is often a problem for smaller logistics companies (Dubey et al., 2017).

Regulatory and Standardization Issues: Some of the regulatory issues that are associated with managing global logistics include the ability to implement specific sustainability standards across different regions. Dubey et al. (2017) explain that differences in environmental regulations, carbon costs, and sustainability requirements leads to issues of supply chain instability. Similarly, (Hussien et al. 2025) emphasize the role of corporate governance on enhancing sustainability performance, underscoring the need for clear and consistent regulations to support SSCM practice This conflicting OEM management constitutes a major challenge in the provision of harmonised SSCM practices especially for companies that have branches across several countries. For example, as the European Union has set up high emissions standards in transportation and logistics while Southeast Asia and Africa have not set up high standards to adopt sustainable practices in their supply chains. Also, the absence of best practices for sustainability and indicators complicates companies' ability to track and evaluate their performance in the progress toward sustainability (Govindan et al., 2014).

Research Questions and Hypotheses

Research Questions

1. Apart from the other consequences, how does Sustainable Supply Chain Management influence the carbon footprint of the global logistics?
2. Which strategies are most suitable to be implemented under SSCM in order to minimize the emission of CO_2 in the logistics operations?
3. How to Identify and analyse the key challenges to the global logistics sector in the context of SSCM practices implementation?

Hypotheses

1. Existing SSCM practices play a very important role towards the reduction of the carbon footprint in the supply chain globally.
2. Green transport and energy consumption reduction warehousing are the most efficient SCSCM approaches to reducing carbon footprint.
3. Some challenges which have been found to affect SSCM implementation in the global logistics are financial limitations and lack of regulations.

Methodology

Research Methodology

This research employs both quantitative and qualitative methods to provide a more holistic look at how SSCM is contributing to the mitigation of the output of greenhouse gases in global supply chain logistics. This is achieved by the combination of qualitative and quantitative data, whereby the study collects tangible data of SSCM practices and environmental impacts figured out from the participant's experiences and perceptions.

Quantitative Research Component

The quantitative part of the study is the online survey based on the questionnaire which is being sent to the logistics companies with the international level of activity. These companies are selected on the basis of their type and location so that the results could be generalized to a large extent. The survey will employ the population of logistics managers, sustainability officers and supply chain professionals with direct participation in sustainability and SSCM.

Survey Design: The questionnaire will be designed with mostly closed questions concerning SSCM adoption; carbon footprint cut measures and perceived usefulness of measures. Types of questions that will be used are the Likert scale questions, multiple choice, and ranking questions. To capture the participants responses, a five-point Likert scale will be used to measure the extent to which the participants agree with the following statements; the extent to which the following SSCM strategies have been implemented in the participants company; Green transportation, sustainable sourcing and Energy efficient warehousing.

Example Likert-scale questions

- *How sustainable is your company when it comes to choosing the means of transportation? This is on a scale 1 "Not at All", 5 "Completely".*
- *How efficient do you think sustainable sourcing is reducing the carbon footprint of your organization? Please rate the following according to the following scale: Not effective = 1, Slightly effective = 2, Moderately effective = 3, Quite effective = 4 and Very effective = 5*

Sampling and Data Collection: Conducting the survey, the research will apply the strategy of the stratified random sampling in order to include the companies of various sizes, scopes and regions in logistics. Participants will be invited by email with gentle reminders sent in a bid to enhance the response rate to the study. This will be achieved using a total of 200-300 companies from across the world in order to achieve a representative sample of the industry. It is hoped that data will be gathered for duration of 2-3 months.

Qualitative Researches Component

The qualitative analysis reinforces the results of the quantitative analysis by offering additional information regarding the state of SSCM practices and the difficulties of decreasing the carbon impact of logistics organisations. This part of the study entails conducting semi structured interviews to the various stakeholders in the logistics.

Interview Design: Semi-structured interviews will be conducted with industry experts, including:

- *Supply Chain Managers*: Apart from the senior professionals mentioned above, there are others who take an active participation in the everyday functioning of the logistics process and who are invariably responsible for the implementation of SSCM practices in the companies.
- *Sustainability Officers*: These specialists deal with effectiveness decrease of the company's logistics impact on the environment with the help of reliable technologies and solutions.

