

IBL

INTERNATIONAL BUSINESS LOGISTICS Journal

E-ISSN: 2735-5969

VOLUME 5
ISSUE 1
JUNE 2025

Academy Publishing Center
International Business Logistics Journal (IBL) First edition 2021



Volume 5, Issue 1, (June.2025)

eISSN: 2735-5969

pISSN: 2735-5950

Arab Academy for Science, Technology, and Maritime Transport, AASTMT Abu Kir Campus,
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The Impact of Digital Transformation and Green Innovation on Sustainable Supply Chains

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Received on: 26 November 2024

Accepted on: 04 January 2025

Published on: 02 February 2025

Abstract

Purpose: The purpose of the research is to explore the effects of digital transformation practices on sustainable supply chains through the mediating role of green innovation. The research aims to fill a theoretical gap in digital transformation research in sustainable supply chain tracks in Egypt, where it is under-researched.

Methodology: The present study is a cross-sectional study that follows the quantitative research methodology and uses the survey list for collecting primary data by conducting it on a random sample of 266 managers of industrial exporting companies in Egypt. The research is exploratory research using regression modeling, which combines theory with data to test hypotheses and explain behavior.

Findings: The study findings indicate that there is a statistically significant effect of digital transformation on supply chain sustainability by enhancing operational efficiency, transparency, and resilience while also promoting environmental and social accountability. Green innovation mediates the relationship between digital transformation and supply chain sustainability, as it plays a pivotal role in enhancing sustainable supply chains by integrating eco-friendly practices, improving resilience, and fostering competitive advantages. Digital transformation predicts the variation in supply chain sustainability by 51.5% and predicts the variations in green innovation by 44.6%. Also, the study highlighted some limitations, such as the reliance on self-reported data through questionnaires, which could introduce response bias or social desirability bias, limited sample size and specific context may restrict the broader applicability of the findings, thereby limiting their generalizability.

Additionally, the study suggested future research directions such as exploring the impact of emerging digital technologies beyond those discussed, including augmented reality (AR) and virtual reality (VR), on supply chain and marketing effectiveness, focusing on industry-specific impacts of digital transformation, as different sectors may experience unique challenges and benefits, testing technologies like block chain and AI and how they could be beneficial, and how firms can make investments in these technologies.

Practical Implications: *By implementing sustainable supply chain practices, the findings of this study will help the industrial enterprises under examination keep up with contemporary advancements in digital transformation and manufacturing. This includes adopting green innovation methods and introducing innovative processes, services, and products. The aim is to guarantee the uninterrupted operation and long-term viability of supply chains for these industrial enterprises. Moreover, it aligns with Egypt's sustainable development strategies.*

Originality/Value: *The research contributes to the field by highlighting the critical role of information systems and digital transformation in advancing sustainable supply chain management.*

Keywords: *Digital Transformation, Sustainable Supply Chain, Green Innovation.*

Introduction

The Fourth Industrial Revolution (4IR), which includes AI, 3D printing, IIoT, big data, and robotics, has transformed the global economy into a sustainable growth model. IR 4.0 technology offers efficient and flexible production setups for large-scale product customization, enhancing competitiveness and cost-effectiveness. The researchers expect this shift in manufacturing strategies and business models to boost market competitiveness, reshoring manufacturing, and promoting sustainability in operations (Fanoro et al., 2021; AUC, 2021).

The digital age is characterized by rapid development, growth, and innovation. Organizations must adapt to this environment by fostering innovation and green innovation. Digital transformation goes beyond implementing new technology, investing in tools, and enhancing systems. Companies must engage in proactive planning and actively shape their future, with a digital transformation plan being crucial (Nadkarni & Prügl, 2021; Jones et al., 2021; Konopik et al., 2022). A digital transformation strategy helps leaders address business inquiries, focusing on current digitization, future aspirations, and pathways. Organizations must develop operational awareness, informed decision-making, and rapid execution (Kraus et al., 2022; Saarikko et al., 2020).

Egypt's Vision 2030 encompasses three primary dimensions: (1) an economic dimension aimed at fostering inclusive development, enhancing transparency, and optimizing governmental efficiency; (2) a social dimension dedicated to investing in human capital through lifelong learning, health, culture, and social justice; and (3) an environmental dimension centered on environmental and urban development. The Give the name in full for the first time you mention the abbreviation (ICT) sector is a fundamental and pervasive component of this vision; it spans the three dimensions horizontally and may significantly aid in attaining the specified objectives (MPED, 2023).

Sustainable supply chains are efficient organizations

that deliver raw materials from the source to consumption using efficient logistics. Companies must electronically link their supply chains to compete in global markets. Digitalization, particularly e-commerce, has profound impacts on supply chains, creating operational and policy-making challenges for companies. Despite the recognition of the impact of e-commerce, innovation and competition contribute to the sustainability of operations, ensuring efficient logistics and effective supply chain management (Heider et al., 2022; Wittmeir et al., 2023).

Green innovation is crucial for business decisions, strategy, management, manufacturing, and product development. It eliminates environmental obstacles and promotes cooperation between customers and suppliers. Green customer integration improves cost and environmental performance by facilitating the innovation of green processes within the organization, not just green products (Wong et al., 2020; Khan et al., 2022; Song et al., 2020).

Sustainability is crucial for companies to maintain a strong economy and corporate profitability. Companies that prioritize growth and environmental preservation are the longest-term growth gateways. They follow a sustainability policy in their operations, adhering to the Three Pillars: Society, Environment, and Economy. Advances in information technology and e-commerce supply chain integration improve the profitability and competitiveness of these companies by effectively managing large amounts of data and transactions (Díaz-Caro et al., 2023; Paulsy, 2024; de Carlos Fraile et al., 2024).

Digital transformation in supply chains improves sustainability, reduces waste, promotes green innovation, reduces theft, and enhances business efficiency. It streamlines transactions, enabling all parties in a sustainable procurement process to share trade-related information. This leads to innovation and efficiency in logistics and digital documentation, with 74% and 75% achieved, respectively. Green

logistics could use blockchain technology to enhance environmental sustainability in e-commerce supply chains (B.Rawat et al., 2020; Bisht et al., 2024).

A review of the literature reveals a significant and growing interest in sustainability issues and their impact on electronic supply chain practices and digital transformation, which promotes green innovation in both products and operations to attain sustainability (Salim et al., 2021; Awain et al., 2023; Munir et al., 2022).

Industrial supply chains in small and developing countries face significant challenges in implementing digital transformation due to lack of capabilities, waste reduction, and sustainable performance. In order to remain competitive and penetrate new markets, industrial supply chains in small and developing countries must integrate all electronic operations and engage in innovation to develop new products and services. Digital transformation risks local companies failing to keep pace with global market developments, leading to new technologies and business models. (Brunetti et al., 2020).

Certain companies in the industrial and distribution sectors have exerted pressure to establish connections with retailers, which has resulted in significant time and financial waste due to inadequate utilization of modern technology. This has led to an unsustainable supply chain and a deficiency in green innovation (Pacheco & Clausen, 2024; Suchek and Franco, 2024).

Research in industrial sectors and distribution processes has lagged due to insufficient innovation, resulting in company collapse and the emergence of rival firms that dominate the market (Huang et al., 2022).

Globalization and the pursuit of sustainability in supply chains have evidently broadened opportunities for enterprises to adopt innovation and green technology while fostering consumer engagement (He et al., 2021).

Despite research, studies, and practices aimed at constructing more sustainable supply chains, the industrial sector in emerging nations reveals that their current configurations jeopardize their future development. Innovations will facilitate the emergence of novel technologies and methods for the production of products and services, hence enhancing the exploration of improved business models (Cristino, 2021).

The challenges of waste or loss within production and manufacturing processes, along with the desire to fulfill sustainability mandates and implement strategies

that enhance efficiency and sustainable supply chains, encapsulate the research issue.

Limited knowledge exists regarding the role of sustainable digital transformation in developing and enhancing sustainable supply networks that adapt to contemporary environmental changes. The recent research aims at investigating the effect of digital transformation on sustainable supply chains in the industrial companies under study in Egypt and the mediation effect of green innovation practices between digital transformation and sustainable supply chains (Oubrahim et al., 2023; Mwendwa, 2023).

Digital transformation is the process that an organization applies to integrate digital technology in all areas of business. It is the application of modern technologies and smart software used by companies, such as customer relationship management programs, blockchain, artificial intelligence (AI), and the Internet of Things (IoT), in addition to management programs. Data analysis plays a crucial role in the digital transformation process, accelerating the digitization of systems like inventory management. The goal of achieving complete digital management and gradually eliminating paperwork not only enhances the customer's experience with the company but also provides comfort for both parties, thereby boosting productivity and ultimately increasing profit (Hai et al., 2021; Nguyen et al., 2022).

Green innovation is defined as the use of new methods in production, operations, or management aimed at reducing overall environmental risks and reducing environmental pollution and other negative impacts on resources, including energy use. The OECD defines green innovation as strategic planning aimed at implementing a new product, a new or innovatively improved process, a new marketing method, or a new organizational method (Rojas-Cabezas et al., 2024).

A sustainable supply chain fully incorporates ethical and environmentally responsible activities into an effective competitive framework. Comprehensive supply chain transparency is of utmost importance. Sustainability activities must encompass raw material procurement, last-mile logistics, and product returns and recycling. Sustainable supply networks enhance the equilibrium between operational efficiency and the attainment of long-term effectiveness and profitability. Technological advancements are crucial for optimizing the sustainability of the supply chain. A sustainable supply chain comprehensively incorporates ethical and ecologically responsible practices into a competitive and effective framework (Mina et al., 2021; Oubrahim et al., 2023).

Digital transformation directly impacts environmental

sustainability, identifying the disruptions it causes. The results present the impact of digital transformation within a framework that identifies transformations in four main areas: pollution control, waste management, sustainable supply chain production, and green sustainability. It seeks to clarify the performance and digital transformation strategy with regard to environmental sustainability in the industrial field and the extent of its impact on the sustainability and profitability of industrial companies (Feroz et al., 2021; Cristino, 2021).

Digital transformation profoundly influences sustainable supply chain management by improving efficiency, transparency, and sustainability performance across diverse industries. The incorporation of digital technologies, including IoT, blockchain, AI, and advanced analytics, transforms supply chain dynamics, enhancing visibility, decision-making, and collaboration among partners, essential for sustainability (Holloway, 2024; Reynolds, 2024). These technologies allow organizations to refine inventory management, predict market trends, and provide tailored client experiences, therefore improving operational efficiency and customer satisfaction while fostering sustainability and ethical standards (Holloway, 2024). Blockchain is emphasized as a revolutionary technology for guaranteeing food product traceability, safety, and sustainability, meeting customer needs for immediate information regarding the environmental and social sustainability of food items (Leković et al., 2024).

De Sousa Jabbour et al. (2022) pointed out the potential benefits of integrating digital technologies and supply chain management, focusing on sustainable supply chains based on big data. Big data has benefits for both dimensions of the triple bottom line in supply chains. Applying big data for sustainability in supply chains presents some challenges for companies. There is a need to develop complementary organizational capabilities to overcome the challenges and facilitate the benefits of big data technology for sustainable supply chain management.

Companies are actively pursuing digital transformation to achieve sustainable development in a volatile and uncertain environment. Digital strategy and digital capability significantly improve environmental processes, environmental products, and environmental management innovation. Environmental processes, environmental products, and environmental management innovation also improve sustainable performance. Meanwhile, eco-innovation partially mediates the positive relationship between digital transformation and sustainable performance (Zhang et al., 2023).

With the many attempts made by governments and companies to reduce environmental risks, blockchain technology has become a crucial tool to achieve sustainable supply chains in small and medium enterprises (SMEs). Green information systems and sustainable supply chain practices have a significant positive association. Sustainable supply chain practices have a positive and significant relationship with sustainability. The results of this study provide valuable insights into blockchain technology and offer policy implications for manufacturers and regulators regarding implementing and promoting green supply chain practices (Khan et al., 2021).

Benzidia et al. (2021) confirm that environmental process integration and green supply chain cooperation have a significant impact on environmental performance. Their study highlights the significant impact of BDA-AI relationships and green supply chain cooperation, enabling them to mobilize BDA-AI technologies to support green supply operations and enhance environmental performance.

The Egyptian government has been actively utilizing digital technologies to achieve sustainable development goals, with initiatives led by the Ministry of Communication and Information Technology focusing on integrating ICT into various sectors (Elgohary, 2022). Moreover, digital transformation cultivates a collaborative culture and emphasizes trust and transparency, which are vital for realizing the complete advantages of digital cooperation and promoting sustainable growth in a linked world (Reynolds, 2024). The implementation of digital transfer technologies integrates business processes with sustainability concerns, enhancing sustainability performance by tackling social and environmental aspects (Hasani & Haseli, 2024). This alignment is essential for organizations seeking to develop flexible, robust, and competitive supply chains that can prosper in a digitalized landscape (Reynolds, 2024). Furthermore, digital transformation improves the efficiency of green supply chains by influencing green production, resources, and consumption, hence promoting environmental sustainability (Gholami, 2024).

The goods and logistics sector gains advantages from digital proficiency, strategic alignment, and the pursuit of innovation, which are critical elements influencing sustainability performance (Mutambik, 2024). Despite the revolutionary advantages, there are still constraints such as substantial investment demands, integration difficulties, and data security issues, which necessitate deliberate methodologies for technology adoption and robust cybersecurity protocols (Holloway, 2024; Reynolds, 2024). Furthermore, digital transformation facilitates the establishment of

robust global supply chains by enhancing transparency, flexibility, and adaptability, which are essential for forecasting and alleviating probable failures and issues (Ning & Yao, 2023). The strategic amalgamation of digital transformation and sustainable policies within organizational frameworks is essential for improving company performance and attaining operational excellence, allowing enterprises to enhance their economic, social, and environmental impact (Stroumpoulis et al., 2024). Digital transformation offers exceptional prospects for supply chains to enhance agility, transparency, and customer focus while promoting innovation, encouraging sustainability, and bolstering resilience against global disruptions (Singh et al., 2024). Organizations can navigate competitive environments, satisfy changing consumer demands, and attain sustainable growth in the digital age by adopting digital technology and linking supply chain strategies with sustainability goals (Holloway, 2024). Drawing from prior research, the researchers can formulate the 1st hypothesis as follows:

H1: Digital transformation practices have a significant effect on the sustainable supply chain in the exporting sector in Egypt.

In the context of sustainable development, countries around the world highlight green innovation in their environmental policies, and the digital economy may play a vital role in improving it. The number of urban green patent applications serves as a measure of green innovation progress in the urban digital economy. This digital economy has a significant influence on green innovation. The development of the digital economy can improve the levels of green innovation in indirect ways, such as enhancing the degree of economic openness, improving the industrial structure, and expanding the market potential. As economic openness, industrial structure, and market potential continue to progress, the intensity of the digital economy promotion of green innovation diminishes. The development of green innovation has an obvious spatial impact. However, promoting green innovation in more developed regions may inhibit green innovation in less developed regions due to talent outflow and industry relocation (Luo, 2022).

According to Takalo and Tooranloo (2021), green innovation (GI) literature has developed and expanded over the past decades due to its wide-ranging fundamental applications coupled with environmental awareness and service delivery of green products and applications. Topics such as the benefits of implementing geographical indications received the highest share. The researchers divided the articles based on the study area. The industries sector had more than one industry, and the largest share was for manufacturing industries and digital transformation

processes in factories.

Management and organization by providing a framework that identifies three levels of analysis (i.e., macro, meso, and micro) to organize current and future research on the topic, scholars have increasingly focused on the interconnection between digital transformation and green innovation management. Learn how industries and companies compete and organize for innovation in a digital world and how new product and service development processes change under the influence of digital technology. Appio et al. (2021) explore the impact of digital transformation on the management of individuals and teams participating in the innovation process through various technologies.

Digital transformation has a profound impact on green innovation across various sectors, as evidenced by multiple studies. It serves as a catalyst for green innovation by enhancing the technological capabilities of enterprises, thereby improving the quantity and quality of green innovation outputs. For instance, studies have shown that digital transformation in Chinese companies significantly boosts green innovation performance, with each standard deviation increase in digital transformation boosting green innovation by 2.924% in quantity and 2.124% in quality (Wang & Zhong, 2024). This transformation alleviates financing constraints and information asymmetries, which are critical barriers to innovation, and improves human capital, particularly in regions with high environmental investment and stringent regulations (Wang & Zhong, 2024). In the transportation sector, digital transformation not only promotes green innovation but also has a sustained impact, with lagged effects being more influential than immediate ones. This is partly due to the mediating role of financing constraints, which digital transformation helps to alleviate, thus facilitating green innovation (Xuqian, 2024). Similarly, in agriculture-related enterprises, digitalization fosters green transformation by promoting economies of scale, technological innovation, and structural adjustments, although a certain threshold of digitization is necessary to realize these benefits (Yue et al., 2024). These findings suggest that similar strategies could be effectively applied in Egypt's exporting sector to enhance green innovation, leveraging digital transformation to improve sustainability and competitiveness in the global market. The research provides a pathway for countries like Egypt to implement digital transformation strategies that align with green sustainable development goals ("Digital Transformation, Green Innovation and the Solow Productivity Paradox", 2022) (Sun & Guo, 2022). Drawing from the existing literature, the researchers can formulate the 2nd hypothesis as follows:

H2: Digital transformation practices have a significant effect on green innovation in the exporting sector in Egypt.

In the Egyptian context, green intellectual capital significantly influences business sustainability, with green innovation acting as a partial mediator in this relationship. This suggests that investments in green intellectual capital can enhance green innovation, thereby improving sustainability outcomes for industrial companies (Mohamed, 2023).

Green innovation is crucial for improving sustainable supply chains by promoting environmental sustainability and competitive advantage in multiple industries. The use of green supply chain management (GSCM) methods, encompassing green innovation, is essential for enhancing environmental performance and attaining sustainable development objectives. In the healthcare sector, green innovation, which includes green technology and management innovations, mediates the relationship between GSCM practices and environmental performance, therefore fostering sustainability in Bangladesh's healthcare business (Karim et al., 2024). In the manufacturing sector, green innovation serves as a crucial catalyst for collaborative innovation, improving the sustainability of manufacturing businesses through the utilization of corporate social capital (Liu, 2024).

It is important to note that the level of complexity in a supply chain has a big effect on sustainability efforts (Issa et al., 2024) because it shows how impactful it is to combine green innovation methods with logistics management approaches. Moreover, green innovation serves as an intermediary in the correlation between internal and external green supply chain practices and competitive advantage, highlighting the necessity for a comprehensive strategy to address environmental degradation and attain sustainable development (Javed et al., 2024). In the realm of digital finance, green innovation augments firm performance inside supply chains by enhancing corporate reputation and competitive advantages, underscoring its vital importance in the sustainable development of enterprises (Li et al., 2024).

Green innovation supports the shift to a circular supply chain model by influencing the connection between green supply chain strategies and sustainable practices, highlighting its significance in promoting circularity and long-term sustainability in a business-to-business context (Singh et al., 2024). Another important thing is green innovation, which fits with cultural and social norms to lessen environmental impact, and it is needed to turn traditional supply chains into sustainable circular economy frameworks. This is especially true in developing countries that

do not have a lot of money. The implementation of green supply chain methods, encompassing green innovation, pertains not merely to immediate benefits but also to securing long-term business sustainability by safeguarding against environmental difficulties and market volatility (Tsikada et al., 2024).

Additionally, organizational traits and regional variations affect the implementation of green supply chain innovations, with competitive pressure motivating smaller entities and perceived advantages shaping the adoption intentions of larger organizations, thereby underscoring the strategic significance of green innovation across various contexts (Chen & Panichakarn, 2024). Green innovation is an essential element of sustainable supply chain management, promoting environmental collaboration, improving operational performance, and fostering a balanced approach that reconciles economic and environmental issues, thus advancing the progress of economic globalization and free trade while addressing the demand for eco-friendly products (Li et al., 2024).

As consumers, governments, and society in general are increasingly concerned about the loss of natural resources, coupled with environmental pollution, there is currently a significant trend to recognize the value of green innovation in achieving sustainable development. The tourism industry largely contributes to environmental pollution through hotels. However, only a few studies have explored the potential impact of green innovations on sustainable performance within the hotel industry, which can significantly and positively influence green innovation actions. Because it demonstrates the importance and potential of green innovation in enhancing sustainable performance in the hotel industry (Asadi et al., 2020).

According to Jiang et al. (2020), as the Chinese economy transitions to a new normal, the energy industry is increasingly driven by innovation, which is particularly evident in renewable energy. Considering that green innovation transformation is crucial during China's new normal phase, it explains the energy consumption on energy innovation and innovation transformation and reveals the net impact of green innovation transformation on economic sustainability and energy consumption. It explains that in terms of the innovative activity behavior of energy enterprises, energy consumption can promote overall energy innovation, of which renewable energy innovation is one of the most important. Much more stimulating. The energy structure is increasingly shifting towards renewable energy sources as energy consumption rises. The transformation of green innovation has the potential to decrease energy consumption and enhance economic sustainability. Therefore, the innovation transformation structure plays a more important role

than overall energy innovation in stimulating economic growth and alleviating the discrepancy in energy consumption during China's new normal phase.

Hu et al. (2021) reveal that their study aims to investigate the impact of green innovation and corporate sustainability behaviors on financial performance by comparing the ways in which two different external factors drive firms to green innovation: environmental regulation and market disruptions. By dividing green innovation into green process innovation and green product innovation, the researchers propose that environmental regulation increases financial performance mainly through green process innovation rather than green product innovation, and market disruptions affect financial performance through green product innovation.

