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CLIMATE CHANGE AND VULNERABILITY AND RESILIENCE OF MANUFACTURING SUPPLY CHAINS IN NIGERIA

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Abstract

Climate change is a pressing global issue with far-reaching implications for various sectors, including manufacturing supply chains. Given the Nigeria diverse geographic and socioeconomic landscape, understanding the presence or absence of cross-sectional dependence within the manufacturing sector will be crucial for implementing effective policy measures and business strategies. Hence, the main objective of this study it to investigate the impact of climate change on manufacturing supply chains in Nigeria using the survey research design. The sample comprised 320 employees and other stakeholders in the manufacturing industry selected through the stratified sampling technique. Instrument used for data collection was a structured questionnaire. Two hypotheses were formulated and tested by means of simple linear regression analysis at the .05 level of significance. Results revealed that climate change has a significant impact on the vulnerability of manufacturing supply chains ($\beta = 0.263$, $t = 13.268$, $p < .05$) and climate change has a significant impact on the resilience of manufacturing supply chains in Nigeria ($\beta = -0.227$, $t = -11.469$, $p < .05$). Based on these findings, it was concluded that climate change significantly impacts the vulnerability and resilience of manufacturing supply chains in Nigeria, with a positive relationship to vulnerability and a negative relationship to resilience**.** It was subsequently recommended, among others, that the management of manufacturing supply chains in Nigeria should proactively develop and implement climate change adaptation strategies such as conducting vulnerability assessments to identify specific risks and vulnerabilities posed by climate change.

Key Words: Climate change, vulnerability, resilience, manufacturing supply chains.

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Introduction

Climate change is a pressing global issue with far-reaching implications for various sectors, including manufacturing supply chains. Climate change refers to the long-term alteration of the earth's average weather patterns, particularly changes in temperature and weather events, which emanate from both natural phenomena and human activities. The major cause of climate change is the increased accumulation of greenhouse gas concentrations in the atmosphere, primarily carbon dioxide (CO2) from burning fossil fuels, deforestation and other industrial activities. These greenhouse gases trap heat, leading to the "greenhouse effect" and global warming (Intergovernmental Panel on Climate Change, 2014). Manufacturing supply chains are the interconnected networks of organizations, processes, resources and technologies involved in the production and distribution of goods. They encompass all the activities required to transform raw materials into finished products and then deliver them to the consumers or other firms (Chopra & Meindl, 2015). According to Monczka, Handfield, Giunipero, and Patterson (2020), supply chains typically involve multiple stages, including sourcing raw materials, manufacturing, assembly, quality control, packaging, warehousing, transportation and distribution. The aim is to optimize the flow of materials and information throughout the entire process, minimizing costs and lead times while maximizing efficiency and customer satisfaction.

The vulnerability and resilience of manufacturing supply chains to climate change impacts have gained significant attention in recent years. Nigeria, as a developing country located in West Africa, is particularly susceptible to the adverse effects of climate change due to its geographical location and socio-economic characteristics. The Intergovernmental Panel on Climate Change (IPCC) has highlighted the increasing frequency and intensity of extreme weather events such as droughts, floods, and heatwaves as key consequences of climate change (IPCC, 2014). These events pose significant risks and disruptions to manufacturing supply chains, leading to potential economic losses, production delays, and disruptions in the flow of goods and services.

Climate change is expected to have far-reaching effects on global supply chains, disrupting production, distribution and transportation systems. Extreme weather events, rising temperatures, changing precipitation patterns and sea-level rise can lead to supply chain disruptions, increased operational costs and reduced efficiency (Gupta, Lim, & Rana, 2020; Pettit, Harris, Beresford, & Zhang, 2018; Rehman, Gligor, & Kovács, 2017).

Assessing the vulnerability of manufacturing supply chains to climate change involves understanding the exposure, sensitivity and adaptive capacity of the system (Fletcher, Gemenne, & Tan, 2018; Wang, Sarkis, & Zhang, 2020). Exposure refers to the degree of climatic changes and associated hazards faced by the supply chain. Sensitivity relates to the supply chain's susceptibility to these changes due to its characteristics, location, and dependencies. Adaptive capacity reflects the ability of the supply chain to respond and recover from climate-related disturbances (Raza, Raza, Shahbaz, & Zafar, 2021).