Interview questions will pertain to the practices of SSCM, organisational perceptions of obstacles to sustainability, as well as the possibility of innovation to address them. Key topics will include:

- The particular SSCM strategies employed by their organisations.
- Nova experiences in implementing low carbon technologies and renewables/new experiences in implementing low carbon and more renewable technologies.
- The cost of implementing SSCM, for instance, cost concerning the sustainability of products.
- Policies and other mean preventive measures in relation to adverse impacts of carbon footprint.

Face to face interviews will be done but some interviews will also be conducted remotely via zoom or Microsoft teams and each interview should take 30 to 45 minutes.

Sampling and Data Collection: Due to the fact that the study's focus is on SSCM practices, purposive sampling technique will be administered in a manner that will ensure that the participants have direct experience with the practices. Interviewees/participants will not be limited to one region or sector of the logistics industry so as to collect diverse views. This is with the aim of conducting between twenty and thirty interviews in order to obtain data saturation meaning that no further information is expected to be elicited from any other interview conducted.

Data Analysis

In order to elaborate the findings arising from the SSCM implementation concerning the carbon footprint of global logistics, significant emphasis is to be placed on the both quantitative and qualitative data analysis. The use of both quantitative and qualitative method of data collection ensures the combining of overlarge statistical data and case studies to make the understanding of the subject complete.

Quantitative Data Analysis: The quantitative survey data will be analysed with the help of statistical software like SPSS or R. Descriptive statistics will be generated to begin with framing details about the demographic features of the sample, the degree of SSCM adoption amongst the respondents and the types of strategies which are most popular for managing carbon footprint. After this, the research hypotheses will be tested through more elaborate statistical analyses.

- ***Regression Analysis***: This will be used to test the hypothesis that levels of adoption of SSCM (independent variable) have an impact on reduction levels of carbon footprint (dependent variable). For example, regression models will currently and progressively reveal the extent of the relation between the identified specific SSCM strategies for green transport and energy-efficient warehousing and decreasing the carbon footprint.
- ***Correlation Analysis***: Pair wise correlation will be employed to determine the nature and the extent of the relationship that exists between different SSCM practices and the perceived feasibility of these practices in minimizing emissions.
- Both bivariate and multivariate analyses for this research will be enabled in order to get a detailed picture of how the SSCM practices provided in the questionnaire respond to the variety of company size, industry type, and location/region.

Qualitative Data Analysis: Coded groups to examining qualitative interview data will be run by thematic analysis that is a technique of identifying, analyse and reporting the patterns in the data. (Alshaketheep et al. (2023) highlight how information technology reshapes retail, supporting sustainable supply chain practices.

In the analysis process, the interview transcript will be line by line coded to determine themes relating to challenges, opportunities, and the best practices of SSCM in logistics.

- ***Initial Coding:*** The transcripts will then go through the first analytical process known as open coding, whereby the data is dissected into conceptual segments. Keywords that will be coded to be entered in the programs include: "cost," "regulations," "novelty in transportation," and "sustainable acquisition."
- ***Thematic Development***: From these initial codes, these will be merged into other broader themes focusing on the key issues and enablers in SSCM adoption process. The themes that you will identify may include; economic balances, regulatory inconsistency, and technological innovations.
- ***Cross-case Analysis:*** These themes will be further compared across the different participants of the interview in order to understand the similarities and the differences in the SSCM implementation across different industries and geographical location.

The features of quantitative and qualitative analysis will allow making more accurate conclusions regarding the involvement of SSCM to solve the issue of carbon footprint within the sphere of global logistics.

Integrating of Quantitative and Qualitative Data

Quantitative as well as qualitative data will be analysed during the interpretation process once the quantitative data analysis is done. The quantitative data will point more on the degree of carbon reduction effected by SSCM while the qualitative data will explain how exactly these results have been arrived at together with other factors that may have interfered and promoted SSCM implementation. These Combined methods will be possible to elaborate a comprehensive analysis of the roles of SSCM in minimising environmental effects of international deliveries.

Results

The results will be presented in tables and graphical forms. The following table provides a summary of the main findings:

Quantitative Research Results

Table (1): The Descriptive Statistics on the Survey Responses.