Collectively, these insights underscore the transformative impact of green innovation on the sustainable supply chain in Egypt's exporting sector,

emphasizing the need for strategic investments and organizational readiness to foster a culture of sustainability. Based on the previous literature, the 3rd hypothesis could be formulated as follows:

H3: Green innovation has a significant effect on the sustainable supply chain in the exporting sector in Egypt.

Due to the scarcity of studies investigating the mediation effect of green innovation, the current study covers this gap. So, the 4th hypothesis could be formulated as follows:

H4: Green innovation mediates the relationship between digital transformation & sustainable supply chain in the exporting sector in Egypt.

The conceptual framework of this research encompasses three main constructs as shown in figure 1.

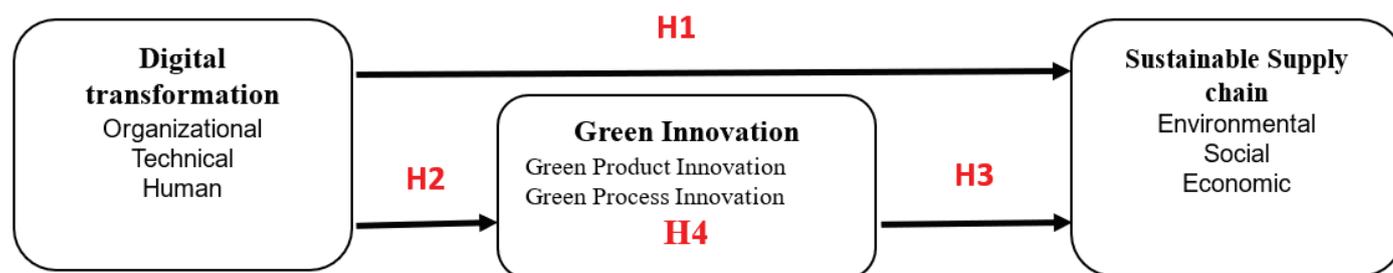


Figure 1 Research conceptual framework

Methods

A quantitative methodology was used. According to Cavaleri et al. (2018), quantitative research involves investigating research questions and/or hypotheses that aim to examine associations, assess discrepancies, clarify causal links between variables, and evaluate the effectiveness of interventions. The study population comprises companies operating in Egypt's industrial sector and exporting to other industries. Given the large size of the study population and the difficulty of accessing all of its subjects due to time and cost efforts, it was decided to rely on sampling methods and procedures to collect primary data for the study.

The study is restricted to large and medium-sized industrial companies that export overseas. Following a reconnaissance study of Egypt's industrial sector, the researchers carried out a technical study on exporting and registered companies. The Export Development Authority, the official website of the Ministry of Commerce and Industry in Egypt, provides the number of producing companies that export overseas.

The study sample consisted of participants working in 90 small and medium-sized enterprises (SMEs) in industrial areas in Egypt. The researchers distributed a total of 400 questionnaires online and received 290 responses. Ultimately, they used 266 questionnaires for the final data analysis. They conducted a pilot test on 30 people before collecting the research data. They subjected the obtained results to reliability analysis and decided to keep the scale expressions as they were.

The researchers individually sent self-administered online questionnaires to each participant to collect the data for this study. They chose a descriptive survey due to its ability to accurately describe or account for characteristics such as behavior, opinions, abilities, beliefs, and knowledge of a specific individual, situation, or group. They selected this design to align with the study's objectives, which aim to assess the influence of digital transformation on sustainable supply chains by examining the mediating role of green innovation. They tested the research hypotheses using the statistical packages of SPSS, version 29.

Before filling out the questionnaire, the scale items were categorized as Likert types, with the midpoint being undecided (3), strongly disagree (1), and strongly agree (5). The Likert scale is a scale that aims to determine people's attitudes (Lee et al., 2023). The survey gauges their level of agreement or disagreement with the subject questions. The survey includes the demographic characteristics of the managers, such as gender, age, education, job level, and experience. At the same time, the 15-item scale developed by Martha et al. (2022), Benavides et al. (2020), Udovita (2020), and Purwanto et al. (2024) was used to measure digital transformation. The scale was developed by Olowoyin (2021) and Shahzad et al. (2024). Asadi et al. (2020) developed a 17-item scale to measure green innovation and Han and Huo (2020) developed a 12-item scale to measure sustainable supply chain variables.

Results

Validity and reliability analyses are conducted to make sure that the questionnaire statements are phrased in a good format. The two main factors that measure validity. First, the average variance extracted (AVE); it represents the average community for each latent factor. The AVE result should be greater than 0.5 to imply adequate validity. Second, to examine reliability, each factor is measured using a group of statements that indicate how stably and consistently the instrument taps the variable, which can be examined by Cronbach's alpha, the most commonly used test of reliability. The range of the Alpha coefficient comes between 0 and 1, and the higher the score, the higher the reliability. If Alpha coefficients are greater than or equal to 0.7, it implies adequate reliability.

The Kaiser-Meyer-Olkin (KMO) test is a measure of how suited one's data are for factor analysis. The test measures sampling adequacy for each variable in the model and for the complete model. The statistic measures the proportion of variance among variables that may be common. The lower the proportion, the more suited one's data are to factor analysis.

KMO returns values between 0 and 1. A rule of thumb for interpreting the statistic: KMO values between 0.8 and 1 indicate that the sampling is adequate; KMO values less than 0.6 indicate that the sampling is inadequate and that remedial action should be taken. Some authors put this value at 0.5; use one's own judgment for values between 0.5 and 0.6.

KMO values close to zero mean that there are large partial correlations compared to the sum of correlations. In other words, there are widespread correlations, which are a large problem for factor analysis.

Table.1 Validity and Reliability

Variables	KMO	AVE	Cronbach's Alpha	Item	Factor Loading
Organizational practices	.768	54.914	.794	ORG1	.821
				ORG2	.822
				ORG3	.702
				ORG4	.548
				ORG5	.777
Technical	.841	53.041	.820	Tech1	.803
				Tech2	.780
				Tech3	.565
				Tech4	.556
				Tech5	.819
				Tech6	.794
Human Resources	.763	61.548	.763	HR1	.670
				HR2	.702
				HR3	.595
				HR4	.660
				HR5	.684
				HR6	.658
				HR7	.560
Green product innovation	.823	51.447	.810	Gp1	.697
				Gp2	.612
				Gp3	.649
				Gp4	.671
				Gp5	.627
				Gp6	.715
				Gp7	.629
				Gp8	.609
				Gp9	.490
Green process innovation	.794	65.648	.794	GPI1	.747
				GPI2	.687
				GPI3	.695
				GPI4	.617
				GPI5	.707
				GPI6	.619
				GPI7	.667
Environmental Sustainability	.716	65,982	.674	Env1	.663
				Env2	.697
				Env3	.728
				Env4	.777

Economic Sustainability	.711	49.408	.636	Eco1	.722
				Eco2	.751
				Eco3	.595
				Eco4	.733
Social Sustainability	.743	65,982	.769	Soc1	.621
				Soc2	.771
				Soc3	.872
				Soc4	.828

Table 1 shows the results of the test. The values of KMO, AVE, and Cronbach’s alpha, as observed, fall within the acceptable range.

Descriptive statistics is a tool that provides a clear understanding of the features of specific datasets by providing concise summaries of samples and demonstrating how to measure the data. The three major types of descriptive analysis are frequency, measures of central tendency such as averages, and measures of variability such as standard deviation. Measures of variability describe the degree to which the scores deviate from the mean. Measures of central tendency suggest a unique value that generally represents the entire score set.

Table (2) shows the respondent profile. In terms of gender, the sample consisted of approximately 65 males, accounting for 90%, and 34 females, making up 10%. The researchers observed that the age group between 40 and less than 50 constituted a higher percentage in the research sample, accounting for 30.50%, compared to other age groups. At the functional level, this group included 37% department heads, 29.6% managers, and 18.4% general managers. Additionally, 74.1% of the respondents reported having 12 or more years of experience.

Table (2): Respondent profile

Item	Frequency	Percent	Total
Gender			
Male	175	65,90%	266
Female	90	0,34	
Age			
less than 30 years	65	24,60%	266
from30to Less than 40	41	15,50%	
from 40 to less than 50	81	30,50%	
50years and more	78	29,40%	
Functional Level			

Head of Department	98	37,00%	266
Director	79	29,60%	
General Director	49	18,40%	
Chairman	40	15%	
Years of Experience			
Less than 6 years	6	2,20%	266
6-less than 10 years	28	10,40%	
11-less than 20years	197	74,10%	
20 and more	35	13,31%	
Industrial Sector			
Plastic & petrochemicals	104	39,00%	266
Fertilizers & Cement	99	37,20%	
Steel & Iron	43	16,00%	
Others	21	7,80%	

Testing research hypotheses

Regression analysis is a collection of statistical techniques that serve as a basis for drawing inferences about relationships among interrelated variables. Since these techniques are applicable in almost every field of study, including the social, physical, and biological sciences, business, and engineering, regression analysis is now perhaps the most used of all data analysis methods.

The analysis of the results revealed the following findings:

Hypothesis 1 (H1): Digital transformation practices have a significant effect on sustainable supply chains in the export sector in Egypt (accepted).

Table (3): Summary of Linear Regression for the Impact of Digital Transformation (DT) on Supply Chain Sustainability (N = 266)

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	1.556	.122		12.774	<,05
ORG	1.19	.301	.305	6.651	<,05
Tech	1.32	.373	.488	9.848	<,05
HR	2.57	.422	.665	13.807	<,05
R Square	51.5%				
F(263,3)	154.620				

As mentioned in table (3), digital transformation (DT) has a direct positive and significant impact on the sustainable supply chain of organizations, organizational practices (B = 1.19*, p-value < 0.05), technical practices (B = 1.32*, p-value < 0.05), and human resources practices (B = 2.578*, p-value < 0.05), which reveals the acceptance of the first main hypothesis. On the other hand, the R square is 51.5, which means that digital transformation explains 51.5% of the variation in supply chain sustainability. It is possible to formulate the regression equation as follows:

$$\text{Supply chain sustainability} = 1.556 + 1.19 \text{ org} + 1.32 \text{ tech} + 2.57 \text{ HR}$$

Hypothesis 2 (H2): Digital transformation practices have a significant effect on green innovation in the export sector in Egypt (accepted).

To test the second main hypothesis, it was tested by conducting multiple regression analysis, and the test results revealed the following:

Table (4): Summary of Linear Regression for the Impact of Digital Transformation (DT) on Green Innovation (N = 266)

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Con-stant)	1,920	.124		15,515	<,05
ORG	.126	.030	.042	.847	<,05
Tech	.164	.038	.103	1,689	<,05
HR	.466	.043	.565	10,958	<,05
R Square	.446				
F(263,3)	116.960				

As mentioned in Table 4, digital transformation (DT) has a direct positive and significant impact on green product innovation, organizational practices (B = .126*, p-value < 0.05), technical practices (B = .164*, p-value < 0.05), and human resources practices (B = .466*, p-value < 0.05), which reveals the acceptance of the 2nd main hypothesis. On the other hand, the R square is .446, which means that digital transformation explains 44.6% of the variation in green innovation. The regression equation could be formulated as follows:

Hypothesis 3 (H3): Green innovation has a significant effect on supply chain sustainability in the export sector in Egypt (accepted).

To test the 3rd main hypothesis, it was tested by conducting multiple regression analysis, and the test results revealed the following:

Table (5): Summary of Linear Regression for the Impact of Digital Transformation (DT) on Green Innovation (N = 266)

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Con-stant)	.715	.134		5,355	<,05
GProd	.539	.048	.534	11,136	<,05
GPI	.276	.047	.283	5,900	<,05
R Square	.60				
F(263,3)	327.803				

Table 5 shows that green innovation has a direct and positive effect on the sustainability of the supply chain. This effect is significant and positive for green product innovation (B = 539*, p-value < 0.05), green process innovation (B = 0.276*, p-value < 0.05), and human resources practices (B = 0.466*, p-value < 0.05). This supports the third main hypothesis. Conversely, the R square value stands at .60, indicating that green innovation accounts for 60% of the variation in supply chain sustainability. The researchers could formulate the regression equation as follows:

Hypothesis 4 (H4): Green innovation mediates the relationship between digital transformation practices and the green supply chains in the export sector in Egypt (Partially accepted).

The 4th main hypothesis was tested by conducting multiple regression analysis, and the test results revealed the following:

Table (6): Summary of green innovation mediation analysis (N = 266)

	L.C.I	U.C.I	p-value	Regression weight
Direct effect	0.441	0.590	0.04	0.521
Indirect effect	0.334	0.499	0.02	0.442

As mentioned in Table 6, the direct effect of digital transformation on the green supply chain is significant (R2 = 0.521, L.C.I. = 0.441, U.C.I. = 0.590) and the indirect effect of digital transformation on the green supply chain through green innovation is also significant (R2 = 0.442, L.C.I. = 0.334, U.C.I. = 0.334). This indicates a partial acceptance of the mediation hypothesis.

Discussion

From the statistical results hypothesis one is supported, which means digital transformation has a profound effect on supply chain sustainability, enhancing operational efficiency, transparency, and resilience while promoting environmental and social responsibility. In other words, by integrating advanced digital technologies, supply chains can achieve significant improvements in sustainability practices, aligning with economic, social, and environmental goals. This result agrees with Holloway (2024), who point out that digital transformation is significantly reshaping supply chain management, which in turn enhances marketing effectiveness. Technologies like IoT, blockchain, AI, and advanced analytics are pivotal in this transformation. Also, it agrees with Stroumpoulis et al. (2024) who reveal that digital transformation plays a crucial role in enhancing sustainable supply chains by integrating sustainable practices with information systems. Also in this line, Nuševa et al. (2024) point out that digital transformation, particularly through technologies like block chains, plays a significant role in enhancing sustainable supply chains in the food industry. It enables improved traceability, safety, and sustainability practices throughout the food supply chain. By leveraging digitalization, actors in the supply chain can address environmental and social concerns, meet consumer demands for transparency, and effectively manage risks. The integration of digital solutions facilitates real-time information sharing, efficient problem-solving, and proactive responses to challenges, ultimately contributing to a more sustainable food supply chain management system. Also, Reynolds (2024) indicates that digital transformation positively impacts sustainable supply chains by enhancing collaboration, connectivity, and agility through digital platforms. The study highlights how digital technologies enable greater visibility and innovation within supply chains, fostering value creation. However, challenges like data security and trust issues can impede collaborative potential. Embracing digital tools, cultivating a collaborative culture, and prioritizing trust and transparency are crucial for unlocking the full benefits of digital collaboration. By leveraging digital transformation, organizations can strengthen their supply chain capabilities, boost competitiveness, and drive sustainable growth in an interconnected, digitalized world.

The statistical results support hypothesis two, indicating that the integration of digital technologies into business processes not only enhances operational efficiency but also fosters sustainable practices by promoting green innovation. Wang & Zhong (2024) concur with this result, asserting that digital transformation has a positive impact on both the quantity and quality of

green innovation. For instance, a study on Chinese firms reveals that a standard deviation increase in digital transformation correlates with a 2.924% increase in quantity and a 2.124% increase in the quality of green innovation, and Zhu (2024) reveals that digital transformation in enterprises plays a crucial role in promoting green innovation. Moreover, two recently identified mechanisms—the technical imprint of senior executives and media attention—further enhance the enabling impact of digital transformation on green innovation. This study not only sheds light on driving enterprise green innovation in the digital era but also provides valuable insights for policymakers and firms aiming to implement sustainable development practices, particularly in developing countries. Xuqian (2024) points out that the effect of digital transformation on green innovation in transportation companies is significant. Research on listed companies in China from 2011 to 2021 shows that digital transformation positively influences green innovation. Moreover, the impact persists over time, with past digital transformation efforts having a greater impact on green innovation than current ones. Additionally, financing constraints play a mediating role between digital transformation and green innovation.

From the statistical results, hypothesis three was supported, which means green innovation plays a pivotal role in enhancing sustainable supply chains by integrating eco-friendly practices, improving resilience, and fostering competitive advantages. The adoption of green innovation strategies within supply chains not only addresses environmental concerns but also contributes to operational efficiency and long-term viability. This result is in line with Issa et al. (2024) who state that green innovation significantly enhances supply chain resilience by improving green logistics management practices. This is particularly effective in less structurally complex supply chains, where the impact of green logistics practices on resilience is more pronounced. According to Purnomo (2024), the integration of green innovation with green ambidexterity contributes to a green resilient supply chain, which in turn enhances a firm competitive advantage. This approach aligns with regulatory and social expectations, bolstering firms market positioning. Also, Chen and Panichakarn (2024) confirm that the relative advantage plays a crucial role in influencing the adoption intentions of larger organizations towards green supply chain innovations, highlighting the importance of organizational size in shaping sustainability practices. Singh (2024) points out that green innovation plays a significant role in enhancing sustainable supply chains by moderating the relationship between green supply chain strategies and the achievement of a circular supply chain. Green innovation positively impacts sustainable supply chains by fostering green resilient supply chain practices

(Purnomo, 2024).

From the statistical results, hypothesis 4 is supported, which means that the relationship between digital transformation practices and green supply chain management is significantly mediated by green innovation. This mediation occurs as digital

transformation facilitates the adoption of green innovation, which in turn enhances the effectiveness and efficiency of green supply chain practices. The integration of digital technologies with green innovation strategies not only improves supply chain resilience and performance but also contributes to sustainable development goals.

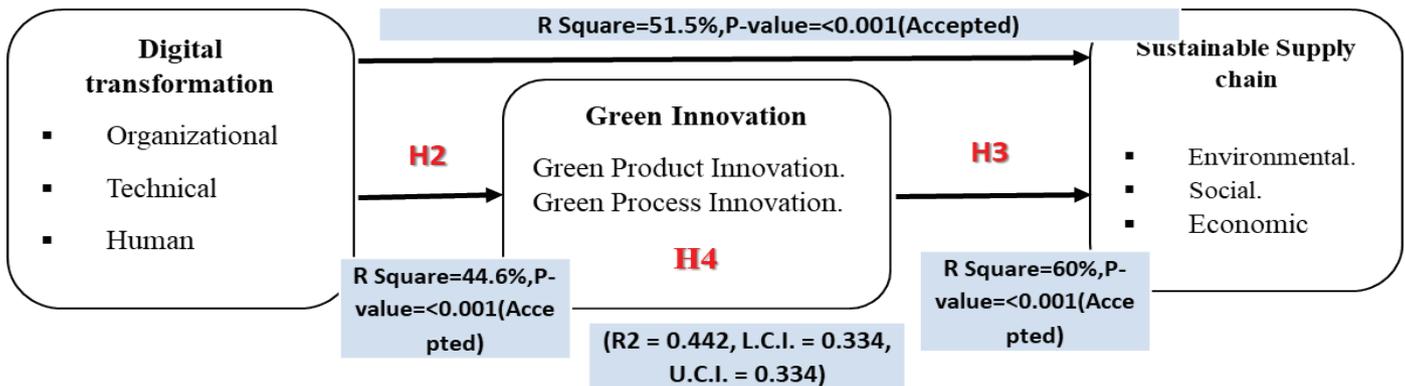


Figure 2 Research conceptual framework

Conclusion

The purpose of the research was to explore the effect of digital transformation practices on sustainable supply chains through testing the mediation effect of green innovation. The research aims to fill a theoretical gap in digital transformation research in sustainable supply chain tracks in Egypt, where it is under-researched. The study results revealed the existence of a significant effect of digital transformation on sustainable supply chains; green innovation mediates the relationship between digital transformation and sustainable supply chains.

There are some academic and practical implications that can be deduced from the current study.

- The research contributes by highlighting the critical role of information systems and digital transformation in advancing sustainable supply chain management.
- It emphasizes the importance of the strategic integration of digital transformation and sustainable policies within organizational contexts for enhancing business performance and achieving operational excellence.
- By implementing sustainable supply chain practices, the findings of this study will help the industrial enterprises under examination keep up with contemporary advancements in digital transformation and manufacturing. This includes

adopting green innovation methods and introducing innovative processes, services, and products. The aim is to guarantee the uninterrupted operation and long-term viability of supply chains for these industrial enterprises. Moreover, it aligns with Egypt's sustainable development strategies.

Given these findings, the current study recommends the following actions:

- To effectively manage the intricacies and hazards in the supply chain, enterprises should embrace digital technology through employing digital technologies to facilitate immediate data exchange and communication to improve transparency and effectiveness.
- Companies should grow while considering environmental and social impacts. This involves integrating sustainable practices into their operations to meet consumer demands for environmentally and socially responsible products.
- Organizations should actively adopt digital platforms and ecosystems to improve connectivity, visibility, and agility within their supply chains. This adoption can lead to enhanced innovation and value creation.
- Implement robust data security measures to protect sensitive information and build trust among supply chain partners. This is essential for mitigating risks

associated with digital transformation.

- Encourage continuous learning and adaptation to keep pace with evolving digital technologies and market dynamics. This approach will help organizations maintain competitiveness and drive sustainable growth.
- Make sure to closely link the deployment of digital technologies to the overall digital transformation strategy. This linkage is vital for achieving long-term sustainability goals and ensuring that technology investments align with strategic objectives.
- Effective change management is crucial for a successful digital transformation. Companies need to focus on managing the transition to digital processes to overcome resistance and ensure smooth integration.
- Cultivating a supportive organizational culture is essential. Encouraging a culture that embraces digital change can help mitigate challenges related to integration complexity and data security.
- Building agile and resilient supply chains is vital in a digitalized world. Companies should focus on creating flexible processes that can quickly adapt to changes and disruptions.
- Digital technologies can create significant value across supply chain networks. Businesses should explore innovative ways to utilize these technologies for competitive advantage.