Resilience is a crucial concept in managing climate change risks in supply chains. Building resilience involves developing adaptive strategies and implementing robust risk management practices to enhance the ability of supply chains to withstand and recover from disruptions (Islam, Meade, & Sarkis, 2019; Wang, Sarkis, & Li, 2018). Resilience measures may include diversifying sourcing locations, implementing climate-responsive logistics

systems, fostering collaboration among supply chain partners, and integrating climate change considerations into business continuity planning (Khan, Sarkis, J., & Geng, 2020; Mishra et al., 2019)

Understanding the specific vulnerabilities and developing strategies to enhance resilience are crucial for the sustainable development and continuity of manufacturing supply chains. This study aims to investigate the climate change vulnerability and resilience of manufacturing supply chains in Nigeria, providing valuable insights for policymakers, industry stakeholders and researchers.

The research gap in this study can be identified as the lack of specific, localized studies that explore the impact of climate change on the vulnerability and resilience of manufacturing supply chains in Nigeria. Although global and regional studies exist, there is a need for focused research that examines the unique challenges and dynamics faced by Nigerian manufacturing supply chains in the context of climate change. There is limited research specifically addressing how climate change affects manufacturing supply chains within the Nigerian context, considering the unique socio-economic and environmental conditions of the country. There is also a lack of detailed, practical climate change adaptation strategies designed for the Nigerian manufacturing sector. Finally, there are insufficient studies involving a wide range of stakeholders within the Nigerian manufacturing industry to comprehensively understand their perspectives and challenges related to climate change.

The research problem in this paper is therefore the significant impact of climate change on the vulnerability and resilience of manufacturing supply chains in Nigeria. The problem is characterized by an increase in the vulnerability of manufacturing supply chains by climate change, a significant negative impact of climate change on the resilience of manufacturing supply chains and a need for structured vulnerability assessments and the development of specific adaptation strategies. By addressing these issues, this study can provide valuable insights and recommendations that can help the Nigerian manufacturing sector to better prepare for and respond to the challenges posed by climate change.

Research Objectives

The main objective of this paper is to examine climate change vulnerability and resilience of manufacturing supply chains in Nigeria. The specific objectives are:

1. to assess the current state of manufacturing supply chains in Nigeria and highlight the negative impacts of climate change.
2. to evaluate the potential risks and impacts of climate change on manufacturing supply chains, including extreme weather events, resource scarcity, and infrastructure disruptions; and
3. to provide recommendations and guidelines for policymakers, industry stakeholders and supply chain managers to enhance the climate resilience of manufacturing supply chains in Nigeria.

Research Questions

1. 1.Does climate change have a significant impact on the vulnerability of manufacturing supply chains in Nigeria?
2. Does climate change have a significant impact on the resilience of manufacturing supply chains in Nigeria?

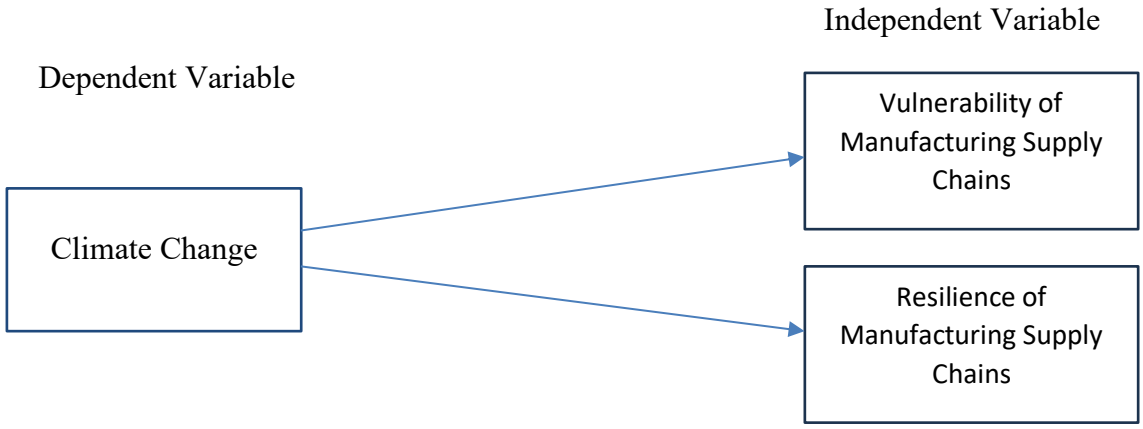
Hypotheses

H1: Climate change has significant impact on the vulnerability of manufacturing supply chains in Nigeria.