Variable	Mean	Standard Deviation	Min	Max
Adoption of SSCM strategies	3.8	0.9	1	5
Effectiveness of green transportation	4.1	0.7	2	5
Effectiveness of sustainable sourcing	3.9	0.8	2	5
Use of energy-efficient warehousing	3.7	0.6	1	5

Table (2): The Correlation amongst SSCM Strategies and Carbon Footprint Reduction.

SSCM Strategy	Correlation Coefficient (r)	p-value
Green transportation	0.62	< 0.001
Sustainable sourcing	0.58	< 0.001
Energy-efficient warehousing	0.45	< 0.05

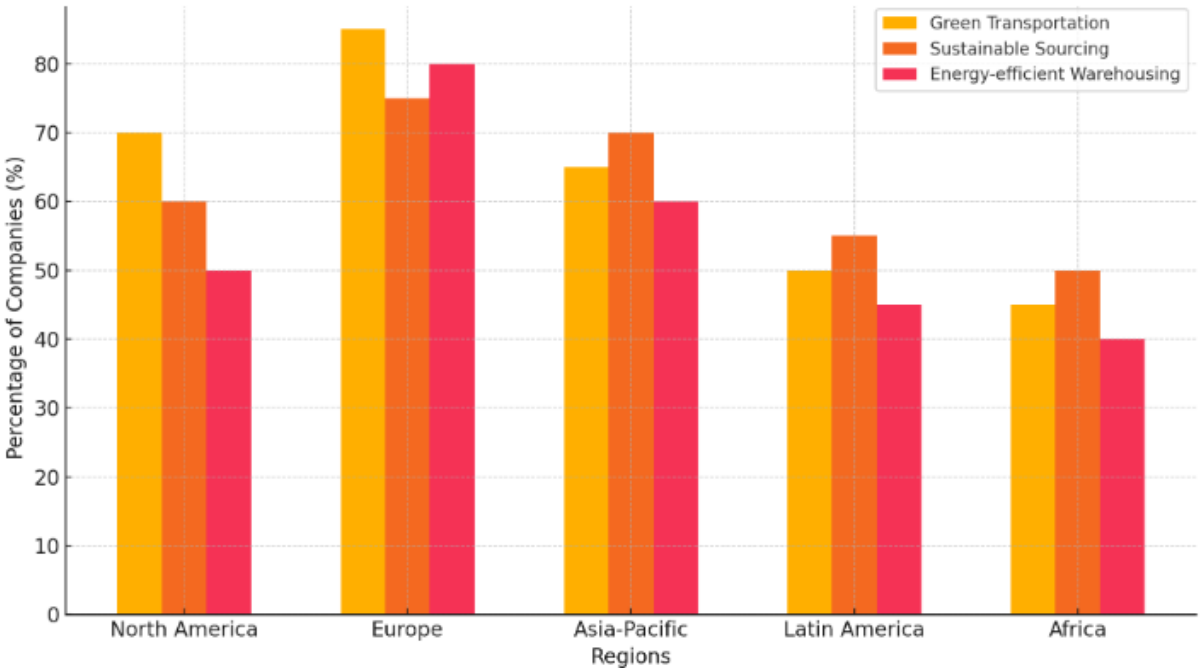

Figure (1): Bar Chart: The overall adoption of SSCM Strategies by different Regions.

This chart displays the percentage of companies adopting green transportation, sustainable sourcing, and energy-efficient warehousing across five regions: These include North America, Europe, Asia Pacific, Latin America and Africa.