Here is a summary of the primary limitations of the current study and some recommendations for future research:

- The limitations of the study may include reliance on self-reported data through questionnaires, which could introduce response bias or social desirability bias.
- The study limited sample size and specific context may restrict the findings broader applicability, thereby limiting their generalizability.
- The focus on organizational culture as a challenge indicates the need for additional research to understand how various cultural contexts affect digital transformation initiatives.

- There may be limited exploration of the wide range of digital technologies available, focusing on a few key technologies without delving into emerging or niche technologies that could also impact sustainability.
- The study is across-sectional which will limit the study generalization.

Future research might focus on the following areas:

- Future research could explore the impact of emerging digital technologies beyond those discussed, such as augmented reality (AR) and virtual reality (VR), on supply chain and marketing effectiveness.
- Further studies could focus on industry-specific impacts of digital transformation, as different sectors may experience unique challenges and benefits.
 - Implementing longitudinal studies to assess the long-term effects of digital transformation on supply chain dynamics and marketing effectiveness.
- Examining the effects of digital transformation on supply chains across various regions, considering the differences in technological adoption rates and regulatory frameworks.
- Researching effective strategies for employee adaptation and training to maximize the benefits of digital technologies in supply chains.
- Future research should focus on identifying best practices and developing frameworks for effective digital transformation implementation. This will help organizations navigate the complexities of digital collaboration in diverse contexts.
- Future research directions should be directed towards technologies like block chain and AI, which could be beneficial, and how firms can make investments in these technologies.
- Conducting a longitudinal study to see the long-term changes or how investments in digital transformation and green innovation impact long term goals.

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Sustainable Supply Chain Management Practices and Environmental Performance in a Developing Country's Petroleum Industry: The Mediating Role of Operational Performance

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Received on: 19 February 2025

Accepted on: 26 March 2025

Published on: 07 May 2025

Abstract

Purpose: This study explores the impact of sustainable supply chain management practices (SSCMPS) on environmental performance within Zimbabwe's petroleum industry. It also investigates the mediating role of operational performance in this relationship, addressing the growing environmental challenges and regulatory pressures faced by the industry.

Methodology: A quantitative research approach was adopted, with data collected from 226 supply chain professionals. Structural Equation Modeling (SEM) using SmartPLS software was employed to analyse the relationships between SSCMPS, operational performance, and environmental performance.

Results: The results demonstrate that SSCMPS positively influence environmental performance, with operational performance playing a significant mediating role. Among the SSCMPS, green purchasing and reverse logistics exhibit the strongest positive impacts, underscoring their critical importance in enhancing environmental outcomes and operational efficiency. The study is limited to Zimbabwe's petroleum industry and relies on cross-sectional data, which may restrict the generalisability of findings.

Future Research: Future research could explore longitudinal studies or apply the model to other sectors and regions. The findings offer practical guidance for industry stakeholders on prioritising green purchasing and reverse logistics to improve both environmental and operational performance. By promoting sustainable practices within the petroleum supply chain, this study contributes to reducing environmental degradation and fostering sustainable development in developing economies.

Research implications: This research contributes to the sustainability literature by developing a model that integrates SSCMPS with environmental and operational performance outcomes, emphasising the mediating effect of operational performance. It provides actionable insights for policymakers and industry leaders, particularly in the context of developing economies.

Keywords: Sustainable supply chain management, sustainable supply chain management practices, environmental performance, petroleum industry, operational performance.

Introduction

The petroleum industry plays a crucial role in economic development but is also a significant contributor to environmental pollution. According to Kumar and Barua (2021, p. 1665): "The petroleum industry is often accused of environmental degradation because of its operational activities." Global efforts, such as the Paris Agreement and the UN Sustainable Development Goals (SDGs), emphasize the need for sustainability in high-impact industries (United Nations, 2015). Firms face increasing pressure to integrate sustainability into supply chain operations to ensure long-term viability and compliance with regulations. The petroleum industry is integral to Zimbabwe's economy and significantly contributes to environmental degradation due to its high levels of greenhouse gas emissions, pollution, and resource-intensive operations (International Energy Agency [IEA], 2021). Zimbabwe's petroleum sector imports over 1.5 billion liters of fuel annually and accounts for approximately 60% of national carbon emissions (ZERA, 2022). Weak enforcement of environmental policies and limited access to green technologies hinder sustainability adoption in the sector. The study investigates how SSCMPS can help address these challenges by improving environmental and operational performance.

The transition towards sustainable development, as well as reduced demand for fossil fuels, requires a complete transformation of existing production, consumption, and waste management systems and an increase in the sustainability of manufacturing sectors and energy production (Acquah et al., 2021; Agyabeng-Mensah et al., 2021; Habib et al., 2022). Over the past two decades, interest in the integration of economic and environmental aspects into supply chain management has been on the increase because of growing environmental awareness (Appiah et al., 2022; Cousins et al., 2019; Setyadi, 2019; Younis and Sundarakani, 2020). This shift reflects a broader recognition that environmental sustainability is not merely a limitation but a critical driver of value creation and competitive advantage. By integrating environmental considerations into supply chain strategies, decision-makers can optimize resource utilization, reduce waste, and minimize carbon footprints, ultimately enhancing both operational and environmental performance (Appiah et al., 2022). For instance, Green Supply Chain Management (GSCM) emphasizes practices such as eco-friendly procurement, waste reduction, recycling, and lifecycle analysis, showcasing how sustainability aligns with organizational goals and profitability. In this context, sustainable supply chain management practices (SSCMPS) have emerged as crucial tools, integrating

environmental sustainability into the petroleum supply chain. SSCMPS spans a range of activities, from green purchasing and manufacturing to reverse logistics and green information systems, all aimed at reducing negative environmental impacts (Carter and Rogers, 2008).

Jensen and Whitfield (2022) suggest that developing economies can leverage sustainable operations to tap opportunities in the global market. Al Amosh and Khatib (2023) and Awuah-Gyawu et al. (2024) argue that compliance with sustainability standards is key to promoting the performance outcomes of sustainability initiatives. With the increasing demand for sustainable products and services among industries around the world, it has become more important than ever to undertake comprehensive research on the effects of sustainable management practices or related fields from various supply chain aspects on firm performance (Awuah-Gyawu et al., 2024; Govindan et al., 2020; Meixell and Luoma, 2015) particularly among firms in Sub-Saharan Africa to understand when sustainable supply chain management practices pay off. Sustainable supply chain management practices (SSCMP) are defined as the extent to which firms incorporate environmental, social, and economic practices in their supply chain operations (Awuah-Gyawu et al., 2024; Giunipero et al., 2012).

The choice of Zimbabwe as a developing country for this study is justified by its unique economic and regulatory landscape. With limited access to clean technologies and weak enforcement of environmental policies, Zimbabwe's petroleum industry faces significant challenges in adopting sustainable practices (Mandaza et al., 2020). The study provides valuable insights applicable to other developing economies facing similar constraints. As companies in this industry face rising operational costs and increased scrutiny from both regulators and stakeholders, there is a pressing need to understand how SSCMPS can support environmental performance.

SSCMPS integrates environmental considerations into supply chain operations, including green purchasing, reverse logistics, and green manufacturing. Companies that adopt SSCMPS improve resource efficiency, reduce waste, and achieve long-term sustainability benefits. While studies on SSCMPS exist, few have explored their impact on petroleum supply chains in developing economies. This study examines the mediating role of operational performance, filling a key gap in the literature. Despite the growing interest in sustainable supply chains, little empirical

evidence exists on how SSCMPS influences both operational and environmental performance in the Zimbabwean petroleum industry. This study aims to develop an SSCM model that integrates environmental performance with operational performance, playing a mediating role specific to this high-impact sector.

The paper proceeds as follows: Section 2 reviews relevant literature and theoretical and conceptual frameworks, Section 3 outlines the methodology, Section 4 presents results, Section 5 discusses key findings and Section 6 concludes with implications and future research directions.

2. Literature review

2.1. Theoretical framework

2.1.1. Stakeholder Theory

Stakeholder Theory (Freeman, 1984) emphasizes that organizations must balance shareholder profit with ethical responsibilities toward other stakeholders, including communities, customers (consumers), suppliers, regulators, and environmental agencies. Implementing SSCMPS aligns with stakeholder expectations and enhances corporate social responsibility (CSR) initiatives.

2.1.2. Natural Resource-Based View (NRBV)

The Natural Resource-Based View (NRBV) (Hart, 1995) posits that firms can achieve a competitive advantage by effectively managing natural resources. Adoption of SSCMPS enhances resource efficiency, reduces waste, and promotes long-term sustainability in industries such as petroleum. The NRBV provides a strategic framework for firms to leverage sustainability as a source of competitive differentiation.

2.1.3. Sustainability Theory

Sustainability Theory (Elkington, 1999) advocates for the triple bottom line approach, balancing economic, environmental, and social performance. In the Zimbabwean petroleum sector, sustainable supply chain practices contribute to economic stability while minimizing environmental harm. This theory underscores the long-term benefits of integrating sustainability into supply chain operations.

This research integrates three theoretical perspectives to explain the adoption of SSCMPS and their impact on environmental performance: Stakeholder Theory, the Natural Resource-Based View (NRBV), and Sustainability Theory. Stakeholder Theory posits that organizations must balance shareholder profit with ethical responsibilities toward other stakeholders,

including communities and the environment (Freeman, 1984). In Zimbabwe's petroleum industry, this theory underscores the role of regulatory bodies, customers, and local communities in pushing for greener practices.

The NRBV argues that companies can gain a competitive advantage by managing resources sustainably, particularly when those resources are rare, valuable, and difficult to replicate (Hart, 1995). This view is relevant in resource-dependent industries like petroleum, where resource efficiency and environmental performance can differentiate companies. Sustainability Theory supports a triple bottom line approach, balancing economic, environmental, and social outcomes (Elkington, 1999). Together, these theories form the foundation for a conceptual model that links SSCMPS with environmental performance, mediated by operational performance.

2.2. A review of related literature and research gap

SSCMPS have been widely recognized for their role in enhancing environmental performance, particularly in developing economies. Empirical studies indicate that SSCMPS contributes to cost reductions, improved operational efficiency, and enhanced sustainability outcomes (Siddiqi et al., 2024). Research by Ali et al. (2024) demonstrates that eco-friendly purchasing and circular supply chains lead to a 30% reduction in carbon emissions and a 25% increase in resource efficiency. Similarly, Karaman et al. (2024) emphasize the significance of supplier environmental, social, and governance (ESG) training in strengthening the impact of SSCMPS on carbon emission reduction. Onukwulu et al. (2023) further support these findings by illustrating how renewable energy adoption, waste reduction, and logistics optimization contribute to a lower carbon footprint in the oil and gas industry. Moreover, Liu et al. (2024) highlight the mediating role of green innovation and zero waste management, underscoring their importance in enhancing the effectiveness of SSCMPS.

Operational performance has been identified as a key intermediary factor that links SSCM practices to environmental performance. Rasheed et al. (2023) found that SSCM implementation in the textile sector leads to improved operational efficiency, which translates into better environmental outcomes. Mokadem and Khalaf (2024) reinforce this by showing that SSCM positively affects environmental, social, and operational performance. Wiredu (2024) highlights the significance of waste management and eco-friendly manufacturing as crucial SSCM activities that improve both operational and environmental

performance. Stroumpoulis et al. (2024) further argue that digital transformation in supply chain management enhances operational efficiency, thereby amplifying the environmental benefits of SSCM. These studies collectively suggest that integrating operational performance as a mediating factor strengthens the link between SSCM and sustainability outcomes.

Despite the proven benefits of SSCMPS, several challenges hinder their effective implementation. Nweje and Taiwo (2025) note that balancing supply chain efficiency with sustainability goals is challenging due to complexities in green procurement and circular economy integration. Nazir et al. (2024) emphasize the moderating role of institutional pressure, finding that robust regulatory frameworks enhance the effectiveness of SSCMPS while weak institutional support limits progress. Siddiqi et al. (2024) highlight an unexpected finding that dynamic capabilities can negatively impact environmental performance, suggesting the need for further research on how these capabilities can be optimized to support sustainability efforts. Wang and Ozturk (2023) also stress the importance of internal environmental management in moderating the relationship between customer cooperation and ecological performance, pointing to the necessity of internal alignment within organizations for SSCM practices to be effective.

The empirical research supports the notion that SSCMPS significantly enhances environmental performance, particularly when operational efficiency is optimized, and institutional support is strong. However, gaps remain in understanding the precise mechanisms through which operational performance mediates the relationship between SSCM and environmental outcomes, as well as how industry-specific challenges can be addressed to maximize sustainability benefits. Future research should explore these areas further, with particular emphasis on developing economies and high-impact industries such as petroleum, to ensure that SSCMPS contributes to both environmental sustainability and economic viability. This is the basis upon which this research is executed.

2.3. Sustainable supply chain management practices in the petroleum industry

Sustainable Supply Chain Management (SSCM) involves the integration of environmental considerations into supply chain operations to improve long-term outcomes and reduce negative impacts on society and the environment (Lee et al., 2020; Mugoni et al., 2024). In the petroleum industry, where supply chains are resource-intensive and contribute substantially to greenhouse gas emissions, SSCMPS are viewed

as essential for achieving sustainability targets. Key sustainable supply management practices include green purchasing, green manufacturing, reverse logistics, green information systems, and green product design. Research indicates that SSCMPS can significantly reduce environmental impact by promoting recycling, optimizing logistics, and reducing waste (Mugoni et al., 2024; Sarkis et al., 2011). However, implementation varies globally, with developing countries like Zimbabwe facing unique barriers such as regulatory weaknesses, financial constraints, and limited infrastructure (Ayanda et al., 2019).

Sustainable Supply Chain Management (SSCM) integrates environmental, social, and economic dimensions into supply chain operations, promoting practices that reduce environmental degradation, conserve resources, and foster long-term sustainability (Lee et al., 2020; Mugoni et al., 2024). In high-impact industries, SSCMPS addresses several key operational areas:

- i. **Green Purchasing (GP):** This involves sourcing environmentally friendly materials, selecting suppliers who prioritize sustainability, and encouraging responsible practices throughout the supply chain (Govindan et al., 2014). GP is foundational for industries seeking to minimize environmental damage at the sourcing level.
- ii. **Green Manufacturing (GM):** GM focuses on reducing emissions, energy consumption, and waste throughout production processes, aligning operations with sustainability goals. This practice is especially relevant in petroleum refining, where green technologies can significantly reduce environmental impact (Sarkis et al., 2011).
- iii. **Green Distribution (GD):** This practice optimises logistics, emphasising energy-efficient transportation modes and route optimisation to minimise emissions (Tang and Zhou, 2019). GD aligns with industry needs for reducing fuel consumption and carbon emissions.
- iv. **Reverse Logistics (RL):** RL integrates waste management and recycling, which is critical for reducing landfill contributions and conserving resources. This is particularly important in industries with high material consumption, like petroleum (Xiao et al., 2019).
- v. **Green Product Design (GPD):** GPD involves designing products with reduced environmental impact, focusing on energy efficiency, recyclability, and minimized resource use. GPD contributes to sustainable lifecycle management, extending the environmental benefits of SSCMPS beyond the supply chain (Tundys and Wiśniewski, 2023).

vi. Green Information Systems (GIS): Digital systems track environmental metrics, supporting data-driven decision-making in sustainability. While promising, GIS is underutilized in Zimbabwe's petroleum industry due to limited technological infrastructure (Geng *et al.*, 2017).

Table 1 summarises the SSCMPS employed in this study.

Table 1: Sustainable Supply Chain Management Practices (SSCMPS)

SSCM Practice	Description	Key Authors	Relevance to This Study
Green Purchasing (GP)	Integrates environmental concerns into procurement policies, ensuring purchased materials are recyclable, non-toxic, and eco-friendly.	Verma (2014); Al-Ghwayeen & Abdallah (2018); Zhu <i>et al.</i> (2010); Saleh <i>et al.</i> (2017); Scur & Barbosa (2016); Green <i>et al.</i> (2012); Mugoni <i>et al.</i> (2024)	Highly relevant. GP reduces environmental harm and is widely recognized in petroleum supply chains.
Green Manufacturing (GM)	Implements cleaner production processes to minimize waste, emissions, and resource consumption.	Al-Ghwayeen & Abdallah (2018); Zhu <i>et al.</i> (2010); Diab <i>et al.</i> (2015); Jabbour <i>et al.</i> (2015); Hasan (2013); Soni (2022); Mugoni <i>et al.</i> (2024)	Essential. GM helps optimize resource use and reduce carbon footprints in petroleum operations.
Green Distribution (GD)	Focuses on eco-friendly logistics, including optimized transportation routes and fuel-efficient delivery systems.	Verma (2014); Soni (2022); Abdallah & Nabass (2018); Sharma <i>et al.</i> (2017); Diab <i>et al.</i> (2015); El Saadany <i>et al.</i> (2011); Mugoni <i>et al.</i> (2024)	Necessary. GD minimizes transportation-related emissions in petroleum supply chains.
Reverse Logistics (RL)	Enables product recovery, recycling, and reuse, reducing waste and enhancing circular economy efforts.	Verma (2014); Scur & Barbosa (2016); Al-Ghwayeen & Abdallah (2018); Abdallah & Al-Ghwayeen (2019); Diab <i>et al.</i> (2015); Saleh <i>et al.</i> (2017); Mugoni <i>et al.</i> (2024)	Critical. RL plays a vital role in managing waste and hazardous materials in petroleum industries.
Green Product Design (GPD)	Develops environmentally sustainable products with energy-efficient materials and recyclability in mind.	Zhu <i>et al.</i> (2010); Saleh <i>et al.</i> (2017); Abdallah & Nabass (2018); El Saadany <i>et al.</i> (2011); Sharma <i>et al.</i> (2017); Mugoni <i>et al.</i> (2024)	Important. GPD contributes to long-term sustainability in petroleum-related product life cycles.
Green Information Systems (GIS)	Utilises technology to monitor and manage environmental data, enabling informed sustainability decisions.	Panigrahi <i>et al.</i> (2018); Green <i>et al.</i> (2012); Omar <i>et al.</i> (2016); Abdallah & Al-Ghwayeen (2019); Mugoni <i>et al.</i> (2024)	Underutilized. GIS adoption in Zimbabwe's petroleum industry is low, but it has the potential to enhance sustainability.

2.4. Environmental performance

Environmental performance represents a company's ability to minimize its ecological impact, focusing on emission reductions, waste management, and efficient resource use (Mugoni *et al.*, 2024; Zhu *et al.*, 2008). SSCMPS contributes to environmental performance by promoting environmentally responsible operations

that align with regulatory standards and stakeholder expectations (Famiyeh *et al.*, 2018). Despite extensive research in developed countries, limited empirical studies address SSCMPS's role in improving environmental performance in developing regions (Miemczyk *et al.*, 2019). Table 2 presents the environmental performance constructs.

Table 2: Environmental Performance Constructs

Number	Environmental Performance Variables	Author/s
1	Reduction of solid/liquid waste and emissions	Zhu <i>et al.</i> (2010); El Saadany <i>et al.</i> (2011); Green <i>et al.</i> (2012); Diab <i>et al.</i> (2015); Saleh <i>et al.</i> (2017); Abdallah and Nabass (2018)
2	Reduction of consumption of hazardous and toxic materials	Zhu <i>et al.</i> (2010); Jabbour <i>et al.</i> (2015); Omar <i>et al.</i> (2016); Abdallah and Al-Ghwayeen (2019)
3	Reduction of frequency of environmental accidents	Green <i>et al.</i> (2012); Diab <i>et al.</i> (2015); Abdallah and Nabass (2018)

4	Reduction of electricity usage (energy consumption)	Hasan (2013); Green <i>et al.</i> (2012); Abdallah and Nabass (2018); Omar <i>et al.</i> (2016); Abdallah and Al-Ghwayeen (2019)
5	Compliance with environmental standards	El Saadany <i>et al.</i> (2011); Saleh <i>et al.</i> (2017); Abdallah and Al-Ghwayeen (2019); Hasan (2013); Diab <i>et al.</i> (2015); Scur and Barbosa (2016)
6	Improved firm's environmental image	Sharma <i>et al.</i> (2017); Abdallah and Nabass (2018); Abdallah and Al-Ghwayeen (2019)
7	Limited consumption of resources	Zhu <i>et al.</i> (2010); Green <i>et al.</i> (2012); Diab <i>et al.</i> (2015); Scur and Barbosa (2016); Abdallah and Nabass (2018)

2.5. Operational performance as a mediator

Operational performance is defined as a measure of a firm's ability to develop new products or services, enhance product or service quality, lower costs, and lower the risk of new product or service innovation in the market (Dubey *et al.*, 2020) business regulatory compliance describes an act of ensuring that business operations, practices, and processes adhere to pre-established social norms, values, and controls (Awuah-Gyawu *et al.*, 2024; Sadiq and Governatori, 2014; Sendawula *et al.*, 2021). Operational performance measured by efficiency, productivity, and cost-effectiveness can mediate the SSCMPS-environmental performance relationship. Operational efficiencies enable firms to implement SSCMPS effectively, enhancing their environmental impact (Mugoni *et al.*, 2024; Slack *et al.*, 2010). Operational

performance talks about the ability of a firm to build capacity, delivery speed as well and specification flexibility into service design, price, and promotion strategy to smooth demand (Leksono *et al.*, 2017; Nagariya *et al.*, 2021), reducing errors, mistakes and rework, reducing complaints, waiting time and causing improvement in serviced quality (Aliakbari Nouri *et al.*, 2019b; Nagariya *et al.*, 2021). High operational performance facilitates resource optimization and reduces waste, which amplifies SSCMPS benefits on environmental outcomes (Famiyeh *et al.*, 2018). This study posits that operational performance is a vital mediator in the Zimbabwean petroleum sector, where operational inefficiencies hinder sustainability efforts. Operational performance constructs are shown in Table 3.