H2: Climate change has no significant impact on the resilience of manufacturing supply chains in Nigeria.

Conceptual Framework

The conceptual framework demonstrates that climate change (the independent variable) affects the vulnerability (the first dependent variable), and resilience (the second dependent variable) of manufacturing supply chains in Nigeria. This is illustrated in Figure 1.



Justification of the Study

This study is justified by several reasons. Firstly, climate change is a pressing global issue, with far-reaching implications for the manufacturing sector. Secondly, as a developing country with a robust manufacturing sector, Nigeria is vulnerable to climate change due to its geographical location and socio-economic characteristics. Thirdly, although several studies have been carried out on climate change and supply chains globally, studies focusing on Nigeria are rare. The country's ability to maintain and improve its manufacturing supply chains is vital for its economic stability and growth. Finally, manufacturing is an important sector in Nigeria's economy. Disruptions in supply chains due to climate change can lead to serious economic losses, production delays and disruptions in the distribution of commodities. All these gaps provide justification for this study.

Literature Review

The Concept of Climate Change

The World Meteorological Organization in 1966 proposed the term climatic change to encompass all forms of variations in the climate variability on timescales of greater than 10 years, whether the cause was natural or anthropogenic. When it was realized that human activities had a potential to drastically alter the climate, the term climate change replaced climatic change as the dominant term to reflect an anthropogenic cause. Climate change was incorporated in the title of the Intergovernmental Panel on Climate Change (IPCC) and the UN Framework Convention on Climate Change (UNFCCC). Since 1988, the IPCC has produced 5 multivolume reports which collate the consensus of all leading scientists across the globe on all aspects of the science of climate change (Geoffrey, 2017).

Climate change refers to changes in the earth’s climates, at local, regional, or global scales, and is most used to describe anthropogenic, or human-caused, climate

change (Hayhoe, 2019). In other words, climate change is used to describe changes in the earth's climate caused mainly by human activities such as the burning of fossil fuels (coal, oil and gas) and deforestation resulting in an increase in the concentration of carbon dioxide in the atmosphere (El-Sheikh, 2022). It can bring about long-term changes in temperatures and weather patterns.

"Global warming" is a term that is commonly used synonymously with climate change. It refers to the rise in average global temperatures, which can pose significant hazards to human life, wildlife and ecosystems. Burning fossil fuels generates greenhouse gas emissions that act like a blanket wrapped around the earth, trapping the sun's heat and raising temperatures. There is strong consensus among climate scientists that human activities have been the major cause of observed warming trends since the 20th century (Rainforest Alliance, 2018). Surface temperature increase in Nigeria has been found to be correlated with greenhouse gas emissions which can cause rise in sea level. Rise in sea level in turn can trigger coastal erosion, flooding, saltwater intrusion, mangrove degradation and other related socio-economic problems (Akintoye & Adedokun, 2023).

Climate Change, a result of global warming, is a reality of universal acceptance, affecting in many ways the life of human societies, business operations and the environment itself (Stern Review, 2016). In fact, businesses must perform their climate change-prone operations in a more vigorous and riskier environment where institutional, resource-based, supply chain and stakeholder views are all important to characterize and understand corporate strategic responses to a sustainability issue (Ibrahim & Udo, 2024). According to (Oluwole & Adeyemi, 2023), there are three types of climate change risks that can affect business: risks to core operations, risks to the value chain and, finally, risks that arise from broader changes in the economy and infrastructure. Moreover, climate change mitigation and adaptation policies may further affect business operations in a rather indirect way. Businesses should think of climate change as a market issue as regulations towards climate change affect, among others, energy prices and availability, thus, creating a ripple effect throughout their entire value chain (Adamu & Hassan, 2024). Market issues and relevant market strategies should be taken into consideration when companies draft climate change policies (Adamu & Hassan, 2024).