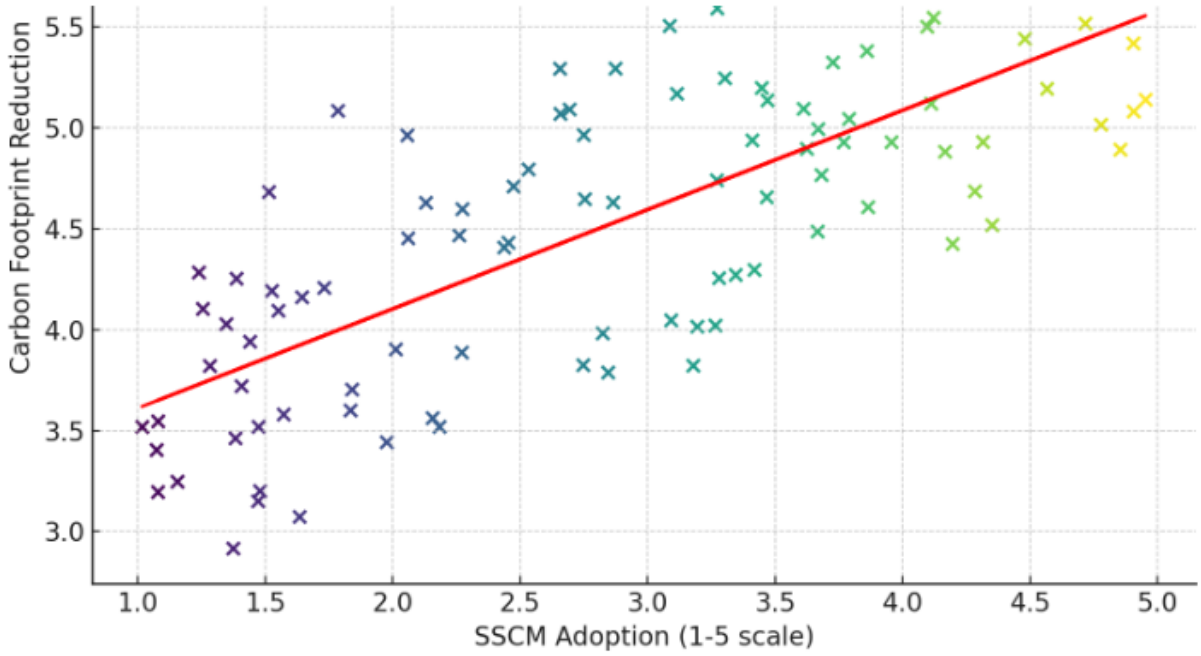

Figure (2): The Scatter Plot with Regression Line.

This is through; Importance of SSCM on Carbon Footprint Reduction. On the right side of Figure 2 are the results on how the level of SSCM adoption relates to the company's reduction of carbon footprints where the former has been measured on a 1-5 scale. The regression line (in red) shows the positive direction with the region that have higher levels of SSCM adoption are likely to be associated with larger extent of carbon footprint mitigation.

Qualitative Research Results

Table (3): Thematic Analysis of Interview Data.

Theme	Frequency	Description
Economic trade-offs	15	Companies report balancing cost constraints with the long-term benefits of SSCM practices.
Regulatory inconsistencies	10	Participants highlight challenges in meeting diverse regulatory requirements across regions.
Innovation in transportation	8	Many stakeholders discuss how innovations, such as electric vehicles, are transforming logistics sustainability.
Barriers to SSCM adoption	12	Common barriers include high upfront costs and a lack of infrastructure for low-carbon technologies.

Figure (3): Word Cloud of Key SSCM Challenges," is an illustration of some of the toughest challenges that organizations encounter when practicing Sustainable Supply Chain Management.

Discussion of Results

Quantitative Findings: The Implementation of SSCM Strategy Adoption on Carbon Footprint Reduction

The findings of the quantitative survey show that SSCM strategy implementation is not well practiced at the same level in all the regions. It is clear from Figure 1 above that Europe leads in the implementation of green transportation whereby 85% of companies have implemented it followed by North America at 70% and Asia-Pacific at 65%. The adoption rates are significantly low in the Latin America and Africa where companies have reported the use of sustainable transportation and energy efficient warehousing at rather a lower level. This trend supports the study conducted by Tang and Zhou (2012) where they stated that developed countries especially Europe use higher levels of advanced SSCM because of the pressure from the market and-policy regulation. Latin America and African continent has reported a low adoption rate of greener logistics and this could be attributed to infrastructural and economic structures that prevent their shift to green logistics. Table 1 offers the means from the questionnaire results where the scale range is 1 for strongly disagree and 7 for strongly agree = Green transportation is seen as an effective SSCM in carving out reduced carbon footprint (Mean = 4.1), Sustainable sourcing is the second strategy where the mean score = 3.9. The applicability of these practices is supported by published research, including McKinnon et al. (2010), demonstrating that transport occupies a considerable share of the overall carbon footprint of logistics and, therefore, further optimization progress in this domain is critical to achieving environmental objectives. Figure 2 shows the regression analysis between adoption of SSCM and reduction of carbon footprint as a positive correlation. The correlation analysis (Table 2) shows that the impact of the green transportation variable on carbon footprint reduction variable is significantly high with the correlation coefficient value of 0.58 and level of significance of 0.001, that is ($r = 0.58$, $p < 0.001$) and energy-efficient warehousing ($r = 0.45$, $p < 0.05$). Such findings are in support of Hickman et al.'s (2018) assertion that the most tangible reduction activities with regards SSCM are in the transportation sector due to the current technologies like electric cars and efficient routing system.