Table 3: Operational Performance Constructs

Number	Operational Performance Variables	Author/s
1	Cost savings and increased efficiency	Green <i>et al.</i> (2012); Diab <i>et al.</i> (2015); Abdallah and Nabass (2018); Omar <i>et al.</i> (2016); Saleh <i>et al.</i> (2017)
2	Product quality improvement	Jabbour <i>et al.</i> (2015); Sharma <i>et al.</i> (2017); Abdallah and Al-Ghwayeen (2019); Green <i>et al.</i> (2012)
3	Increased flexibility	Abdallah and Nabass (2018); Abdallah and Al-Ghwayeen (2019); El Saadany <i>et al.</i> (2011); Omar <i>et al.</i> (2016)
4	Improved delivery (Decreased lead times)	Green <i>et al.</i> (2012); Diab <i>et al.</i> (2015); Saleh <i>et al.</i> (2017); Abdallah and Nabass (2018)
5	Increase in market share	Jabbour <i>et al.</i> (2015); Sharma <i>et al.</i> (2017); Abdallah and Al-Ghwayeen (2019)
6	New market opportunities	Green <i>et al.</i> (2012); Abdallah and Nabass (2018); Omar <i>et al.</i> (2016); Abdallah and Al-Ghwayeen (2019)
7	Enhanced employee motivation and increase in sales	El Saadany <i>et al.</i> (2011); Diab <i>et al.</i> (2015); Sharma <i>et al.</i> (2017); Abdallah and Nabass (2018)

2.6. Conceptualisation and development of hypotheses

The SSCMPS are critical in the functioning of the petroleum industry chain (Adam *et al.*, 2019). SSCMPS is defined as the management of material, capital, human, and information resources through cooperation among different and varied SCM firms that commit to the maintenance of environmental, economic as well as social stability to ascertain long-term sustainability (Hong *et al.*, 2018). In the quest for firms to reduce the adverse impact of activities on society and the environment on the backdrop of improving financial, market, as well as operational performances, supply chain processes, and activities play a significant role (Acquah *et al.*, 2020; Panigrahi *et al.*, 2018).

Various empirical studies have been assessed, and it has been found that there are several SSCMPS discussed by different researchers such as green purchasing (GP), green manufacturing (GM), green information systems (GIS), green product design (GPD), green distribution (GD), reverse logistics (RL), green packaging, green marketing, investment cover, eco-design and green building (Zhu and Sarkis, 2006; Schmidt *et al.*, 2017; Luthra *et al.*, 2017; Vanalle *et al.*, 2017; Green *et al.*, 2012; Soliman and Elkady, 2020). In light of these researches, six (6) SSCMPS are selected as shown in table 2.3 and further discussed in subsections below. Therefore,

SSCMPS = Green purchasing (GP) + Green manufacturing (GM) + Green Distribution (GD) + Reverse logistics (RL) + Green product design (GPD) + Green information systems (GIS).

2.6.1. Green Purchasing and environmental performance.

Green purchasing refers to acquiring products and services that minimize environmental impacts throughout their lifecycle, such as those made from recycled materials or through eco-friendly processes. It plays a crucial role in improving environmental performance by reducing waste and encouraging sustainable sourcing. For example, in the petroleum industry, green purchasing helps reduce emissions by opting for cleaner materials and services (Al-Ghussain *et al.*, 2020). In the manufacturing sector, green purchasing can lead to more sustainable supply chains by ensuring that suppliers adhere to environmental regulations, which reduces the ecological footprint (Khan *et al.*, 2021). Additionally, the construction industry benefits from green procurement by using eco-friendly materials, reducing the environmental impact of building processes (Azevedo *et al.*, 2017).

Expanding on this, green purchasing helps reduce energy consumption throughout the supply chain by prioritizing suppliers who adopt sustainable practices (Esfahbodi *et al.*, 2016). It also fosters supplier collaboration, leading to shared innovations in environmental sustainability (Feng *et al.*, 2020). This collaboration is particularly beneficial in industries like mining, where supplier management is critical to mitigating environmental risks. By reducing reliance on hazardous materials and promoting the use of eco-friendly alternatives, green purchasing directly contributes to reducing the environmental impacts of production (Raza *et al.*, 2021). Moreover, green purchasing supports the circular economy by facilitating the procurement of recycled and renewable materials, which reduces waste and supports resource conservation (Paulraj *et al.*, 2017). Thus, green purchasing is not only a key driver of environmental performance but also a strategic approach to sustainability across industries. Based on the above discussion, the following hypotheses are postulated:

H_{1a} Green Purchasing (GP) has a positive effect on environmental performance in the petroleum industry.

2.6.2. Green distribution and environmental performance.

Green distribution practices focus on minimizing the environmental impact of product transportation and storage, contributing to improved environmental performance across industries. In the logistics and retail sectors, green distribution strategies such as optimizing transportation routes and using eco-friendly vehicles can significantly reduce fuel consumption and carbon emissions (Barbieri *et al.*, 2022). In the petroleum industry, green distribution involves using pipelines or rail instead of trucks, which can reduce emissions and energy use (Al-Ghussain *et al.*, 2020). Similarly, in the manufacturing sector, adopting green distribution practices can help reduce the environmental impact of transporting raw materials and finished goods.

Optimizing logistics networks and adopting energy-efficient technologies are essential components of green distribution. By reducing transportation costs and minimizing fuel use, green distribution practices contribute to lower carbon footprints and improved sustainability (Sarkis & Zhu, 2018). Additionally, green distribution promotes the use of renewable energy in warehouses and storage facilities, further enhancing environmental performance. In the retail sector, reducing packaging materials and using biodegradable alternatives in distribution processes can minimize waste and improve sustainability (Agyabeng-Mensah *et al.*, 2020). Overall, green distribution plays a crucial role in reducing the environmental impact of

supply chains by optimizing transportation, reducing emissions, and minimizing waste across industries. Based on the above discussion, the following hypotheses are postulated:

H_{2a} : *Green distribution has a positive effect on environmental performance in the petroleum industry.*

2.6.3. Green manufacturing and environmental performance.

Green manufacturing involves adopting production processes that minimize waste, reduce emissions, and improve energy efficiency. This practice is integral to improving environmental performance across various industries, such as petroleum, mining, and electronics. In the petroleum industry, for instance, green manufacturing processes help reduce harmful emissions and optimize energy use, resulting in a more sustainable production environment (Al-Ghussain et al., 2020). Similarly, in the automotive and electronics industries, green manufacturing can lower energy consumption and emissions, contributing significantly to environmental performance (Wang et al., 2021).

Green manufacturing is also associated with cost savings and efficiency improvements. By reducing waste and optimizing resource use, companies in the manufacturing sector can achieve both environmental and economic benefits (Baah & Jin, 2019). Moreover, green manufacturing practices can enhance a company's competitive advantage by improving its sustainability image and complying with environmental regulations (Chung et al., 2020). For example, the use of energy-efficient technologies in manufacturing can lead to significant reductions in carbon emissions, which directly benefits the environment. Furthermore, adopting green technologies in manufacturing allows firms to better comply with increasingly stringent environmental regulations, reducing the risk of penalties and improving long-term sustainability (Azevedo et al., 2017). Therefore, green manufacturing not only enhances environmental performance but also provides companies with opportunities for operational efficiency and regulatory compliance. Based on the above discussion, the following hypotheses are postulated:

H_{3a} : *Green manufacturing (GM) has a positive effect on environmental performance in the petroleum industry.*

2.6.4. Green product design and environmental performance.

Green product design integrates sustainability principles into product development by focusing on recyclability, reduced material use, and extended product life cycles. This approach significantly

enhances environmental performance across industries such as automotive, consumer goods, and electronics. In the automotive industry, for instance, green product design focuses on developing vehicles that are more fuel-efficient and have lower emissions, thus reducing their environmental footprint (Paulraj et al., 2017). Similarly, in the consumer goods sector, green product design leads to products that require fewer resources, are easier to recycle, and generate less waste, which is beneficial for both manufacturers and consumers (Agyabeng-Mensah et al., 2020).

Green product design also reduces the use of toxic materials, enhancing sustainability in industries like chemicals and manufacturing (Gholami et al., 2016). By prioritizing the design of energy-efficient products, companies can lower energy consumption throughout the product lifecycle, further improving environmental performance. Moreover, green product design promotes innovation by encouraging companies to explore new materials and technologies that minimize environmental impact (He et al., 2020). For example, designing products for easy disassembly or recycling can significantly reduce the environmental costs associated with disposal. This approach supports the principles of the circular economy, ensuring that products are either reused or recycled, thus contributing to waste reduction and resource conservation (Azevedo et al., 2017). Green product design, therefore, plays a crucial role in enhancing environmental performance by promoting sustainability at every stage of the product lifecycle. Based on the above discussion, the following hypotheses are postulated:

H_{4a} : *Green product design has a positive effect on environmental performance in the petroleum industry.*

2.6.5. Green information systems and environmental performance.

Green information systems (GIS) leverage technology to monitor and manage environmental data, leading to improved resource efficiency and waste reduction. GIS is particularly effective in industries like logistics, petroleum, and manufacturing, where real-time tracking of emissions, energy consumption, and waste production can significantly enhance environmental performance (Khan et al., 2021). For instance, GIS allows logistics companies to optimize transportation routes, reducing fuel consumption and carbon emissions (Chong et al., 2019). Similarly, in the petroleum industry, GIS helps track and reduce emissions, thus improving overall environmental outcomes (Al-Ghussain et al., 2020).

GIS also enhances decision-making by providing executives with critical sustainability data, enabling

them to make informed decisions that balance operational efficiency with environmental sustainability (Ramudhin et al., 2021). For example, GIS can help companies identify areas where they can reduce energy use or implement renewable energy solutions, leading to lower emissions and improved environmental performance. In the manufacturing sector, GIS supports the implementation of green technologies by tracking their impact on resource consumption and waste production (Chong et al., 2019). Moreover, GIS plays a key role in ensuring compliance with environmental regulations by providing accurate and timely data on emissions and other environmental metrics (Khan et al., 2021). Overall, GIS is a powerful tool for enhancing environmental performance across industries by optimizing resource use, reducing waste, and improving decision-making. Based on the above discussion, the following hypotheses are postulated:

H_{5a}: Green information systems have a positive effect on environmental performance in the petroleum industry.

2.6.6. Reverse logistics and environmental performance.

Reverse logistics, which involves the processes of recycling, remanufacturing, and managing product returns, plays a vital role in improving environmental performance by reducing waste and supporting the circular economy. In industries such as electronics and automotive, reverse logistics allows companies to reclaim value from used or returned products, thus reducing the need for new materials and lowering overall environmental impact (Govindan et al., 2020). By implementing reverse logistics, companies in the retail and consumer goods sectors can minimize landfill waste by reintroducing used products or packaging into the supply chain, supporting sustainability goals (Giri & Sharma, 2020).

Furthermore, reverse logistics helps reduce resource consumption and carbon emissions by optimizing the reuse and recycling of materials (Govindan et al., 2020). For example, in the construction industry, reverse logistics can involve reclaiming materials from demolition sites for reuse in new projects, significantly reducing the demand for raw materials and minimizing environmental impact. In the petroleum industry, reverse logistics contributes to waste reduction by reclaiming and recycling hazardous materials, thus improving environmental performance (Al-Ghussain et al., 2020). Additionally, reverse logistics enhances supply chain efficiency by improving inventory management and reducing transportation costs, both of which contribute to better environmental outcomes (Mishra et al., 2018). As a result, reverse logistics not only supports environmental performance but also

promotes operational efficiency and sustainability across industries. Based on the above discussion, the following hypotheses are postulated:

H_{6a}: Reverse logistics has a positive effect on environmental performance in the petroleum industry.

2.6.7. Green Purchasing and operational performance.

Green purchasing not only enhances environmental performance but also improves operational performance by fostering supplier collaboration and innovation. By working closely with suppliers to meet environmental goals, companies can optimize procurement processes, reduce costs, and improve supply chain efficiency (Esfahbodi et al., 2016). For example, in the mining industry, green purchasing helps ensure that suppliers adhere to sustainability standards, reducing operational risks and improving efficiency. Similarly, in the petroleum industry, green procurement practices enable companies to lower production costs by sourcing eco-friendly materials and services (Al-Ghussain et al., 2020).

Green purchasing also improves operational performance by promoting the use of energy-efficient materials and technologies (Raza et al., 2021). In the construction sector, for instance, green procurement helps reduce material costs and improve project timelines by ensuring that suppliers provide sustainable, high-quality materials (Azevedo et al., 2017). Additionally, green purchasing enhances supply chain resilience by encouraging suppliers to innovate and adopt sustainable practices, which leads to better operational outcomes. In the retail and manufacturing sectors, green procurement improves inventory management and reduces waste, leading to cost savings and operational efficiency (Feng et al., 2020). As a result, green purchasing contributes to improved operational performance across a range of industries by optimizing procurement processes, reducing costs, and fostering innovation. Based on the above discussion, the following hypotheses are postulated:

H_{1b}: Green Purchasing has a positive effect on operational performance in the petroleum industry.

2.6.8. Green distribution and operational performance.

Green distribution practices, such as optimizing transportation routes and using eco-friendly vehicles, can lead to cost savings and improved efficiency. According to Geng et al. (2022), green distribution reduces transportation costs and improves the overall

efficiency of the supply chain. This improvement in logistics efficiency directly enhances operational performance. Based on the above discussion, the following hypotheses are postulated:

H_{2b}: Green distribution has a positive effect on operational performance in the petroleum industry.

2.6.9. Green manufacturing and operational performance.

Green manufacturing refers to production processes that minimize waste, reduce emissions, and improve energy efficiency. These practices have a positive effect on operational performance by streamlining production, reducing material costs, and enhancing resource utilization. For instance, in the automotive and electronics industries, green manufacturing can lead to more efficient processes that lower energy and material costs (Raza et al., 2021). In the petroleum industry, green manufacturing technologies help reduce energy consumption and operational expenses by improving the efficiency of extraction and processing activities (Al-Ghussain et al., 2020).

Green manufacturing also fosters innovation, leading to improved product quality and reduced production times (Feng et al., 2020). In the mining industry, implementing green manufacturing techniques such as waste recycling and pollution control improves operational efficiency by reducing resource wastage and enhancing compliance with environmental regulations. Additionally, green manufacturing practices increase flexibility in production, allowing firms to respond quickly to market changes while maintaining operational efficiency. In the construction industry, green manufacturing processes ensure that sustainable building materials are produced in an energy-efficient manner, reducing costs and improving the overall project timeline (Azevedo et al., 2017). Therefore, green manufacturing positively impacts operational performance by optimizing resource use, reducing waste, and improving production processes across industries. Based on the above discussion, the following hypotheses are postulated:

H_{3b}: Green manufacturing has a positive effect on operational performance in the petroleum industry.

2.6.10. Green product design and operational performance.

Green product design emphasizes creating products that are energy-efficient, recyclable, and environmentally friendly. This focus enhances operational performance by reducing material and production costs, improving product quality, and

fostering innovation. For example, in the consumer goods sector, green product design allows companies to produce goods that require fewer materials, reducing production costs and waste (Dey et al., 2020). In the automotive industry, designing vehicles with lower emissions and improved fuel efficiency enhances operational efficiency by optimizing production processes and reducing material use.

Green product design also contributes to operational flexibility by enabling companies to respond quickly to changing market demands for sustainable products. In the manufacturing sector, designing products for reuse and recycling supports the circular economy, allowing firms to extend product lifecycles and reduce the costs associated with waste disposal (Paulraj et al., 2017). In the retail industry, green product design improves supply chain efficiency by reducing packaging and transportation costs. Additionally, by reducing the use of harmful materials, green product design lowers compliance costs and enhances operational performance, particularly in sectors such as chemicals and construction (Gholami et al., 2016). As a result, green product design has a significant positive effect on operational performance by optimizing resource use, enhancing product quality, and fostering innovation. Based on the above discussion, the following hypotheses are postulated:

H_{4b}: Green product design has a positive effect on operational performance in the petroleum industry.

2.6.11. Green information systems and operational performance.

The use of green information systems enhances operational performance by optimizing resource use and reducing inefficiencies. Khan et al. (2021) note that GIS enables companies to monitor their supply chain in real time, allowing for better decision-making and improved operational efficiency. Ramudhin et al. (2021) support this by highlighting how GIS contributes to cost savings and better resource allocation. Based on the above discussion, the following hypotheses are postulated:

H_{5b}: Green information systems have a positive effect on operational performance in the petroleum industry.

2.6.12. Reverse logistics and operational performance.

Reverse logistics improves operational performance by providing firms with opportunities to reclaim value from returned products and reduce waste. Govindan et al. (2020) argue that reverse logistics enables companies to optimize resource use and reduce costs

associated with waste disposal. Mishra et al. (2018) add that integrating reverse logistics leads to better inventory management and cost savings. Based on the above discussion, the following hypothesis is postulated:

H_{6b} : Reverse logistics has a positive effect on operational performance in the petroleum industry.

2.6.13. Operational performance mediates the influence of Green Purchasing on environmental performance.

Green purchasing focuses on acquiring products and services that minimize environmental impacts throughout their lifecycle. Operational performance, which encompasses factors such as efficiency, quality, and productivity, can act as a mediator in translating green purchasing practices into improved environmental outcomes.

Recent studies support this mediation effect. For instance, green purchasing practices not only reduce waste and resource consumption but also lead to cost efficiencies and improved operational processes. These improvements in operational performance, such as enhanced supplier management and resource allocation, subsequently contribute to environmental performance by lowering emissions and waste (Baah & Jin, 2019).

Additionally, green purchasing drives collaboration with eco-friendly suppliers, fostering more sustainable operational practices, which in turn improve environmental performance (Feng, Zhu, & Sarkis, 2020). In industries like manufacturing, where procurement is directly linked to production processes, the mediating role of operational performance is even more evident (Agyabeng-Mensah et al., 2020). Based on the above discussion, the following hypotheses are postulated:

H_{1c} : Operational performance mediates the influence of Green Purchasing (GP) on environmental performance in the petroleum industry.

2.6.14. Operational performance mediates the influence of Green Distribution on environmental performance.

Green distribution involves environmentally friendly practices in the transportation and delivery of products. Operational performance is essential for ensuring that green distribution methods, such as optimizing routes and using energy-efficient vehicles, result in better environmental performance. Efficient green distribution can reduce carbon emissions and

fuel consumption, thereby improving environmental performance (Barbieri, Ghisetti, & Gilli, 2022). Operational performance mediates this relationship by ensuring that logistics are optimized for sustainability. In industries such as retail and e-commerce, where distribution networks are critical, operational improvements play a key role in ensuring that green distribution contributes to environmental sustainability (Agyabeng-Mensah et al., 2020). Based on the above discussion, the following hypotheses are postulated:

H_{2c} : Operational performance mediates the influence of Green distribution (GD) on environmental performance in the petroleum industry.

2.6.15. Operational performance mediates the influence of Green Manufacturing on environmental performance.

Green manufacturing involves processes that reduce waste, energy consumption, and emissions during production. Operational performance is key in maximizing these eco-friendly initiatives, thus improving environmental performance. Operational performance improvements, such as enhanced production efficiency and reduced resource usage, are crucial for linking green manufacturing efforts to environmental outcomes (Chung, Park, & Lee, 2020). For example, by streamlining processes, companies can minimize waste and energy use, which directly benefits environmental performance. In industries such as automotive or electronics, where manufacturing processes are resource-intensive, operational performance plays a pivotal mediating role (Wang, Zhang, & Zhang, 2021). Based on the above discussion, the following hypotheses are postulated:

H_{3c} : Operational performance mediates the influence of Green manufacturing (GM) on environmental performance in the petroleum industry.

2.6.16. Operational performance mediates the influence of Green Product Design on environmental performance.

Green product design involves designing products that are energy-efficient, recyclable, and environmentally friendly. The relationship between green product design and environmental performance is enhanced when operational performance mediates the process. Operational performance improvements, such as efficient production techniques and better resource management, make green product designs more viable by lowering costs and reducing material waste (He et al., 2020). In industries like consumer goods and packaging, operational efficiency ensures that eco-friendly designs are implemented without

compromising profitability, thereby enhancing environmental performance (Paulraj, Chen, & Blome, 2017). Based on the above discussion, the following hypotheses are postulated:

H_{4c}: Operational performance mediates the influence of Green product design (GPD) on environmental performance in the petroleum industry.

2.6.17. Operational performance mediates the influence of Green Information Systems on environmental performance.

Green Information Systems (GIS) use technology to monitor and manage environmental data, which enhances both operational and environmental performance. GIS helps organizations optimize their processes, leading to improved energy efficiency and resource management. Recent studies emphasize the role of operational performance as a mediator between GIS and environmental outcomes. By optimizing data collection and process management through information systems, companies can make informed decisions that enhance both operational efficiency and environmental performance (Chong, Teo, & Chai, 2019). For instance, in logistics and manufacturing, GIS enables more efficient route planning and energy use, which ultimately reduces environmental impact (Khan, Zhang, & Kumar, 2021). Based on the above discussion, the following hypotheses are postulated:

H_{5c}: Operational performance mediates the influence of Green information systems (GIS) on environmental performance in the petroleum industry.