Manufacturing Supply Chains

A manufacturing supply chain refers to the interconnected network of organizations, activities, resources, and processes involved in the production and distribution of goods or products. It is a dynamic and complex system that aims to ensure the timely, cost-effective and reliable flow of materials and products from the initial sourcing of raw materials to the delivery of finished goods to customers. Manufacturing supply chains typically involve multiple stages, including procurement, production, logistics, and distribution. They encompass various entities such as suppliers, manufacturers, wholesalers, retailers, and transportation providers, all working together to ensure the smooth and efficient flow of materials and products. The key components of a manufacturing supply chain include suppliers, manufacturers, logistics and distribution and customers (Adebanji, Oyewunmi, & Afolabi, 2020).

Climate Change and Manufacturing Supply Chains

Climate change impacts industrial supply chains through various channels, including extreme weather occurrences, resource

availability, and evolving market dynamics. The Intergovernmental Panel on Climate Change (2014) underscores the importance of assessing vulnerability and establishing resilience to adapt to these repercussions.

In the present volatile environment, climate change alters the competitive landscape for manufacturing firms. Consumers increasingly demand high-quality products and services at competitive prices, while also valuing environmental considerations such as carbon footprint and energy efficiency (Okoro & Eze, 2023). Companies that fail to integrate this message into their supply chain strategy or neglect to address climate change concerns will inevitably face repercussions from environmentally conscious customers.

Moreover, recognizing that "supply chains compete, not companies" (Adebanjo & Olaniyan, 2024), it becomes evident that Supply Chain Management (SCM) will play a pivotal role in meeting the evolving demands of customers in the context of climate change. Employing an appropriate supply chain strategy becomes imperative for firms to fully capitalize on the opportunities presented by climate change while mitigating associated threats. In the era of low carbon emphasis, it appears that low-carbon SCM will serve as the driver for enhancing competitiveness (Yang & Zhang, 2011). Regulatory, physical, and market influences stemming from climate change create both challenges and prospects for supply chains.

Vulnerability of Manufacturing Supply Chains in Nigeria

Climate change introduces significant uncertainties into supply chain networks, particularly those that operate globally across multiple continents. As revealed by McKinnon (2009), the concentration of inventory over the last four decades has amplified the vulnerability of supply chains to extreme weather phenomena like flooding. Hence, it becomes very important to account for climate change risks during the initial design phase of supply chain networks to safeguard them from potential disruptions and susceptibilities to both physical and regulatory instabilities.

Addressing supply chain strategic considerations, five key clusters of implications emerge: facility location, product design, transportation and distribution, sourcing, and supply chain network configuration. Regarding supply chain configuration, the lean, agile, and leagile paradigms have been identified as the most prevalent paradigms under which supply chains can be structured and operated (Adebanjo & Olaniyan, 2024; Geoffrey, 2017).

Determining which of the three paradigms is more environmentally friendly and accounts for fewer emissions poses a complex challenge. For instance, whether the lean paradigm aligns with green principles lacks scientific consensus (Geoffrey, R.M. (2017)). Similarly, it is challenging to ascertain which paradigm is more susceptible to the stresses brought about by climate change. Each paradigm has its unique characteristics, leading to diverse exposure levels to climate-related hazards. Consequently, in the context of climate change, all three paradigms face mounting pressures as their building blocks' configuration demands a predefined level of synchronization and alignment. Furthermore, aspects of coordination, collaboration, and information sharing may also emerge. While substantial changes in the configuration of supply chains might not result directly from climate change, adjustments that reduce vulnerabilities and confer competitive advantages should be implemented. These adjustments stem from the differential vulnerability levels presented by their building blocks in the face of climate change hazards. Certain supply chain configurations capable of absorbing adverse climate change

effects could indeed confer a competitive edge.

Studies indicate that manufacturing supply chains in Nigeria grapple with diverse vulnerabilities linked to climate change. Akpan (2018) underscores the risks linked to severe weather events, such as flooding and heatwaves, which have the potential to disrupt transportation infrastructure and harm production facilities. Additionally, Essien (2020) emphasizes the susceptibility of supply chains to water scarcity, considering Nigeria's uneven distribution of water resources.