Qualitative Findings: Antecedent Factors to SSCM Implementation

The thematic analysis of interview data has identified several major difficulties of SSCM implementation. As presented in Table 3, this problem is most familiar with economic trade-offs (15 times) and regulatory differences (10 times). People from different regions pointed to the cost factor, this is due to the capital required before one can implement SSCM strategies like buying electric cars or installing energy efficient systems in warehouses. They bring about conflicts between organisations short-term financial gains/options and sustainable development goals as identified by Wu & Pagell (2011). For instance, companies operating in the developing countries complained of weak financial base to fund such form of investment mainly attributing it to the nonexistence of government support and subsidies. Another challenge which was cited frequently by the respondents is the issue of regulation inconsistencies, especially where the companies are operating across different regions. Numerous participants mentioned that the existence of new rules more complex in terms of the generally changing rules for the regulation of sustainability with different standards in different countries poses a major challenge. This issue corresponds to the issues highlighted by Kumar et al. (2014) on the challenges of fulfilling regulatory requirements in cross country operations more so in countries that lack or have poorly developed environmental laws. On the facilitator side, Figure 3 (word cloud) stress the ''innovation'' with the frequency of 75 times; this implies that technology is playing an essential role in addressing

SSCM implementation challenges. Analysts also observed that decision-makers pointed out the need to invest in systems that enhance the transportation of goods and products by extending the use of electric cars and better route planning algorithms as critical to restricted emissions linked to logistics. This finding is in line with Montabon et al. (2016) who highlight the functions of technology advancement in facilitating sustainable logistics operations.

Integrating of Quantitative and Qualitative Findings

Lastly, by integrating the quantitative and the qualitative results, it is possible to get a detailed picture of the factors that affect SSCM implementation. The metrics used in this study show causality between the use of SSCM and levels of carbon footprint, while the findings give a detailed understanding of the factors that impact the implementation of these low-carbon strategies in practice. For instance, while the analysis of quantitative outcomes demonstrates that SSCM strategies, like green transportation, are very effective, the qualitative data defines the economic and governmental challenges that companies face while implementing such SSCM strategies–particularly in the areas with less developed infrastructure or improper regulation. In conclusion, it can be summed up that Figure 2 appear a strong statistical relationship between the implementation of SSCM practices and carbon footprint decrease; however, Table 3 point out that various barriers are still unavoidable to attain the full potential of those practices. This has been revealed in the literature as a significant issue, while SSCM underpinning the reduction of carbon footprints may have a great potential, it is highly dependent on the external environmental factors such as, regulatory support, innovation, and access to financial capital as has been identified by authors such as Seuring & Müller (2008).

Therefore, this discourse shows that SSCM has an essential role of minimizing the carbon footprint of logistics in the world, consequently, green transportation, sustainable procurement; effective energy warehouse was seen as key strategies. However, the three SSCM strategies' effectiveness is constrained by the regional factors such as economic costs of SSCM and standardization. Referring to the conclusions derived from the qualitative data analysis, one could assert that new technologies have a potential to serve as a solution for the problem, although more facilitative policies and conditions have to be created to engender diffusion. This is in contrast with the current literature on SSCM where, Carter and Rogers (2008) highlight on the significance of social, economic and environmental factors aimed at attaining sustainability.