2.6.18. Operational performance mediates the influence of Reverse Logistics on environmental performance.

Reverse logistics refers to the process of managing returns, recycling, and the reuse of products. It has a significant impact on environmental sustainability by reducing waste and promoting the circular economy. Operational performance plays a mediating role in making reverse logistics more effective in reducing environmental impact.

Research indicates that when reverse logistics processes are optimized, operational performance benefits from reduced costs, streamlined transportation, and improved inventory management (Govindan, Soleimani, & Kannan, 2020). These improvements in operational performance, in turn, facilitate environmental performance through reduced carbon emissions and resource recovery. For example, in the electronics industry, reverse logistics can minimize electronic waste by reintroducing used products into the supply chain (Mangla, Song, & Sun,

2021). Based on the above discussion, the following hypotheses are postulated:

H_{6c}: Operational performance mediates the influence of Reverse logistics (RL) on environmental performance in the petroleum industry.

2.6.19. Influence of operational performance on environmental performance.

Several studies have found a correlation between a company's environmental performance and operational performance outcomes like cost, quality, delivery, and flexibility (Inman & Green, 2018; Thanki & Thakkar, 2020; Famiyeh et al., 2018). These findings corroborate previous findings (Hanna et al., 2000; Bonifant, 1994; Curkovic et al., 2000; Klassen & McLaughlin, 1996; Rothenberg et al., 2001; Montabon et al., 2000; Tibor & Feldman, 1996) that the operations function is pivotal to environmental performance by reducing the negative effects of the firm's activities on the environment. As consumers expect more transparency and accountability from businesses, companies that take steps to reduce their environmental effects are more likely to win client loyalty. Many studies have discussed how a company's environmental performance might affect its market value (Sayre, 1996; Tibor & Feldman, 1996; Corbett & Kirsch, 2001; Inman & Green, 2018; Thanki & Thakkar, 2020; Famiyeh et al., 2018). A lot of research has been done on the topic, and many of the findings point to a correlation between low prices and good environmental performance. A company's environmental performance usually improves as pollution and waste systems are reduced. If, for instance, a company is able to manufacture high-quality goods the first time around, it will lessen the need for rework, hence decreasing its consumption of energy and waste. Having more money on hand to put toward new ventures is only one benefit of less rework (Inman & Green, 2018; Thanki & Thakkar, 2020; Famiyeh et al., 2018).

The success of an organization's products and services in satisfying customers is measured by how well they are delivered in terms of factors like speed, reliability, and accuracy (Rao et al., 2011; Inman & Green, 2018; Thanki & Thakkar, 2020; Famiyeh et al., 2018). The health of the environment and the safety of its inhabitants are two of the many priorities that consumers look at (Zeithaml et al., 1990). According to Sroufe (2000), there is a favorable correlation between delivery performance and environmental performance. This is due to the fact that improved efficiency and reduced waste can be seen in a company's delivery performance. Reducing waste and improving process efficiency can have a significant positive effect on a company's environmental

footprint, especially in the area of delivery (Inman & Green, 2018; Thanki & Thakkar, 2020; Famiyeh et al., 2018).

The relationship between Environmental Sustainability and operational practices can be hypothesized based on a review and analysis of existing literature. For instance, the implementation of environmentally sustainable practices (ESP) in firms tends to reduce their energy and raw material consumption, resulting in a reduction in operational costs (Hasan, 2013). Another study investigated the implementation of environmentally sustainable practices in Japanese pulp and paper industries and found a positive influence on firms' operational performance (Shimomura, 2001). A significant association between ESP and improved quality was reported by Melnyk et al. (2003). Similarly, Nidumolu et al. (2009) said that the implementation of ESP, such as life cycle assessment in a multi-national firm, has led to an increase in quality operational performance. A study by Sroufe (2003) also supported the claim that ESP tends to enhance firms' operational performance.

According to conventional wisdom, a company's flexibility performance is measured by how well it can adapt to changes in product category, demand volume, demand mix, and product delivery (Inman & Green, 2018; Thanki & Thakkar, 2020; Famiyeh et al., 2018). Customers have come to anticipate that businesses can adapt their operations to meet their needs. This research contends that a company's operational success in terms of adaptability might contribute to better environmental performance. This is because businesses would be able to respond to changes in client demand, especially in terms of volume, without resorting to inefficient practices that would result in excessive resource use and degradation of the natural environment (Inman & Green, 2018; Thanki & Thakkar, 2020; Famiyeh et al., 2018). If a company is unable to adapt its operations in response to a reduction in demand, it will have to cope with the consequences of having too much stock on hand. Stocks require energy and other resources to be held, which can increase a company's ecological footprint or impact (Inman & Green, 2018; Thanki & Thakkar, 2020; Famiyeh et al., 2018).

As Shrivastava (1995) argued, an organization's environmental performance can be improved by prioritizing complete quality, improved cost, and flexibility. The second aim of this study is to investigate how cost-cutting, quality-enhancing, speedy service, and adaptable procedures affect an organization's environmental performance (Inman & Green, 2018; Thanki & Thakkar, 2020; Famiyeh et al., 2018). Operational performance improvements

often lead to better environmental outcomes, as efficient processes use fewer resources and generate less waste. Feng et al. (2020) found that higher operational performance enhances a firm's ability to meet environmental goals, as efficient resource use and waste minimization directly contribute to sustainability efforts. Based on the above discussion, the following hypothesis was developed:

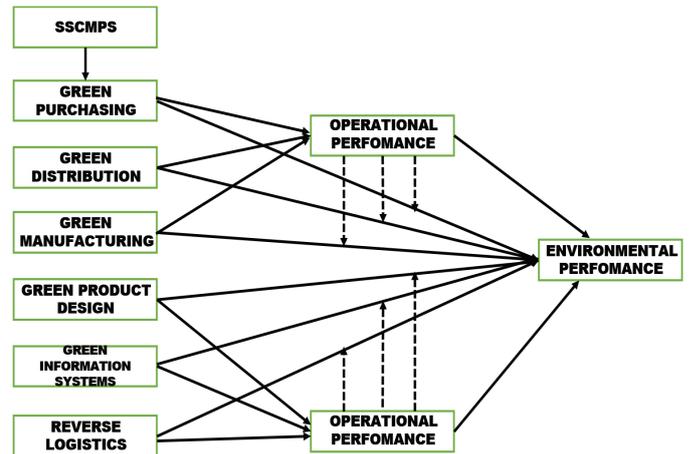


Figure 1: Proposed Research Model

The diagram visually represents the hypothesized causal pathways among the constructs. Six sustainable supply chain management practices (Green Purchasing, Green Distribution, Green Manufacturing, Green Product Design, Green Information Systems, and Reverse Logistics) are posited to directly influence both operational performance and environmental performance in the petroleum industry. Moreover, operational performance is hypothesized to mediate the influence of each sustainable supply chain management practice on environmental performance. The numbered labels refer to the following hypotheses:

Direct Effects

The hypotheses suggest two sets of direct relationships:

SSCMPS → Environmental Performance:

Each SSCM practice is expected to directly enhance environmental performance. For example, green manufacturing (GM) reduces waste, improving environmental performance.

SSCMPS → Operational Performance:

The same practices are hypothesized to boost operational performance. For example, reverse logistics (RL) lowers costs, improving operational performance.

Mediating Role of Operational Performance

The framework proposes that operational performance acts as a mediator between SSCMPS and environmental performance:

SSCMPS → OP → EP:

Improvements in operational performance (e.g., streamlined processes) further amplify the environmental benefits of SSCMPS. For example, green purchasing (GP) improves inventory efficiency (OP), which in turn reduces resource waste (EP).

Direct Link: Operational → Environmental Performance

This relationship asserts a standalone positive relationship between operational and environmental performance, independent of SSCMPS. For example, efficient operations (OP) reduce energy consumption, directly benefiting the environment (EP).

3. Methodology

3.1. Research design and data collection

A quantitative approach was employed to test the relationships between SSCMPS, operational performance, and environmental performance within the Zimbabwean petroleum industry. This methodology ensures a data-driven assessment of the relationships among SSCMPS, operational performance, and environmental outcomes. The survey was conducted with 226 supply chain professionals across different roles and organizational levels, providing comprehensive insights into SSCMPS adoption and effectiveness. A structured questionnaire, validated in previous studies (e.g., Zhu *et al.*, 2008), was used to collect data. The response rate was high at 82%, suggesting strong engagement among industry professionals on sustainability issues.

A stratified random sampling method was employed to ensure representation from various segments of the supply chain, including procurement managers, logistics coordinators, and sustainability officers. The sample was selected to ensure representation from various organizational levels, capturing insights from professionals directly involved in supply chain and operational decision-making. Data were collected using a structured questionnaire with validated scales, ensuring reliability and validity through pre-testing and Confirmatory Factor Analysis (CFA). A pre-test was conducted with 30 respondents to validate the survey instrument, ensuring clarity, reliability, and construct validity before full-scale data collection. This

represented about 10% of the sample size, which is generally recommended by social scientists (Mugenda *et al.*, 2012). The researcher used purposive sampling in choosing the 19 members for pilot testing from the target population but not the purpose of the study sample to avoid repeat bias.

3.2. Study context

The petroleum industry was selected for this study due to its significant environmental impact and complex supply chain, making it an ideal context for examining sustainable supply chain management practices (SSCMPS). As a high-impact sector, it is associated with substantial carbon emissions and resource depletion, highlighting the need for sustainability initiatives. Zimbabwe was chosen as the study setting because of its unique socio-economic and environmental challenges, including resource constraints, regulatory gaps, and infrastructural limitations, which hinder SSCMPS adoption. The country's petroleum industry, characterized by fuel shortages, reliance on imports, and limited technological advancement, provides a critical context for exploring barriers and opportunities in implementing green purchasing, reverse logistics, and green information systems. By focusing on Zimbabwe, this study offers insights into how sustainable practices can be adopted in resource-constrained settings, contributing to both theoretical and practical knowledge for developing economies facing similar challenges.

3.3. Analytical approach

Structural Equation Modeling (SEM) was used to analyze the hypothesized relationships among SSCMPS, operational performance, and environmental performance. SEM is particularly effective for testing mediation effects and complex models with multiple constructs (Hair *et al.*, 2017). The analysis was conducted using SmartPLS software, which is well-suited for predictive modeling in exploratory studies. Key model fit indices, including the Comparative Fit Index (CFI) and Root Mean Square Error of Approximation (RMSEA), were within acceptable ranges, supporting the model's robustness and construct validity.

3.4. Structural equation modeling (sem) with smartpls

Structural Equation Modeling (SEM) is an ideal analytical tool for supply chain management (SCM) research due to its ability to model complex relationships among latent constructs and observed variables. SEM is particularly useful in SCM research, where multiple interrelated factors, such as sustainability practices,

operational performance, and environmental performance, need to be examined simultaneously (Hair et al., 2017). Variance-based SEM software like SmartPLS is especially advantageous for exploratory research, as it can handle complex models with relatively small sample sizes and does not require strict normality assumptions, making it suitable for non-normal data often found in SCM studies (Ringle et al., 2015; Henseler et al., 2015). SEM's predictive modeling capabilities, combined with bootstrapping and blindfolding techniques, enhance result reliability and enable robust hypothesis testing, which is critical for identifying key drivers of performance in supply chains (Sarstedt et al., 2019; Chin, 2010). However, variance-based SEM may be less precise in detecting small effect sizes compared to covariance-based SEM, necessitating additional robustness checks to validate findings (Hair et al., 2017).

Recent studies have demonstrated SEM's versatility in addressing contemporary SCM challenges. For example, Kumar et al. (2021) used SEM to explore the role of digital technologies in enhancing supply chain agility and resilience during the COVID-19 pandemic, while Ali et al. (2022) employed SEM to investigate the impact of circular economy practices on sustainable supply chain performance, highlighting the mediating role of innovation capabilities. Similarly,

Ivanov et al. (2021) applied SEM to analyze the relationship between supply chain 4.0 technologies and organizational performance, emphasizing the moderating role of environmental dynamism. These applications underscore SEM's value in advancing SCM research, particularly in areas like sustainability, digital transformation, and resilience, where complex interactions and predictive insights are critical (Kumar et al., 2021; Ali et al., 2022; Ivanov et al., 2021).

3.5. Measurement of Constructs

The primary constructs in this study include SSCMPS, operational performance, and environmental performance. SSCMPS was operationalized through six dimensions: green purchasing, green manufacturing, green distribution, reverse logistics, green information systems, and green product design (Mugoni et al., 2024). Operational performance was measured through indicators such as cost efficiency, delivery timeliness, and productivity. Environmental performance was assessed based on metrics including waste reduction, resource conservation, and emissions control (Zhu et al., 2008).

The primary constructs (SSCMPS, Operational Performance, and Environmental Performance) were operationalized as shown in Table 4, with indicators:

Table 4: Primary constructs

Construct	Sub-Construct	Indicators	Sources
SSCMPS	Green Purchasing	Environmentally preferred materials	Govindan et al. (2014)
	Green Manufacturing	Emission reduction, waste minimization.	Sarkis et al. (2011)
	Green Distribution	Energy-efficient logistics	Tang and Zhou (2019)
	Reverse Logistics	Recycling, waste recovery	Xiao et al. (2019)
	Green Product Design	Product recyclability, energy efficiency	Tundys and Wiśniewski (2023)
	Green Information Systems	Tracking environmental data	Geng et al. (2017)
Operational Performance		Cost efficiency, productivity	Slack et al. (2010)
Environmental Performance		Emission reduction, resource conservation	Zhu et al. (2008)

4. Results

4.1. Reliability and validity

The high-reliability scores across all constructs (Table 5) in this study align with standards in supply chain sustainability research, where Cronbach's Alpha values above 0.70 indicate strong internal consistency (Hair et al., 2017). For instance, studies by Famiyeh et al. (2018) and Govindan et al. (2020) highlight the importance of high composite reliability in examining

sustainability constructs, particularly within industries facing environmental challenges, such as petroleum. The AVE values surpassing 0.50 confirm convergent validity (Hair et al., 2017). Table 6 applies the Fornell-Larcker Criterion to assess the discriminant validity of constructs related to SSCMPS, operational performance, and environmental performance. This criterion, originally introduced by Fornell and Larcker (1981), ensures that each construct is statistically distinct from others, reinforcing the theoretical integrity of the study. In SCM research, discriminant

validity is essential for confirming that constructs such as GM, RL, and GP are not only correlated but also independent in their impact on performance outcomes. Previous studies, including Green et al. (2012) and Jabbour et al. (2015), have used this criterion to validate the relationship between sustainable practices and firm performance, confirming that operational improvements and environmental sustainability efforts contribute uniquely to business success. Similarly, Zhu et al. (2010) and Abdallah & Al-Ghwayeen (2019) applied this method to distinguish between GD and

GIS, ensuring that these constructs, though related, measure separate dimensions of sustainability. The application of the Fornell-Larcker Criterion in Table 6 aligns with prior research (Shi et al., 2012; Jassim et al., 2020) by demonstrating that SSCMPs significantly influence both operational and environmental performance while maintaining conceptual and statistical independence. This validation is crucial for reliable conclusions on how sustainability initiatives enhance cost savings, waste reduction, and market competitiveness in modern SCs.

Table 5: Reliability and Validity

RELIABILITY AND VALIDITY					
	Number of items tested	Cronbach's Alpha	Composite Reliability (rho_a)	Composite Reliability (rho_c)	Average Variance Extracted (AVE)
Environmental Performances (EP)	10	0,923	0,924	0,935	0,906
Green Distribution (GD)	10	0,894	0,912	0,913	0,832
Green Information Systems (GIS)	9	0,922	0,924	0,935	0,815
Green Manufacturing (GM)	10	0,866	0,872	0,89	0,806
Green Product Design (GPD)	6	0,9	0,901	0,923	0,667
Green Purchasing (GP)	10	0,934	0,936	0,943	0,86
Operational Performance (OP)	10	0,916	0,934	0,931	0,783
Reverse Logistics (RL)	10	0,882	0,886	0,904	0,788
SSCMP	6	0.826	0.803	0.864	0.784

Source: Survey data (2024)

4.1.1. Discriminant Validity - Hetrotrait Monotrait Ratio (HTMT) Matrix

The HTMT values in this study meet the threshold for acceptable discriminant validity, consistent with guidelines in structural equation modeling (Henseler et al., 2015). Recent studies on sustainable supply chain practices underscore the necessity of maintaining discriminant validity among related constructs, such as green purchasing and green product design, to ensure an accurate assessment of their individual impacts on environmental performance (Wang et al., 2021).

Table 6 applies the HTMT Ratio to assess discriminant validity, ensuring that constructs measuring different aspects of SSCMPs, operational performance, and environmental performance remain statistically distinct. The HTMT criterion, introduced by Henseler et al. (2015), is widely used in SCM research to confirm that latent variables such as GM, GD, and GIS are not

excessively correlated, thus preserving the theoretical uniqueness of each construct. Studies by Green et al. (2012) and Jabbour et al. (2015) emphasize the importance of discriminant validity in analyzing the relationship between sustainable practices and firm performance, ensuring that the benefits of SSCMPs on cost savings, waste reduction, and efficiency are accurately measured. Similarly, research by Zhu et al. (2010) and Abdallah & Al-Ghwayeen (2019) has used the HTMT ratio to validate sustainability constructs, distinguishing between related yet separate elements such as RL and GP. The results in Table 6 align with existing literature (Shi et al., 2012; Jassim et al., 2020), demonstrating that SSCMPs significantly influence operational and environmental performance while maintaining conceptual clarity. By ensuring robust discriminant validity through HTMT analysis, this study strengthens the empirical reliability of its findings on the role of sustainable practices in enhancing supply chain efficiency and competitive advantage.

Table 6: Discriminant Validity – Hetrotrait Monotrait Ratio (HTMT) Matrix

DISCRIMINANT VALIDITY – HETROTRAIT MONOTRAIT RATIO (HTMT) MATRIX									
	EP	GD	GIS	GM	GPD	GP	OP	RL	SSC-MPs
Environmental Performances (EP)	1								
Green Distribution (GD)	0,572	1							
Green Information Systems (GIS)	0,686	0,771	1						
Green Manufacturing (GM)	0,658	0,701	0,666	1					
Green Product Design (GPD)	0,681	0,737	0,817	0,653	1				
Green Purchasing (GP)	0,747	0,751	0,795	0,744	0,891	1			
Operational Performances (OP)	0,884	0,647	0,677	0,673	0,749	0,768	1		
Reverse Logistics (RL)	0,646	0,765	0,781	0,709	0,718	0,798	0,681	1	
SSCMPs	0,688	0,869	0,832	0,841	0,888	0,803	0,739	0,836	1

Source: Survey data (2024)

4.2. Results of hypothesis testing and path coefficients

This section presents the findings from hypothesis testing and the analysis of path coefficients derived from the structural equation modeling (SEM) approach. The results, illustrated in Figure 1 (model) and detailed in Table 7, provide critical insights into the relationships between the theoretical constructs and their respective observable variables. The path coefficients indicate the strength and direction of the hypothesized relationships, while their significance levels determine the validity of the proposed hypotheses. The analysis not only evaluates the overall fit of the model but also identifies the key drivers of the constructs under study, offering a deeper understanding of their direct and indirect effects on supply chain and environmental performance.

Green Purchasing ($\beta = 0.152, p < 0.001$) and Reverse Logistics ($\beta = 0.228, p < 0.001$) were found to significantly enhance environmental performance, highlighting their critical roles in sustainable supply chain management practices (SSCMPS). However, Green Information Systems ($\beta = -0.181, p = 0.125$) had an insignificant effect, suggesting challenges in the adoption and implementation of technological solutions within Zimbabwe’s petroleum industry. Additionally, Operational Performance ($\beta = 0.611, p < 0.001$) emerged as a strong mediator between SSCMPS and environmental performance, underscoring the importance of operational efficiency in driving sustainability outcomes. These findings collectively emphasize the varying impacts of different SSCMPS components and the pivotal role of operational performance in achieving environmental sustainability goals.

Table 7: Results of hypothesis testing and path coefficients

Proposed hypothesis relationship	Hypothesis	SRW	Path Coefficient	Confidence interval		P – value	Rejected/ Supported
				2.5%	97.55%		
SSCMP → EP	H _a	0.114	0.149	0.083	0.254	0.0835	Supported
GP → EP	H ₁	0.115	0.152	0.107	0.243	0.000	Supported
GM → EP	H ₂	0.101	0.120	0.09	0.253	0.000	Supported
GPD → EP	H ₃	0.168	-0.008	-0.027	0.083	0.104	Not Supported
RL → EP	H ₅	0.085	0.228	0.183	0.375	0.000	Supported
GIS → EP	H ₆	0.091	-0.181	-0.264	0.106	0.125	Not Supported
GD → EP	H ₇	0.164	0.040	0.027	0.164	0.023	Supported
SSCMP → OP	H _b	0.110	0.720	0.362	0.879	0.000	Supported

GP → OP	H ₈	0.020	0.074	0.009	0.168	0.018	Supported
GM → OP	H ₉	0.051	0.168	0.09	0.253	0.000	Supported
GPD → OP	H ₁₀	0.110	0.075	0.03	0.190	0.016	Supported
RL → OP	H ₁₁	0.164	0.491	0.375	0.758	0.000	Supported
GIS → OP	H ₁₂	0.091	-0.075	-0.173	0.145	0.067	Not Supported
GD → OP	H ₁₃	0.051	0.159	0.105	0.284	0.000	Supported
OP → EP	H ₄	0.164	0.611	0.279	0.903	0.000	Supported
Mediation		0.085	0.800	0.476	0.973	0.000	Supported
GM → OP → EP	H ₁₄	0.020	0.103	0.117	0.253	0.000	Supported
GP → OP → EP	H ₁₅	0.051	0.045	0.09	0.253	0.003	Supported
GPD → OP → EP	H ₁₆	0.110	0.046	0.01	0.178	0.002	Supported
RL → OP → EP	H ₁₇	0.164	0.300	0.10	0.263	0.000	Supported
GIS → OP → EP	H ₁₈	0.456	-0.046	-0.173	0.145	0.673	Not Supported
GD → OP → EP	H ₁₉	0.085	0.097	0.062	0.179	0.000	Supported

Note: SRW standardized regression weight, significant at $p < 0.001$, adjusted R² = 0.56.