Drivers of Vulnerability

Geographical location, sector-specific characteristics, and reliance on scarce resources are identified as key drivers of vulnerability within manufacturing supply chains. Ologunde (2019) suggest that coastal manufacturing supply chains in Nigeria face heightened risks due to rising sea levels and coastal erosion. Furthermore, Olawoye and Elegbede (2021) highlight the vulnerabilities associated with resource-intensive industries, such as energy-intensive manufacturing processes.

Resilience Strategies

Research reveals several strategies for enhancing the resilience of manufacturing supply chains in Nigeria. These include diversifying sourcing locations (Nwachukwu 2019), implementing contingency plans for disruptions (Adebanji *et al.*, 2020), and adopting green technologies to reduce environmental impact (Ismaila, 2021). Furthermore, government policies and support mechanisms, such as renewable energy incentives and climate change adaptation plans, are identified as crucial in promoting resilience (Adelekan, Fayeun, & Johnson, 2020).

Collaborative Networks

Collaboration and information-sharing among stakeholders within manufacturing supply chains are essential for building resilience. Studies emphasize the role of partnerships between manufacturers, suppliers, customers, and governmental agencies in sharing knowledge, resources, and risk management strategies (Okoroh, 2021; Chukwuemeka, 2022). This literature review highlights the importance of understanding the vulnerability and resilience of manufacturing supply chains in Nigeria in the face of climate change. It underscores the need for research and practical interventions to enhance adaptive capacity and mitigate the risks associated with climate change impacts. By incorporating strategies such as diversification, resource optimization, and collaboration, manufacturing supply chains in Nigeria can become more resilient in the face of a changing climate.

Appraisal of Literature and Theoretical Framework

The literature review is adequate, current and recent. It integrates various perspectives on climate change impacts and supply chain resilience (Akintoye & Adedokun, 2023; Okoro & Eze, 2023). The underpinning theoretical framework combines supply chain management paradigms (lean, agile, leagile) with climate change resilience strategies and emphasize the need for adaptive and strategic responses (Adebanjo & Olaniyan, 2024). This framework is highly applicable to the study as it provides a structured approach to understanding and mitigating climate-related vulnerabilities within Nigeria's manufacturing supply chains and highlights the importance of diversification, resource optimization and collaboration (Ibrahim & Udo, 2024; Adamu & Hassan, 2024).

Methods

Research Design

This study adopted a descriptive survey research design and primary data which were collected through surveys or questionnaires. This design enabled the researcher to capture large sample size and employ a questionnaire to gather data for analysis for the purpose of generalizing on the impact of climate change on the vulnerability and resilience of manufacturing supply chains in Nigeria.

Population

The population of interest for this study comprised of all the, approximately 39,600, employees of manufacturing companies in South-West Nigeria.

Sample and Sampling Technique

A multi-stage sampling technique was employed. In the first stage, a purposive sampling method was used to select three states in South-West Nigeria. In the second stage, a list of manufacturing companies operating within these selected States was obtained. Within each stratum, manufacturing companies were randomly selected based on their size, sector and vulnerability to climate change impacts. Stratified random sampling technique was then applied to select a representative sample of 396 employees, selected through the Taro Yamani's formula, from the manufacturing industry. The technique was used because the data meet the following assumptions:

1. The observations within each stratum and across different strata were independent or distinct from one another.
2. There was homogeneity within strata, i.e., the units within each stratum were relatively homogeneous with respect to the variable of interest.
3. There was heterogeneity between strata, i.e., the strata should be different from each other in terms of the variable being studied.
4. Every member of the population could be assigned to one and only one stratum.
5. Each stratum had a sufficient sample size to allow for reliable statistical inference.

Research Instruments

A self-constructed structured questionnaire titled "Climate Change and Vulnerability and Resilience of Manufacturing Supply Chain Questionnaire" (CCVRMSCQ) was used by the researcher. The questionnaire was developed to collect quantitative data on vulnerability and resilience of manufacturing supply chains using the theoretical approach. The questionnaire contains 20 items related to climate change impacts, collaboration among stakeholders, supply chain disruptions and adaptation strategies. It has two sub-scales: Climate Change & Vulnerability of Manufacturing Supply Chains sub-scale and Climate Change & Resilience of Manufacturing Supply Chains sub-scale, with each sub-scale having 10 items. The CCVRMSCQ is a 4-point Likert-type instrument having responses ranging from 1 = strongly disagree to 4 = strongly agree. Sample items on the scale are: 1. *There is an increase in transportation costs or logistical challenges due to climate-related changes (e.g., rising sea levels, changing weather patterns)* and 2. *My organization's manufacturing supply chain can adapt and thrive in the face of climate change challenges*.