Conclusions

As the current research has shown, the implementation of Sustainable Supply Chain Management (SSCM) can prevent the carbon emissions in the global logistics industry that plays the most extensive role in greenhouse gas emissions. As evidenced in the four elements of SSCM, namely green transport, sustainable supply chain procurement, energy efficiency in warehousing, the role of logistics companies is critical if sustainability is to be achieved. Quantitative data drawn from the study provide empirical support to the application of the stated strategies, especially in developed regions that have recorded high levels of SSCM traits. In such areas, the regulatory framework, consumers' expectations, and improved infrastructure have provided the necessary impetus for the absorption of effective measures that objectively have led to a decrease in the carbon footprint. For instance, the regression analysis showed that there was a positive relationship between the adoption of SSCM and decrease in carbon footprint, where green transportation as a best practice. However, the study also indicates some pitfalls or barriers that limit the implementation of SSCM practices including those existing in the Latin American and African countries. The qualitative analysis established that rigidity of economic gains where high initial expenses detract potential users out of sustainable technologies is a challenge. This finding has similar implications to previous works in the literature where authors have noted that financial incentives would help the business overcome the initial cost barrier. Also, an issue was pointed concerning regulatory gaps which remain critical especially for multinational corporations. Some of the interviewees/participants complaints included the absence of strict measures that organisations have to adhere to when it comes to sustainability issues, thus making the compliance process a bit hectic not to mention the added cost implication. In such countries, the support of governments and relevant infrastructures are relatively weak, which makes the efforts of enterprises in developing countries even more arduous in adapting to SSCM.

There was consensus in identifying technology as a driver to SSCM adoption with emphasis towards transport and warehousing. Technologies such as electric cars, routing optimization that saves fuel, renewable energy technology are some of the technologies aiding corporate emissions reduction. Alhawamdeh et al. (2024) highlight how digital approaches and CSR enhance customer loyalty, supporting sustainable supply chain practices. However, high costs are still a factor that prevents adoption of these technologies, more so, the SMEs, who cannot afford the costs as seen with larger firms. The qualitative results indicate that incremental advancement in technology and availability of government funding will encourage the organizations to adopt SSCM practices even in the less developed infrastructure regions. A multi-stakeholder approach to SSCM is also a significant implication of the research to emphasize the implementation. It is clear that everyone should work together, the governments, the industries, and technology providers need to synchronize in order to develop the right conditions that would allow SSCM to grow. Much more responsibilities fall on the governments to ensure that such policies to support sustainable development's execution bear minimal costs on the companies. One way of managing the economic trade-offs related to SSCM adoption is through offering more incentives such as tax credits, or grant to encourage organization to invest in the development of green technologies. Also, sustainability should form part of the business continuity plans of industry leaders to get to the core of the meaning of the sustainability concept so that sustainability could be an important business strategy that would take the companies to great heights than just being compliance products that industry leaders impose on their employees. The strategic benefits that may accrue to companies who champion the implementation of SSCM include improved brand image, customer loyalty and efficiency.

In conclusion, it is possible to state that SSCM can become a useful tool to minimize the environmental footprint of globalization in the sphere of logistics, yet if logistic companies are to continue apply SSCM widely, they have to solve the problems of economics, regulations, and infrastructures that are in place at the moment. Thus, the results of this research recommend that more effective governmental policies and monetary enticements should be implemented to popularize SSCM practices till technological innovation occurs and makes them more accessible for all sizes of companies and all regions. The incorporation of SSCM into supply chain network reduces the planets environmental footprint and improves the competitive advantage and adaptability of businesses as consumers shift toward green shopping. This is the premise that stakeholders of the global provide the environment suitable for SSCM, while

logistics remains the band of efficiency when its impacts cannot be fully contained.

Recommendations for Future Research

Thus, further studies should bring more information in terms of regional factors influencing SSCM adoption and standardization of regulation measures to encourage companies adopts SSCM.

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- **Ethical Approval:** All ethical guidelines were strictly followed in conducting this research. Ethical approval was obtained where required, and all participants provided informed consent before participating in the study. Confidentiality and anonymity of all participants and businesses involved have been ensured throughout the research process.
- **Data Availability:** All data and materials underpinning the findings of this study are accessible upon request from the corresponding author
- **Author Contributions:** All authors contributed significantly to the research process, including conceptualization, methodology, data analysis, and manuscript preparation. All authors have reviewed and approved the final version of this paper.
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