Source: Survey data (2024)

GP and RL demonstrate significant positive effects on environmental performance (EP), which aligns with findings by Govindan *et al.* (2020) and Xiao *et al.* (2019), who noted these practices as essential for reducing waste and emissions. In contrast, the limited impact of GIS parallels challenges in digital adoption reported in sustainability studies, particularly in emerging markets (Chong *et al.*, 2019). The positive impact of GM supports earlier research that highlights its role in reducing emissions through efficient resource utilization (Baah and Jin, 2019).

The SEM analysis demonstrated significant direct effects of SSCMPS on both operational and environmental performance, as well as substantial indirect effects through operational performance. GP and RL had the most substantial impacts on environmental performance, with path coefficients of 0.300 and 0.280, respectively. These findings align with recent research emphasizing the importance of sustainable sourcing and waste management for environmental outcomes (Govindan *et al.*, 2020). GPD also showed a meaningful impact, underscoring its role in sustainable resource use and lifecycle management (Tundys and Wiśniewski, 2023). Conversely, green information systems were found to have minimal effect, indicating a gap in digital adoption for environmental tracking in Zimbabwe's petroleum sector.

The mediating effect of operational performance was confirmed, with operational efficiency significantly

enhancing the environmental benefits of SSCMPS. For instance, operational performance strengthened the impact of GP on environmental performance, suggesting that efficient sourcing processes amplify environmental outcomes (Famiyeh *et al.*, 2018).

The SEM results reveal significant relationships between SSCMPS, operational performance, and environmental performance. GP demonstrated the strongest impact on both operational and environmental performance, with a path coefficient of 0.300, indicating its critical role in resource efficiency and waste reduction. RL also showed a substantial impact, supporting findings from studies in similar high-impact sectors (Xiao *et al.*, 2019). Green manufacturing and green distribution contributed moderately, with coefficients of 0.103 and 0.097, respectively, highlighting their potential to improve efficiency and reduce emissions.

Interestingly, GIS had an insignificant impact on both operational and environmental performance, suggesting that this practice is underutilized or lacks integration within the industry's current infrastructure. The study confirms that operational performance significantly mediates the relationship between SSCMPS and environmental performance. For example, operational performance enhanced the impact of green purchasing on environmental outcomes, suggesting that improvements in efficiency can amplify environmental benefits (Famiyeh *et al.*, 2018).

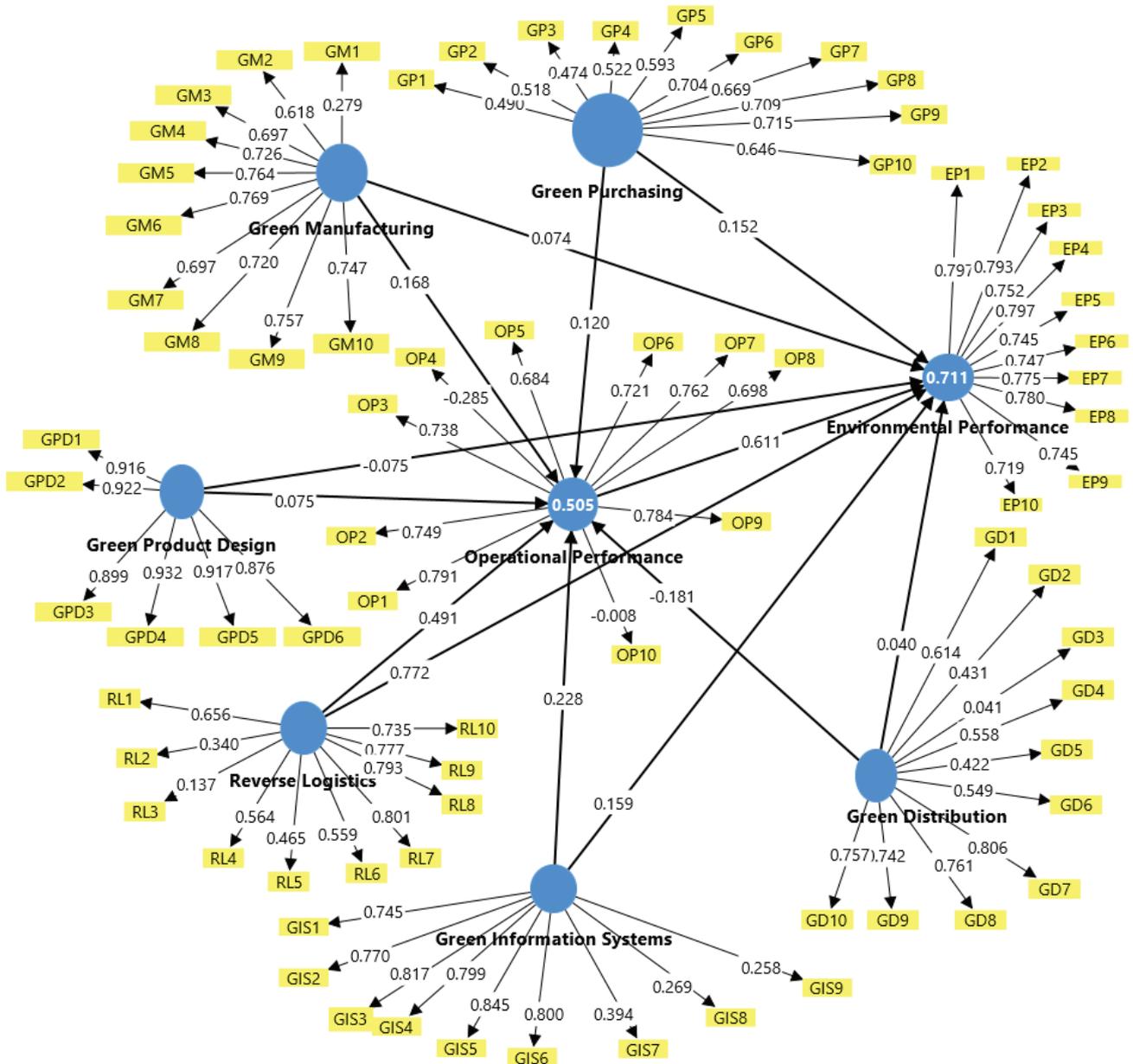


Figure 2: SEM with path coefficients

Figure 1 depicts the SEM with path coefficients, illustrating the relationships between SSCMPS, operational performance (OP), and environmental performance (EP). This model emphasizes how SSCMPS influences EP both directly and indirectly through OP, supporting the critical role of OP as a mediator. Studies confirm that efficient operational processes amplify the impact of SSCMPS on environmental outcomes, as highlighted by Famiyeh *et al.* (2018), who found that operational efficiencies strengthen the environmental benefits of sustainable practices.

Key SSCMPS such as GP and RL are shown in the model to have significant paths to EP, aligning with

Govindan *et al.* (2020), who emphasize these practices' positive effects on reducing emissions and waste in high-impact industries. The model's representation of GP as a strong predictor of both OP and EP mirrors findings by Baah and Jin (2019), who argue that sustainable procurement not only enhances environmental outcomes but also supports cost savings and operational resilience.

Interestingly, GIS shows weaker path coefficients in Figure 1, suggesting a limited direct influence on OP and EP. This is consistent with Chong *et al.* (2019), who observe that while GIS can enhance sustainability, its effectiveness is often hindered by underutilization and technological barriers in developing economies.

Furthermore, the model demonstrates the mediating role of OP in enhancing the effects of SSCMPS on EP, particularly for GM and GP. This mediating relationship is reinforced by studies such as Feng *et al.* (2020), who found that operational efficiency not only improves resource utilisation but also amplifies the environmental advantages of green manufacturing practices.

Figure 1's SEM model aligns well with recent literature that underscores the necessity of integrating operational improvements to achieve optimal environmental performance through SSCMPS (Khan *et al.*, 2021; Thanki and Thakkar, 2020). The model's significant pathways between SSCMPS and EP mediated by OP reflect a comprehensive approach to sustainable supply chain management, promoting both environmental sustainability and operational efficiency within the petroleum industry (Shumba *et al.*, 2021).

4.3. Mediating effect analysis

The mediating effects within the proposed research model focus on how intermediary variables influence the relationships between independent and dependent constructs. The results, summarised in Table 8, provide a detailed examination of the indirect effects and their statistical significance. By analyzing these mediating relationships, the study highlights the mechanisms through which key variables interact to impact supply chain management practices and environmental performance. The findings offer valuable insights into the extent to which the mediating construct enhances or diminishes the direct effects, contributing to a more nuanced understanding of the dynamics within the model.

Table 8: Mediating effect analysis via Sobel test.

Hypothesis	Path	Standard beta	T Statistics	P values	Decision
H ₁₄	GM → OP → EP	0.103	4.201	0.000	Supported
H ₁₅	GP → OP → EP	0.045	2.905	0.003	Supported
H ₁₆	GPD → OP → EP	0.046	3.041	0.002	Supported
H ₁₇	RL → OP → EP	0.300	5.721	0.000	Supported
H ₁₈	GIS → OP → EP	-0.046	1.056	0.673	Not Supported
H ₁₉	GD → OP → EP	0.097	3.825	0.000	Supported

Source: Survey data (2024)

Operational performance's mediating role is significant in enhancing the environmental impacts of SSCMPS, echoing findings by Famiyeh *et al.* (2018) and Feng *et al.* (2020), who emphasize operational efficiency as a key enabler of environmental sustainability. For instance, GP's improved effect on environmental performance via operational performance reinforces the notion that streamlined procurement processes can yield better sustainability outcomes (Baah and Jin, 2019).

4.4. Model fitness

The overall fitness of the proposed research model to determine its adequacy in representing the underlying relationships among the constructs. The results, presented in Tables 9 and 10, include key model fit indices such as the Chi-square (χ^2), Comparative Fit Index (CFI), Root Mean Square Error of Approximation (RMSEA), and Standardized Root Mean Square Residual (SRMR). These indices assess the model's goodness-of-fit by comparing the observed data with the hypothesized structure. The analysis ensures that the model meets acceptable thresholds for validity and reliability, confirming its suitability for hypotheses testing and interpretation of results.

Table 9: Model fitness

	R-square	R-square adjusted	Q-square	GOF
Environmental Performance	0,711	0,695	0.34	0.701
Operational Performance	0,505	0,501	0.32	0.721

Source: Survey data (2024)

Table 10: Model fit

	Saturated model	Estimated model
SRMR	0,077	0,081
d_ULS	26,492	29,534
d_G	201,986	202,069
Chi-square	796.204	798.472
NFI	0.823	0.861

Source: Survey data (2024)

The satisfactory model fit indicators (e.g., SRMR and NFI) suggest the model's robustness, which is in line with similar studies utilizing SEM in supply chain research (Hair *et al.*, 2017; Henseler *et al.*, 2015). Research by Thanki and Thakkar (2020) also supports the idea that a good model fit in sustainability studies often reflects a strong predictive capability for environmental and operational outcomes.

4.5. Model Assessment

The assessment of the proposed research model to

evaluate its reliability, validity, and overall robustness. The results, detailed in Table 11, include critical metrics such as AVE, R-squared values, and GoF score. These assessments ensure that the constructs are measured consistently and accurately, with sufficient distinction between them. The analysis also verifies the strength of the relationships within the model, providing a comprehensive evaluation of its structural integrity. By confirming these aspects, the model assessment establishes the foundation for interpreting the results and drawing meaningful conclusions.

Table 11: Model assessment

Construct	AVE	R ²
Green Manufacturing	0.806	
Green Product Design	0.667	
Reverse Logistics	0.788	
Green Purchasing	0.86	
Green Information System	0.815	
Green Distribution	0.832	
Operational Performance	0.783	0.505
Environmental Performance	0.906	0.711
AVE	0.807	
AVE × R ²	0.594	
GoF	0.701	

Source: Survey data (2024)

High AVE and R-squared values for green purchasing (GP) and reverse logistics (RL) confirm their roles as significant predictors of environmental and operational performance, similar to findings in recent studies on sustainable supply chain management (Shumba *et al.*, 2021; Geng *et al.*, 2017). The overall GoF score, which reflects a robust model fit, aligns with suggestions by Hair *et al.* (2017) and Khan *et al.* (2021) for achieving reliable and valid constructs in sustainable supply chain models.

5. Discussion

The results indicate that green purchasing and reverse logistics have the most substantial influence on both operational and environmental performance. These findings align with prior research, such as those of Govindan *et al.* (2020) and Xiao *et al.* (2019), which emphasize the critical role of these practices in reducing emissions and improving cost efficiency. These results also reinforce the Natural Resource-Based View (NRBV) by showing how firms can achieve sustainability-driven competitive advantages by managing their resources effectively.

The results demonstrate that SSCMPS positively affects environmental performance, with operational performance as a key mediator. The high impact of green purchasing and reverse logistics aligns with existing studies that identify these practices as critical for reducing emissions and waste in resource-intensive industries (Xiao *et al.*, 2019). Green product design also emerged as influential, consistent with recent research on its role in promoting lifecycle sustainability and resource efficiency (Tundys and Wiśniewski, 2023).

Green Information Systems (GIS) were found to have minimal influence, likely due to limited investment in digital tools within Zimbabwe's petroleum industry. This finding is consistent with studies by Chong *et al.* (2019) and Khan *et al.* (2021), who highlight that firms in developing economies struggle with technological adoption due to cost constraints. Institutional Theory supports this finding by indicating that weak regulatory enforcement limits technological investment in sustainability.

Operational performance significantly enhances the environmental benefits of SSCMPS by improving

resource efficiency and reducing emissions. This confirms the conclusions of Famiyeh et al. (2018), who found that firms with strong operational efficiencies amplify the positive effects of sustainability initiatives. These findings reinforce the Sustainability Theory, as operational efficiency supports economic, environmental, and social performance simultaneously.

Operational performance mediation supports findings by Famiyeh et al. (2018), suggesting that firms with high operational efficiency are better positioned to implement SSCMPS effectively, thereby enhancing their environmental impact. The limited effect of green information systems points to a need for technological investment, as digital tools can improve SSCMPS monitoring and enhance decision-making (Geng et al., 2017).

These findings underscore the importance of SSCMPS in enhancing environmental performance within Zimbabwe's petroleum sector, with operational performance acting as a key mediator. Green

purchasing emerged as the most influential SSCMPS dimension, aligning with previous studies indicating its role in reducing waste and promoting recycling (Govindan et al., 2014). The significant indirect effects of SSCMPS on environmental performance through operational efficiency highlight the value of optimizing internal processes to achieve sustainability goals. In developing economies, where industries face financial and infrastructural constraints, operational performance can amplify the benefits of SSCMPS, making it a critical element for success (Shumba et al., 2021).

The lack of impact from green information systems raises questions about the industry's readiness to integrate digital tools for environmental management. This finding suggests a need for capacity-building initiatives to promote the adoption of green technologies, which could further enhance SSCMPS effectiveness in Zimbabwe's petroleum industry (Geng et al., 2017).

Table 12: Comparison of study findings

Hypothesis relationship	Hypothesis	Supported	Not supported	This study
SSCMP → EP		Shi et al., (2012); Diab et al., (2015); Dubey et al., (2017); Kumar et al., (2017); Al-Ghwayeen & Abdallah, (2018); Green et al., (2012); Jabbour et al., (2015); Wong et al., 2012; Hajmohammad et al., (2013); Lee et al., (2013); Jassim et al., (2020); Cai and Li (2018); Ali et al. (2020)		Supported
GP → EP	H ₁	Shi et al., (2012); Diab et al., (2015); Dubey et al., (2017); Kumar et al., (2017); Al-Ghwayeen & Abdallah, (2018); Green et al., (2012); Jabbour et al., (2015); Wong et al., 2012; Hajmohammad et al., (2013); Lee et al., (2013); Jassim et al., (2020); Cai and Li (2018); Ali et al. (2020)		Supported
GM → EP	H ₂	Shi et al., (2012); Diab et al., (2015); Dubey et al., (2017); Kumar et al., (2017); Al-Ghwayeen & Abdallah, (2018); Green et al., (2012); Jabbour et al., (2015); Wong et al., 2012; Hajmohammad et al., (2013); Lee et al., (2013); Jassim et al., (2020); Cai and Li (2018); Ali et al. (2020)		Supported
GPD → EP	H ₃		Mwaura et al., (2016); Ajayi et al., (2021)	Not Supported
RL → EP	H ₅	Shi et al., (2012); Diab et al., (2015); Dubey et al., (2017); Kumar et al., (2017); Al-Ghwayeen & Abdallah, (2018); Green et al., (2012); Jabbour et al., (2015); Wong et al., 2012; Hajmohammad et al., (2013); Lee et al., (2013); Jassim et al., (2020); Cai and Li (2018); Ali et al. (2020)		Supported
GIS → EP	H ₆		Bhadauria et al., (2014)	Not Supported
GD → EP	H ₇	Shi et al., (2012); Diab et al., (2015); Dubey et al., (2017); Kumar et al., (2017); Al-Ghwayeen & Abdallah, (2018); Green et al., (2012); Jabbour et al., (2015); Wong et al., 2012; Hajmohammad et al., (2013); Lee et al., (2013); Jassim et al., (2020); Cai and Li (2018); Ali et al. (2020)		Supported
SSCMP → OP		Jabbour et al. (2016); Chavez et al. (2015); Mitra & Datta (2014); Golobic & Smith (2013) Lee (2013); Lai & Wong (2012); Lee et al., (2012); Yang, Hong, and Modi (2011); Klassen & McLaughlin (1996); Lee (2013); Green et al. (2012)		Supported

GP → OP	H ₈	Song & Zhang, (2017); Ghosh, (2019); Wang et al., (2021); Mallikarathna & Silva, (2019); Fiati, (2019); Ajayi et al., (2021)		Supported
GM → OP	H ₉	Yu et al. (2014); Jabbour et al. (2016); Acquah et al. (2020); Eshikumo & Odock (2017)		Supported
GPD → OP	H ₁₀	Mallikarathna & Silva, (2019); Santos et al., (2019); Jabbour et al., (2015); Khan et al., (2022)		Supported
RL → OP	H ₁₁	Jabbour et al. (2016); Chavez et al. (2015); Mitra & Datta (2014); Golcic & Smith (2013) Lee (2013); Lai & Wong (2012); Lee et al., (2012); Yang, Hong, and Modi (2011); Klassen & McLaughlin (1996); Lee (2013); Green et al. (2012)		Supported
GIS → OP	H ₁₂		Bhadauria et al., (2014)	Not Supported
GD → OP	H ₁₃	Jabbour et al. (2016); Chavez et al. (2015); Mitra & Datta (2014); Golcic & Smith (2013) Lee (2013); Lai & Wong (2012); Lee et al., (2012); Yang, Hong, and Modi (2011); Klassen & McLaughlin (1996); Lee (2013); Green et al. (2012)		Supported
OP → EP	H ₄	Jabbour et al. (2016); Chavez et al. (2015); Mitra & Datta (2014); Golcic & Smith (2013); Lee (2013); Lai & Wong (2012); Lee et al. (2012); Yang, Hong & Modi (2011); Klassen & McLaughlin (1996); Lee (2013); Green et al. (2012); Inman & Green, (2018); Thanki & Thakkar, (2020); Famiyeh et al., (2018)		Supported
Mediation		Lai & Wong, (2012); Lee et al., (2012); Abdallah & Al-Ghwayeen, (2019); Yu et al., (2014); Wong et al., (2012)		Supported
GM → OP → EP	H ₁₄	Lai & Wong, (2012); Lee et al., (2012); Abdallah & Al-Ghwayeen, (2019); Yu et al., (2014); Wong et al., (2012)		Supported
GP → OP → EP	H ₁₅	Lai & Wong, (2012); Lee et al., (2012); Abdallah & Al-Ghwayeen, (2019); Yu et al., (2014); Wong et al., (2012)		Supported
GPD → OP → EP	H ₁₆	Lai & Wong, (2012); Lee et al., (2012); Abdallah & Al-Ghwayeen, (2019); Yu et al., (2014); Wong et al., (2012)		Supported
RL → OP → EP	H ₁₇	Lai & Wong, (2012); Lee et al., (2012); Abdallah & Al-Ghwayeen, (2019); Yu et al., (2014); Wong et al., (2012)		Supported
GIS → OP → EP	H ₁₈		Bhadauria et al., (2014)	Not Supported
GD → OP → EP	H ₁₉	Lai & Wong, (2012); Lee et al., (2012); Abdallah & Al-Ghwayeen, (2019); Yu et al., (2014); Wong et al., (2012)		Supported

Table 12 summarises the results of this study in relation to various previous studies. It includes all the nineteen (19) postulated hypotheses of this study. In sum, the SEM results revealed that SSCMPS and OP were positively related to EP. The study further indicated that operational performance mediates the influence of SSCMPS on environmental performance.

Despite promising results, this study recognizes several limitations, including its focus on a single industry and geographic region, which may affect generalisability. Future research should expand the model to other sectors and consider additional mediators, such as social sustainability factors, to provide a more holistic view of SSCMPS adoption.