Reliability and Validity of the Instruments

The reliability of the instrument was tested using the test-retest method. Consequently, it was administered on a sample of 25 employees of manufacturing organizations in the study area on two separate occasions with an interval of two weeks between the two

administrations. An analysis of the two sets of scores obtained yielded test-retest reliability coefficients of .87 and .81 for the Climate Change & Vulnerability of Manufacturing Supply Chains sub-scale and Climate Change & Resilience of Manufacturing Supply Chains sub-scale respectively. These indices indicate that the items on the CCVRMSCQ are stable over time and the instrument is reliable. To ensure the validity of the research instruments, a thorough literature review was conducted to identify relevant variables and constructs. The questionnaire was also reviewed by experts in the field who determined their face and content validity.

Method of Data Collection

After obtaining ethical approval for the study, data collection commenced. The questionnaires were administered manually to the employees in the selected manufacturing companies while adhering to the ethical principles of informed consent, confidentiality and anonymity. Interested employees were at liberty to complete the survey or refuse to complete it. Of the 396 copies of the questionnaire distributed, 384 were completed and returned. This gave an attrition rate of 3.03%. This indicates a high rate of return.

Method of Data Analysis

Quantitative data obtained from the questionnaires were analyzed using simple linear regression analysis to test the hypotheses at the .05 level of significance. However, descriptive statistics was used to analysis the demographic characteristics of the respondents.

Ethical Considerations

i. Informed Consent: Participants were provided with detailed information about the study's purpose, procedures and potential risks and benefits. Their voluntary participation and right to withdraw at any time without consequence were emphasized. Informed consent forms were obtained from all participants.

ii. Anonymity and Confidentiality: Participants' identities and responses were kept confidential. Data were stored securely and accessible only to the researcher.

iii. Data Protection: All data collected were used solely for research purposes and were securely stored in accordance with data protection regulations.

iv. Ethics *Approval:* This study sought and obtained ethical approval from the relevant institutional review board or ethics committee.

Results

A total of 396 questionnaires were distributed to the respondents both online, using google form, and offline, but 384 responses were received and find valid for analysis, making 97% response rate. Both descriptive and inferential statistics were employed for the analysis, while descriptive was used for the demographic distribution, simple regression was used to test the stated hypothesis, which was also used answer the research questions, at 5% level of significant.

Demographic Presentation

Table 1: Participants' Demographic Data

S/No	Variable	Category	N = 384	Frequency	Percentage
1	Gender	Male		226	58.9
		Female		158	41.1
2	Age (years)	Below 30		72	18.8
		30 – 49		193	50.3
		50 & above		119	30.9
3	Qualification	Below First Degree		93	24.2
		First Degree/HND		189	49.2
		Master's Degree		79	20.6
		PhD		23	6.0
4	Work Experience (years)	Less than 10		84	21.9
		10 - 19		192	50.0
		20 & above		108	28.1

Source: Field Survey, 2024

Table 1 showed the frequency and percentage distribution of participants. It revealed that most of the participants (58.9%) were male while 41.1% of the participants were female. Thus, there were more male than female participants in this study. Most of the participants (50.3%) were 30 – 49 years old. This was successively followed by those who were 50 years old and above (30.9%) and below 30 (18.8%). The greatest proportion of the participants (49.2%) had First Degree/HND qualification. This was successively followed by those who had below First-Degree qualification (24.2%), Master's degree (20.6%) and Ph.D. (6.0%). Finally, exactly a half of the participants (50%) had 10 - 19 years' work experience. This was successively followed by those who had 20 & above years' (28.1%) and less than 10 years' (21.9%) work experience.

Test of Hypotheses

Hypothesis One

Climate change has no significant impact on the vulnerability of manufacturing supply chains in Nigeria.