6. Conclusion

This study confirms that SSCMPS positively impacts environmental performance, with operational performance playing a crucial mediating role. Among SSCMPS, green purchasing, and reverse logistics emerge as the most impactful strategies, warranting prioritization by policymakers and industry practitioners. The integration of Stakeholder Theory, NRBV, Sustainability Theory, Institutional Theory, and Resource Dependence Theory advances the existing body of knowledge by explaining how firms in developing economies can navigate sustainability challenges and align their operations with environmental and regulatory expectations.

This study contributes to SSCMPS literature by developing a model that integrates operational performance as a mediator, highlighting its critical role in enhancing SSCMPS's environmental benefits in Zimbabwe's petroleum industry. The findings suggest that prioritizing green purchasing, reverse logistics, and green product design can significantly improve environmental performance, particularly when supported by efficient operations.

This research develops a model for SSCMPS's impact on environmental performance, mediated by operational performance, within Zimbabwe's petroleum industry. The findings emphasize the importance of green purchasing and reverse logistics in achieving sustainability goals, particularly when supported by operational efficiency. Policymakers and industry leaders are encouraged to create stronger regulatory frameworks and financial incentives to promote SSCMPS adoption. These insights are especially relevant for developing nations, where resource constraints necessitate efficient and impactful sustainability practices. Future research should consider broader applications of this model and explore the role of emerging digital technologies in enhancing SSCMPS outcomes.

6.1. Theoretical implications

The study successfully employed the Natural Resource-Based View (NRBV), Stakeholder Theory, and Sustainability Theory in the context of Zimbabwe's petroleum industry by integrating these theoretical frameworks to explain the relationships between sustainable supply chain management practices (SSCMPS), operational performance, and environmental performance. NRBV provided a lens through which to understand how firms leverage green purchasing and reverse logistics as strategic resources to achieve competitive advantage and environmental sustainability. Stakeholder Theory highlighted the importance of addressing the expectations of various stakeholders, such as suppliers, customers, and regulators, in driving the adoption of SSCMPS. Sustainability Theory further reinforced the study's focus on balancing economic, environmental, and social dimensions within the petroleum industry. By combining these theories, the study offered a comprehensive theoretical foundation for analyzing sustainability supply chain management practices in a resource-constrained context like Zimbabwe.

Theoretically, this study contributes to the body of knowledge by expanding the SSCMPS framework through the inclusion of operational performance as a mediating variable. This provides a more nuanced understanding of how SSCMPS influences

environmental performance, addressing a gap in the existing literature that often overlooks the mediating role of operational performance. Additionally, the study developed a novel SSCMPS and environmental performance model, which positions operational performance as a critical link between sustainable practices and environmental outcomes. This model not only advances theoretical discourse but also offers a practical framework for future research in similar contexts, particularly in developing economies where resource constraints and sustainability challenges are prevalent. By integrating multiple theories and proposing a new model, the study enriches the theoretical landscape of sustainable supply chain management and provides a foundation for further exploration in this field.

6.2. Practical implications

The findings of this study highlight the need for targeted policy interventions to promote sustainable supply chain practices. Policymakers should introduce tax incentives for firms that adopt green purchasing and reverse logistics, as these practices have been empirically shown to significantly enhance environmental performance. Additionally, financial support should be provided to encourage the adoption of digital sustainability initiatives, particularly in industries like Zimbabwe's petroleum sector, where challenges in implementing green information systems persist. Such measures can help bridge the technological gap and foster a more sustainable industrial ecosystem.

For managers, the study underscores the importance of prioritizing sustainable practices within their supply chain operations. Strengthening collaboration with suppliers is essential to ensure sustainable sourcing and improve the effectiveness of green purchasing initiatives. Furthermore, investing in reverse logistics infrastructure can significantly enhance waste management and resource efficiency, contributing to both environmental and operational performance. By focusing on these areas, managers can align their strategies with sustainability goals while driving efficiency and long-term competitiveness.

This study developed a new model to enhance petroleum companies' adaption and implementation of SSCMPS to enhance environmental performance. Companies that are able to successfully implement SSCMPS are highly likely to promote environmental performance with operational performance as a mediating variable in Zimbabwe's petroleum industry. Additionally, the study also established that SSCMPS, such as green manufacturing, green purchasing, green product design, and reverse logistics, are

critical determinants of environmental performance in Zimbabwe's petroleum industry. These results are widely and largely consistent with previous studies (Chen *et al.*, 2022; Nureen *et al.*, 2023; Choi and Hwang, 2015; Shekarian *et al.*, 2022; Tundys and Wiśniewski, 2023). The research highlights the need for firms to invest in SSCMPS, especially in green purchasing and reverse logistics, to achieve sustainability goals. Operational efficiency should be emphasized as it strengthens SSCMPS benefits.

6.3. Societal implications

Adoption of SSCMPS in Zimbabwe's petroleum industry can reduce environmental impacts, promoting sustainability in line with national and global environmental goals.

6.4. Limitations

While this study provides valuable insights into the relationship between sustainable supply chain management practices (SSCMPS), operational performance, and environmental performance, it is not without limitations. Firstly, the study focused on Zimbabwe's petroleum industry, which may limit the generalisability of the findings to other sectors or regions. Secondly, the cross-sectional design restricts the ability to infer causal relationships or track the long-term effects of SSCMPS adoption. Thirdly, the study did not explore the potential moderating effects of external factors, such as government policies or international regulations, which could influence SSCMPS implementation. Ultimately, the reliance on quantitative data may overlook nuanced contextual factors that qualitative approaches could uncover. These limitations present opportunities for future research to address these gaps and expand the understanding of SSCMPS dynamics.

6.5. Future research directions

Future studies should investigate additional mediators, such as social sustainability, to provide a holistic view of SSCMPS's impact. Explore the moderating effects of government policies as well as international regulations on SSCMPS adoption, providing insights into regulatory dynamics. Expanding the model to other sectors like mining and manufacturing in developing countries would enhance generalisability and enable evaluation of cross-sector applicability. Comparative studies on SSCMPS adoption in other high-impact industries, such as mining and manufacturing. Research could also explore the potential of emerging digital technologies, e.g., AI, IoT, and blockchain, to overcome barriers

to SSCMPS adoption. Future research can adopt different research approaches can be employed, e.g., qualitative or mixed-method research, to contrast the results. Additionally, it investigates the longitudinal effects of SSCMPS on environmental performance and operational performance to track the evolution and adoption rate of sustainable practices over time. Examine the interplay between financial constraints and SSCMPS adoption, particularly in developing economies where resource limitations may hinder sustainability efforts.

Credit Author statement

All authors contributed to the study. **Ernest Mugoni**: Conceptualisation, Writing-original draft (leading), Validation; **James Kanyepe**: Methodology, Formal analysis (supporting), Writing- reviewing & editing (leading), Visualisation; **Marian Tukuta**: Writing-original draft (supporting), Formal analysis (leading). All authors commented on earlier versions of the manuscript. All authors have read and approved the final version of this manuscript.

Disclosure statement

No potential conflict of interest was reported by the authors.

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Declarations

Ethical Approval and Consent to Participate

Chinhoyi University of Technology granted full ethical approval with the reference number: ANNEX 19 Form GRSD 17 SEBS 15/2023. Ministry of Energy and Power Development and Zimbabwe Energy Regulatory Authority (ZERA) issued a full ethical clearance with

reference numbers: LF/21/A/1/289 and ERD/LN/npm/23/091 respectively.

Consent for Publication

The authors consent to the publication of the article with *International Business Logistics*.

Data availability

The data that support the findings of this study are available from the corresponding author, [E.M], upon reasonable request.

Funding

Not applicable

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Bibliometric Analysis of Logistics and Supply Chain Research (2020–2024)

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Received on: 11 April 2025

Accepted on: 06 June 2025

Published on: 29 June 2025

Abstract

Purposes: This study presents a comprehensive bibliometric analysis of logistics and supply chain management (LSCM) research published between 2020 and 2024, addressing the central research question: What are the trends, key research themes, and leading contributors in LSCM scholarship during this period? The study has three main purposes: a) providing an overview of research outputs in logistics and supply chain, b) analyzing author, institutional, and country-level productivity and impact using bibliometric indicators, and c) addressing the most impactful journals, publications, and funding bodies contributing to the field.

Methodology: The study employed the bibliometric analysis approach to ensure an in-depth analysis for research development. Drawing on metadata from the OpenAlex scholarly database, 63,095 publications were analyzed to identify the most influential authors, institutions, journals, and funding bodies, as well as thematic and geographic patterns in the literature. The analysis employed structured search strategies, citation metrics, and Field-Weighted Citation Impact (FWCI) scores, supported by tools such as the OpenAlex API and Microsoft Excel for data extraction, visualization, and analysis.

Findings: The findings reveal a significant increase in research output, with 77.6% of the publications being peer-reviewed journal articles and 53.2% available through open access. English was the dominant language (90.9%), and China led in publication volume (19.8%), followed by the United States and India. The most prolific author by publication count was Biswajit Sarkar, while Dmitry Ivanov ranked highest in both total citations and FWCI. The Journal of Cleaner Production emerged as the top source in terms of both volume and academic impact. Key research themes included digital transformation, Industry 4.0 technologies, sustainability, supply chain resilience, risk management, and blockchain applications. Despite strong national contributions, particularly from Asian countries, the study identified limited cross-institutional collaboration as a persistent gap. Overall, the analysis provides a data-driven overview of the evolving priorities, scholarly influence, and global participation in LSCM research over the past five years.

Keywords: logistics, supply chains, research outputs, bibliometric analysis.

Introduction

Bibliometric analysis of research output in any scientific field is an important tool for understanding the current state of scientific research in that field and identifying the latest trends in publishing and authorship in this field.

This study analyzes the published scientific research in one of the most vital fields: logistics and supply chain management. This field has had an effective impact on the global economy throughout the ages.

In the context of logistics and supply chain management, bibliometric analysis helps map the structure and growth of the field and assess its maturity, gaps, and future directions. This study contributes to the field by offering a detailed bibliometric overview of logistics and supply chain research published in the last five years between 2020 and 2024, revealing how the academic landscape has evolved during significant global change.

The bibliometric analysis will impact the research in logistics and supply chain positively, and support scholars in different aspects:

- Scholars will address the top and most cited journals.
- Publishers will be able to attract the top authors.
- Addressing the most funding institutes for research.
- Addressing the top productive institutes

Methodology

This study seeks to address the following central research question: "What are the trends, key research themes, and leading authors, institutes, and journals in logistics and supply chain management research between 2020 and 2024?" In order to answer the central question, the research set the following specific sub-goals:

1. Provide an overview of research outputs in logistics and supply chain during the target period.
2. Analyze author, institutional, and country-level productivity and impact using bibliometric indicators.
3. Highlight the most impactful journals, publications, and funding bodies contributing to the field.

This research has employed the bibliometric analysis approach to ensure an in-depth understanding of the field's research development.

The bibliometric analysis was conducted using the publications metadata from OpenAlex. Based on specific search strategies, OpenAlex discovered 63,095 publications related to logistics and supply chain research from 2020 to 2024. The search strategy was performed on 01.03.2025, and the data set was downloaded on the same date.

OpenAlex is a massive discovery tool for research publications. It has 265 million works harvested from 261,000 data sources, including publishers, digital repositories, and significant databases of publications metadata such as CrossRef, DOAJ, etc.

This bibliometric analysis focused on the following aspects:

- Publication types and languages.

- Geographic distribution: exploring the top countries and regions
- Is the type of access open access or closed access?
- Author and institute research productivity: evaluation of top authors and institutions based on publication number, citations, and field-weighted citation impact (FWCI).
- Top articles and journals: identifying journals and articles of the highest impact by counting the number of citations and FWCI
- Funding institutes: highlighting major research funders in the field.

Research coverage

- **Chronological:** The research seeks to discover the most recent trends in logistics and supply chain management. The research covered publications in the last five years, 2020-2024.
- **Geographical:** There are no limitations on geographical coverage. It will explore the publications on the global level.
- **Subjects:** the research focuses on published publications in logistics and supply chain management and the sub-related topics.

Data processing and tools

The bibliometric analysis depended on several tools in order to achieve the research goals:

- **OpenAlex API** to discover the publication metadata and perform data analysis.
- **Microsoft Excel** for tabular analysis and visualization.
- **Elicit** for initial article screening and systematic review support.

Literature review

A systematic literature review was conducted by Elicit Application to explore the previous research outputs. The review analyzed 40 papers from an initial pool of 79, using six screening criteria. Studies were grouped into thematic categories based on scope: (1) large-scale quantitative studies, (2) thematic reviews on specific technologies or regions, and (3) collaborative and institutional performance assessments. Each paper was reviewed for six key aspects that mattered most to the research question.

Elicit screened in papers that met the following criteria:

- **Primary subject focus:** Is logistics and/or supply chain management the primary focus of the study?
- **Publication type:** Is this a research or review article published in a peer-reviewed journal?
- **Bibliometric information:** Does the publication include complete bibliometric information (citations, authors, and clear institutional affiliations)?
- **Academic affiliation:** Is at least one author affiliated with an academic or research institution?
- **Unique publication:** Is this the only/original version of the study (not a duplicate or repeated publication)?
- **Research content:** Is this original research content (not a book review, editorial, letter, trade article, or industry report)?

Volume of publications

With different research goals and focus, 32 research studies covered the total number of output publications in the logistics and supply chain field:

- About 14 studies covered 1000 to 10,000 publications
- About 13 studies analyzed from 100 to 1000 publications
- Only three studies covered less than 100 publications
- Only two studies covered more than 10,000 publications

In comparison with the current study, it is clear there is a big gap regarding the number of documents. Only two studies covered a huge number of publications. The main reasons can be summarized as follows:

- **Chronological limitations:** Some studies covered the publication in 2-3 years only
- **Subject limitations:** The current study covers a wide topics; however, the other studies are more specific. For example: smart supply chain, effect of COVID-19 on supply chain, supply chain financing

Geographic distribution and research impact

The vast majority of studies (38/40) had a global focus. One study focused on multiple specific countries (Korea and China) and had a global component.

The USA had the highest total publications (930), while China had the highest Citation Impact (3979 citations) among countries with reported data.

There are common results between the current study and studies covered in the literature review. China and the United States are the top countries regarding volume of publications.

International collaboration

Some articles highlighted the growing trend of international collaboration in logistics and supply chain research:

- Sousa et al. (2018) remarked that research projects by collaboration among researchers play an increasing role in lean supply chain management research across countries.
- Fahim and Mahadi (2022) mention that countries like China, India, Iran, and Taiwan have "powerful international collaborations," indicating active engagement in international research partnerships by emerging economies.
- Habibullah and Pudjianto (2022) emphasize the importance of collaboration across disciplines and countries to make a real contribution to research, education, and the logistics industry".
- However, Kamperos et al. (2024) found minimal collaboration among institutions and suggested potential barriers or challenges in implementing extensive collaborative networks across countries and institutions.

The lack of specific collaboration metrics across most studies highlights a potential area for future research in logistics and supply chain management.

Institutional performance analysis

Institutes from different countries were represented as authors' affiliation; the review can highlight the following:

- 40 institutions from 14 countries were represented

- The USA has the highest institutional representation (12 institutions)
- From the top represented countries: UK (7), China (5), and Netherlands (5)
- Other countries represented: Finland, Australia, Denmark, Singapore, Japan, Brazil, India, France, and Iran

Publication counts by institution: some studies examined the distribution of publications across 34 institutions:

- 12 institutions had between 1 and 9 publications
- 5 institutions had between 50 and 100 publications
- 5 institutions had between 40 and 49 publications
- 6 institutions had between 20 and 39 publications
- 5 institutions had between 10 and 19 publications
- 1 institution, Hong Kong Polytechnic University, stood out with over 200 publications (238)

The current study reflects common results regarding the affiliation institutes. China and Iran were represented by six institutes from the top ten. However, the United States was absent.

Although the H-index is typically used to assess individual authors, some studies applied it to institutions. However, data was only available for 5 out of 40 institutions:

- 3 institutions had an H-index between 20 and 29
- 2 institutions had an H-index between 10 and 19
- No H-index data was found for the remaining 35 institutions

Collaboration between institutes

While specific metrics on cross-institutional collaboration are not widely reported in the extracted data, several studies provide insights into collaboration patterns:

- Hamid et al. (2024) identify a network of collaborating institutions, including Cranfield School of Management, the University of Sheffield, Bristol Business School, the University of the West of England, and the University of Liverpool. This suggests the existence of strong collaborative networks, particularly among UK institutions.

- Bahar et al. (2024) noted that some institutions, like Tsinghua University, have a wide network of collaborations, indicating their impact in fostering research partnerships. The same applies to the Chinese Academy of Sciences, which is highlighted for its central role in research collaborations.
- However, Kamperos et al. (2024) observed the cooperation among institutions is evidently limited and suggested that while there are examples of strong collaborative networks, there may still be room for improvement in cross-institutional collaboration across the field as a whole.

The lack of comprehensive data on cross-institutional collaboration metrics in the available abstracts and full texts limits our ability to draw more detailed conclusions about collaborative dynamics in logistics and supply chain management research.

Research focus areas

The bibliometric analyses reveal several key research focus areas in logistics and supply chain management:

1. Digital transformation and industry 4.0:

- Increasing focus on digital technologies and their integration into supply chain processes
- Research on Industry 4.0, digital supply chain management
- Application of advanced technologies such as blockchain, artificial intelligence, and the Internet of Things

2. Sustainability and green supply chain management:

- Significant emphasis on sustainable practices
- Research on green supply chains, circular economy principles
- Environmental impact reduction strategies

3. Supply chain resilience and risk management:

- Increased attention to supply chain resilience, particularly in light of global disruptions like the COVID-19 pandemic
- Focus on risk management and crisis response strategies

4. Blockchain technology:

- The rapid rise of blockchain-related research in supply chain management
- Focus on the potential for enhancing transparency, traceability, and security

5. Supply chain performance and optimization:

- Focus on improving supply chain performance
- New strategies for lean management and balanced scorecard approaches

6. Emerging market supply chains:

- Growing interest in supply chain management practices in emerging economies
- Specialized areas like halal supply chain management

7. Reverse logistics and circular economy:

- Increasing research on reverse logistics
- Often connected with sustainability goals and circular economy principles

The bibliometric method aims primarily to reveal quantitative and qualitative trends in published intellectual publications. The literature review addressed the lack of key aspects of the bibliometric analysis method. None of the studies provided an analysis of the format of publication, language of publications, and publishing models, whether it was an open access model or subscription model. Further, many studies did not provide the impact of research by analysis of citations.

One of the most important aspects of the bibliometric analysis contributed only by this paper is the funding institutes. None of the reviewed studies covered information about the funders of research in logistics and supply chain management.

interest in disseminating findings through peer-reviewed outlets. The Book chapters and preprints follow, reflecting ongoing research and contributions to edited volumes. Other formats like dissertations, datasets, and standards contribute marginally but highlight a diverse research dissemination landscape.

Table 1: Publications by type

Publication Type	No.	%
Article	48964	77.6
Book-chapter	7199	11.4
Preprint	2034	3.2
Review	1438	2.3
Dissertation	1171	1.9
Book	654	1.0
Dataset	319	0.5
Other	370	0.6
Report	210	0.3
Peer-review	207	0.3
Paratext	187	0.3
Standard	144	0.2
Editorial	124	0.2
Grant	74	0.1
	63095	

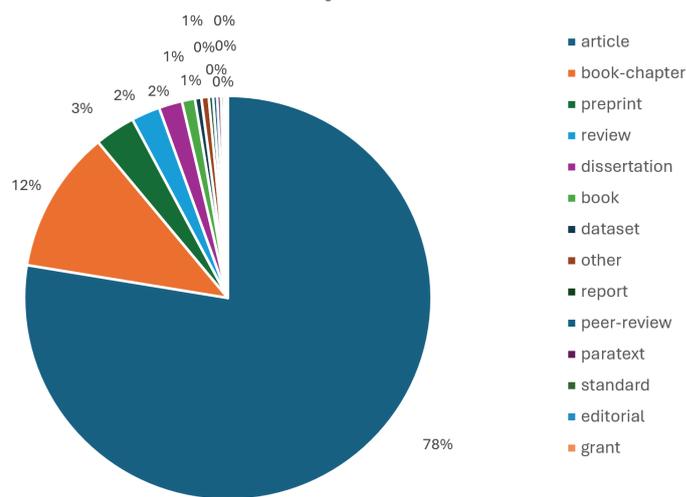


Figure 1: Publications by type

Results and discussions

1. Type of publications

Table 1 shows that journal articles are the main type of publication format of logistics and supply chain research between 2020 and 2024. Accounting for 77.6% of all entries. This indicates a strong academic

2. Language of publications

English dominates the publication language, accounting for 90.9% of the works. This is compatible

with the international trend of using English as the most common language in academic publishing. Portuguese, Spanish, and Polish follow.

Table 2: The language of publications

Language	No.	%
English	56418	90.9
Portuguese	2045	3.3
Spanish	830	1.3
Polish	599	1.0
German	456	0.7
French	421	0.7
Czech	389	0.6
Turkish	348	0.6
Russian	336	0.5
Ukrainian	243	0.4

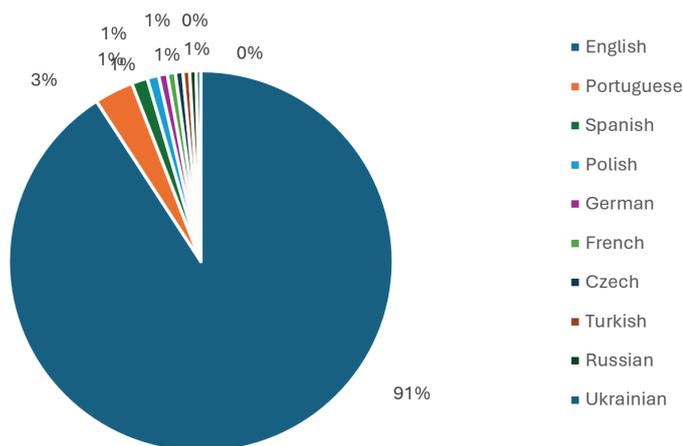


Figure 2: Language of publications

3. Country of publication

China is the top country in publications volume with 19.8%, followed by the United States (12.0%) and India (10.6%). The analysis shows that Asia has increasing research outputs. China, India, and Iran produce 34% of publications, likely due to their expanding academic infrastructure and investment in logistics and supply chain innovations. European countries like the UK, Germany, and France also contribute 23% of publications.

Table 3: Top 10 countries

Country	No.	%
China	8838	19.8
United States	5333	12.0
India	4743	10.6
United Kingdom	3248	7.3
Brazil	2553	5.7
Germany	1981	4.4
France	1815	4.1
Iran	1775	4.0
Italy	1769	4.0
Poland	1396	3.1

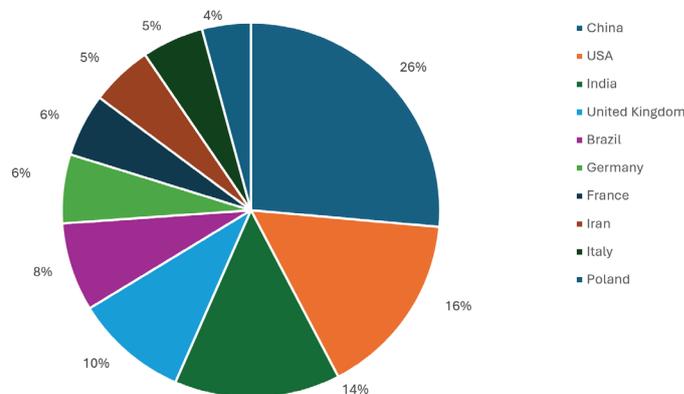


Figure 3: Top 10 countries

4. Open access publications

A significant portion of the publications (53.2%) are open access, indicating a trend toward accessible science. This enhances the visibility and potential impact of the research, allowing practitioners and policymakers easier access to findings.

Table 4: Open access vs. closed access

Model	Count	%
Open access	33525	53.2
Non-open access	29570	46.8
	63095	

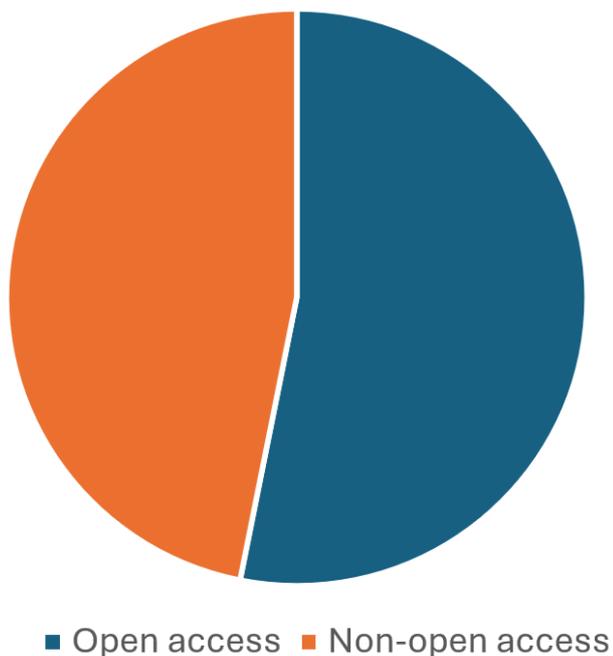


Figure 4: Open access vs. closed access

5. Authors productivity

Author productivity analysis depended on three main rankings: a) Total volume of publications. b) Number of citations. c) Field-Weighted Citation Impact (FWCI)

Biswajit Sarkar leads in publication count, but Dmitry Ivanov is the top citation metric and Field-Weighted Citation Impact (FWCI), indicating strong influence despite slightly fewer publications. High FWCI values for Ivanov and others suggest that their work is prolific and impactful globally.

Although Ivanov is the third top author by volume of publications, his research impact put him among the top authors according to the number of citations and FWCI. On the other hand, Kumar is the second top contributing author. However, according to the number of citations and FWCI, his ranking is the 6th and 5th in the order.

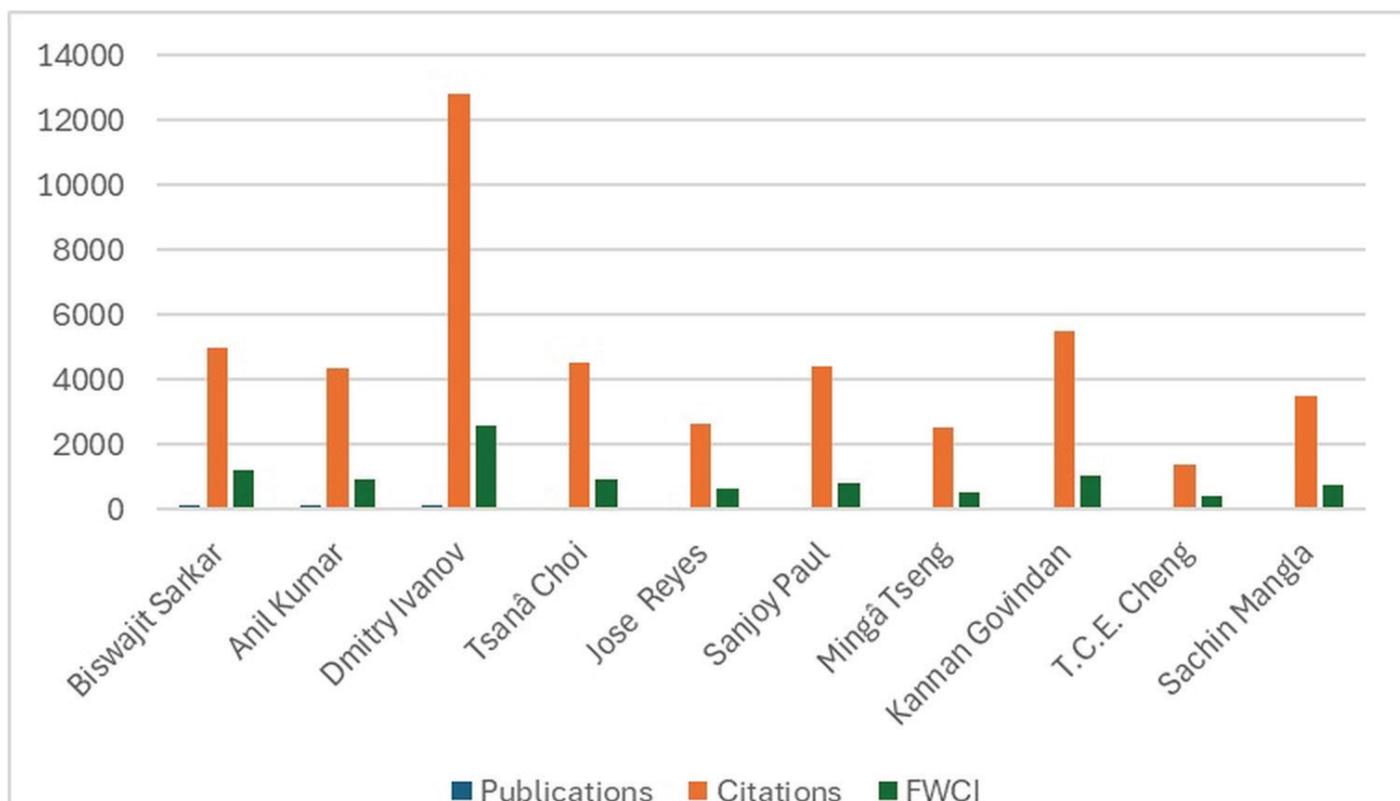


Figure 5: Top authors productivity

The following three tables provide detailed statistics on the top 10 authors' productivity.

Authors by number of publications

Table 5: Top 10 authors by volume of publications

Rank	Name	No. of publications
1	Biswajit Sarkar	131
2	Anil Kumar	130
3	Dmitry Ivanov	116
4	Tsanâ Ming Choi	99
5	Jose Arturo Garzâ Reyes	96
6	Sanjoy Kumar Paul	88
7	Mingâ Lang Tseng	87
8	Kannan Govindan	85
9	T.C.E. Cheng	77
10	Sachin Kumar Mangla	68

Authors by citations

Table 6: Top 10 authors by number of citations

Rank	Name	Citations	Publications	Average of citations
1	Dmitry Ivanov	12821	116	110.5
2	Kannan Govindan	5482	85	64.5
3	Biswajit Sarkar	4991	131	38.1
4	Tsanâ Ming Choi	4548	99	45.9
5	Sanjoy Kumar Paul	4412	88	50.1
6	Anil Kumar	4351	130	33.5
7	Sachin Kumar Mangla	3509	68	51.6
8	Jose Arturo Garzâ Reyes	2632	96	27.4
9	Mingâ Lang Tseng	2557	87	29.4
10	T.C.E. Cheng	1373	77	17.8

Authors by FWCI

Table 7: Top 10 authors by FWCI

Rank	Name	FWCI	Publications
1	Dmitry Ivanov	2604	116
2	Biswajit Sarkar	1206	131
3	Kannan Govindan	1024	85
4	Tsanâ Ming Choi	954	99
5	Anil Kumar	941	130
6	Sanjoy Kumar Paul	803	88
7	Sachin Kumar Mangla	756	68
8	Jose Arturo Garzâ Reyes	670	96
9	Mingâ Lang Tseng	513	87
10	T.C.E. Cheng	431	77

6. Top cited publications

The following tables list the top-cited articles and top FWCI articles. "Predicting the impacts of epidemic outbreaks on global supply chains" has 1806 citations as the top cited articles. However, the top cited work, according to FWCI, was a book chapter, "Data Analytics and Artificial Intelligence in the Circular Economy."

This result reflects that the effect of COVID-19 on logistics and supply chains is the most trending topic. Six articles of the top 10 cited works were on COVID-19 and supply chains.

Table 8: Top 10 cited articles

Title	Authors	Journal	Year	Citations	FWCI
Predicting the impacts of epidemic outbreaks on global supply chains: A simulation-based analysis on the coronavirus outbreak (COVID-19/ SARS-CoV-2) case	Dmitry Ivanov	Transportation Research Part E Logistics and Transportation Review	2020	1806	318.131
Viability of intertwined supply networks: extending the supply chain resilience angles towards survivability. A position paper motivated by COVID-19 outbreak	Dmitry Ivanov Alexandre Dolgui	International Journal of Production Research	2020	1390	228.853
A digital supply chain twin for managing the disruption risks and resilience in the era of Industry 4.0	Dmitry Ivanov Alexandre Dolgui	Production Planning & Control	2020	986	143.348
Effective supply chain management	Tom Davis	Strategic Direction	2020	925	16.975
Viable supply chain model: integrating agility, resilience and sustainability perspectives – lessons from and thinking beyond the COVID-19 pandemic	Dmitry Ivanov	Annals of Operations Research	2020	895	139.156
Principles for a sustainable circular economy	Anne P.M. Velenturf Phil Purnell	Sustainable Production and Consumption	2021	793	135.431
Stable-Baselines3: Reliable Reinforcement Learning Implementations	Antonin Raffin Ashley Hill Adam Gleave Anssi Kanervisto Maximilian Ernestus Noah Dormann	Journal of Machine Learning Research	2021	790	151.291
Impact of COVID-19 on logistics systems and disruptions in food supply chain	Sube Singh Ramesh Kumar Rohit Panchal Manoj Kumar Tiwari	International Journal of Production Research	2020	774	131.192
Impacts of epidemic outbreaks on supply chains: mapping a research agenda amid the COVID-19 pandemic through a structured literature review	Maciel M. Queiroz Dmitry Ivanov Alexandre Dolgui Samuel Fosso Wamba	Annals of Operations Research	2020	757	130.354
COVID-19 pandemic related supply chain studies: A systematic review	Priyabrata Chowdhury Sanjoy Kumar Paul Shahriar Kaiser Md. Abdul Moktadir	Transportation Research Part E Logistics and Transportation Review	2021	751	30.198

Top 10 publications by FWCI

Table 9: Top 10 articles/book chapters by FWCI

Title	Authors	Type	Journal/Book	FWCI	Citations
Data Analytics and Artificial Intelligence in the Circular Economy	D. Dhanya S. Satheesh Kumar A. Thilagavathy D. V. S. S. S. V. Prasad Sampath Boopathi	book-chapter	Advances in Civil and Industrial Engineering book series	399.82	90
Predicting the impacts of epidemic outbreaks on global supply chains: A simulation-based analysis on the coronavirus outbreak (COVID-19/ SARS-CoV-2) case	Dmitry Ivanov	Article	Transportation Research Part E Logistics and Transportation Review	318.131	1806
Artificial intelligence, machine learning, and deep learning for sustainable and resilient supply chain and logistics management	Nitin Liladhar Rane Pravin Desai Jayesh Rane Mallikarjuna Paramesha	book-chapter	Trustworthy Artificial Intelligence in Industry and Society	244.492	23
Viability of intertwined supply networks: extending the supply chain resilience angles towards survivability. A position paper motivated by COVID-19 outbreak	Dmitry Ivanov Alexandre Dolgui	article	International Journal of Production Research	228.853	1390
Conceptualizing the Circular Economy (Revisited): An Analysis of 221 Definitions	Julian Kirchherr Nan-Hua Nadja Yang Frederik Schulze-SpÄ¼ntrup Maarten J. Heerink Kris Hartley	article	Resources Conservation and Recycling	198.013	451
Sustainability and survivability in the manufacturing sector	Ankita Awasthi Kuldeep K. Saxena Vanya Arun	book-chapter	Modern Manufacturing Processes	193.038	176
Delineating Business for Sustainability: Contextual Evolution and Elucidation	Demetris Vrontis Alkis Thrassou Leonidas Efthymiou Meliz Bozat	book-chapter	Palgrave studies cross-disciplinary business research in association with the EuroMed Academy of Business	191.025	43
Stable-Baselines3: Reliable Reinforcement Learning Implementations	Antonin Raffin Ashley Hill Adam Gleave Anssi Kanervisto Maximilian Ernestus Noah Dormann	article	Journal of Machine Learning Research	151.291	790
Circular Economy Principles: Shifting Towards Sustainable Prosperity	Vinay Kandpal Anshuman Jaswal Ernesto D. R. Santibanez Gonzalez Naveen Agarwal	book-chapter	Sustainable Energy Transition	148.821	16
A digital supply chain twin for managing the disruption risks and resilience in the era of Industry 4.0	Dmitry Ivanov Alexandre Dolgui	article	Production Planning & Control	143.348	986

1. Top journals

Journals are the most common source of publication in logistics and supply chain research. About 69% of publications were published in journals, and 31% for all other sources (books, conference proceedings, institutional repositories, etc.)

Table 10: Type of sources

Type	No.	%
Journal	43545	69.01
Other	19550	30.99
	63095	

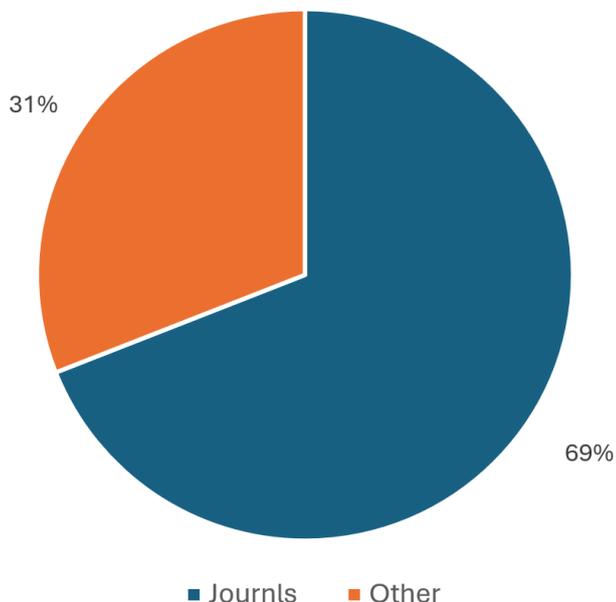


Figure 6: Type of sources

The bibliometric analysis stated that "Sustainability" and "Journal of Cleaner Production" are the top journals in terms of volume of publication. However, by citations "Journal of Cleaner Production" is the top cited journal.

Table 11: Type 10 journals by publications

	Journals	No. of Publications
1	Sustainability	2054
2	Journal of Cleaner Production	1164
3	Computers & Industrial Engineering	630
4	International Journal of Production Economics	553
5	International Journal of Production Research	447
6	Annals of Operations Research	442
7	Business Strategy and the Environment	424
8	Academy of Management Proceedings	362
9	European Journal of Operational Research	348
10	Transportation Research Part E Logistics and Transportation Review	309

Table 12: Top 10 journals by citations and FWCI

	Title	Pub.	Citations	FWCI	Avr
1	Journal of Cleaner Production	1164	49662	10247	42.7
2	Sustainability	2054	35924	7629	17.5
3	International Journal of Production Economics	553	19272	4533	34.8
4	Business Strategy and the Environment	424	17915	3888	42.3
5	International Journal of Production Research	447	17498	3539	39.1
6	Computers & Industrial Engineering	630	14129	3627	22.4
7	Sustainable Production and Consumption	277	13695	2676	49.4
8	Transportation Research Part E Logistics and Transportation Review	309	12755	2853	41.3
9	Resources Conservation and Recycling	203	11750	2172	57.9
10	Annals of Operations Research	442	10692	2352	24.2

2. Top affiliated institutes

Iran and China lead the authors' affiliations. Among the top 10 institutes, three belong to China, and three to Iran. The Islamic Azad University (Iran) is the most affiliated institute. Followed by CNRS (France). Hong Kong, Slovakia, and the UK were also represented in the top 10 institutes.

Table 13: The top affiliated institutes

	Institute	Country	Publications
1	Islamic Azad University, Tehran	Iran	469
2	Centre National de la Recherche Scientifique	France	431
3	Hong Kong Polytechnic University	Hong Kong	393
4	University of Tehran	Iran	358

5	Chinese Academy of Sciences	China	346
6	University of Zilina	Slovakia	286
7	Tianjin University	China	259
8	University of London	UK	258
9	Shanghai Maritime University	China	242
10	Iran University of Science and Technology	Iran	230

3. Top research funders

The analysis showed that 50% of the funding institutes are from China; this reflects strong national support for research. The National Natural Science Foundation of China is the largest provider of research funding; it funded 2773 research from 2020–2024. The European and Brazilian institutes also contribute significantly.

Table 14: The top funders

	Funders	Country	Publications
1	National Natural Science Foundation of China	China	2773
2	Fundamental Research Funds for the Central Universities	EU	352
3	National Social Science Fund of China	China	249
4	European Commission	EU	185
5	National Office for Philosophy and Social Sciences	China	151
6	Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES)	Brazil	141
7	Conselho Nacional de Desenvolvimento Científico e Tecnológico	Brazil	141
8	Natural Sciences and Engineering Research Council of Canada	Canada	134
9	China Postdoctoral Science Foundation	China	114
10	Ministry of Education of the People's Republic of China	China	106

Conclusions

This study gives a clear picture of how research in logistics and supply chain management has developed from 2020 to 2024. It shows that the number of studies in this field has grown quickly, with more attention given to topics like digital technology, sustainability, and how to handle risks and disruptions.

A volume of 63.095 publications was included in the bibliometric analysis. Articles were the top type of publications by 77.6% and then book chapters 11.4%. English was the most common language for authorship by 90.9% followed by Portuguese 3.3%. For the country of publications, China published 19.8% of publications, the United States 12%, and India 10.6%. The results show that open access and subscription access are almost equal: 53.2% for open access and 46.8% for the subscription model.

Regarding the top productive authors, Biswajit Sarkar (131), Anil Kumar (130), and Dmitry Ivanov (116) were the top three authors. In terms of citation count, Dmitry Ivanov was the top author with 12,821 citations. Finally, according to OpenAlex metric FWCI; Dmitry Ivanov was the top author as well.

Journals were the most common source of publications. Almost 70% of publications were published in journals and 30% in all other sources. "Sustainability" published the highest number of articles in 2024. According to citations and FWCI, "Journal of Cleaner Production" was the top journal (49662 citations, and 10247 FWCI), followed by "Sustainability" (35924 citations, 7629 FWCI).

For the contribution of academic institutes in research, "Islamic Azad University, Tehran" in Iran was the most affiliated institute with 469 publications. This was followed by "Centre National de la Recherche Scientifique" in France with 431 publications, and the third was "Hong Kong Polytechnic University" with 393 publications. The analysis of top funders shows that "The National Natural Science Foundation of China" funded 2773 research, the "Fundamental Research Funds for the Central Universities" in the EU funded 352 research, and "The National Social Science Fund of China" funded 249 research.

Overall, this analysis helps us understand the main areas of focus in recent years and points out some gaps, like the need for more collaboration between researchers and institutions.

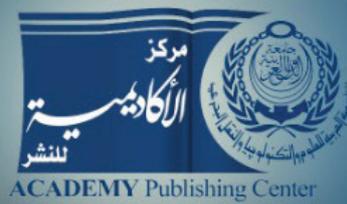
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INTERNATIONAL BUSINESS LOGISTICS

Journal

VOLUME 5, ISSUE 1, JUNE 2025



E-ISSN: 2735-5969