Table 2: Simple Linear Regression Coefficients for Impact of Climate Change on Vulnerability of Manufacturing Supply Chains

	B	Std. Error	Beta	t	Sig.
(Constant)	3.836	6.108		17.035	.000
Climate Change	.127	.029	.263	13.268	.000

Dependent Variable: Vulnerability of Manufacturing Supply Chains
Source: Field Survey, 2024

Table 2 showed the impact of climate change on vulnerability of manufacturing supply chains. It revealed significant results (β = .263, t = 13.268, p <.0005) leading to the rejection of the null hypothesis and the upholding of the alternative hypothesis that climate change has a significant impact on the vulnerability of manufacturing supply

chains in Nigeria. Table 2 further indicated a significant positive relationship between climate change and vulnerability of manufacturing supply chains (β = .263).

Hypothesis Two

Climate change has no significant impact on the resilience of manufacturing supply chains in Nigeria.

Table 3: Simple Linear Regression Coefficients for Impact of Climate Change on Resilience of Manufacturing Supply Chains

	B	Std. Error	Beta	t	Sig.
(Constant)	2.906	4.574		12.375	.000
Climate Change	-.103	.033	-.227	-11.469	.000

Dependent Variable: Resilience of Manufacturing Supply Chains
Source: Field Survey, 2024

Table 3 showed the impact of climate change on resilience of manufacturing supply chains. It revealed significant results (β = -.227, t = 11.469, $p < .0005$) leading to the rejection of the null hypothesis and the upholding of the alternative hypothesis that climate change has a significant impact on the resilience of manufacturing supply chains in Nigeria. Table 3 further indicated a significant negative relationship between climate change and resilience of manufacturing supply chains (β = -.227).

Discussion

The findings of the study provide significant insights into the impact of climate change on the vulnerability and resilience of manufacturing supply chains in Nigeria. The test of the first hypothesis showed that climate change has a significant impact on the vulnerability of manufacturing supply chains in Nigeria (β = .263, t = 13.268, p <.0005): This indicates a strong positive relationship between climate change and the vulnerability of manufacturing supply chains. The beta coefficient (β = .263) suggests that as climate change intensifies, the vulnerability of supply chains increases significantly. This finding corroborates the assertions made in the literature. For example, Akpan (2018) highlighted the risks posed by severe weather events such as flooding and heatwaves to supply chain infrastructure in Nigeria. Similarly, Essien (2020) emphasized the susceptibility of supply chains to water scarcity, which aligns with the study's findings on increased vulnerability. The positive relationship between climate change and the vulnerability of manufacturing supply chains is supported by multiple studies. McKinnon (2009) discussed how concentrated inventory practices increase supply chain vulnerability to extreme weather events. Ologunde (2019) and Olawoye and Elegbede (2021) further identified geographical and sector-specific characteristics as drivers of vulnerability, which the study's findings reinforce.

The test of the second hypothesis showed that climate change has a significant impact on the resilience of manufacturing supply chains in Nigeria (β = -.227, t = 11.469, p < .0005): This result demonstrates a significant negative relationship between climate change and the resilience of manufacturing supply chains. The beta coefficient (β = -.227) indicates that the increasing impacts of climate change negatively affect the resilience of these supply chains. This finding aligns with existing literature. Research by Adebanji et al. (2020)

and Ismaila (2021) has stressed the importance of adopting resilience strategies, such as diversifying sourcing locations and implementing contingency plans, to mitigate climate-related disruptions. The study's findings underscore the critical need for these resilience-building measures. The negative relationship between climate change and supply chain resilience is in line with the findings of Islam, Meade, and Sarkis (2019) and Wang, Sarkis, and Li (2018). These studies emphasized the importance of adaptive strategies and robust risk management practices to enhance supply chain resilience. The study's findings highlight the critical role of resilience measures, such as collaboration among supply chain partners and integration of climate change considerations into business continuity planning, as recommended by Khan, Sarkis, and Geng (2020) and Mishra et al. (2019).

Finally, the underpinning theoretical framework combining supply chain management paradigms (lean, agile and leagile) with climate change resilience strategies is validated by the study's findings. The need for adaptive and strategic responses, as highlighted by Adebanjo and Olaniyan (2024), Ibrahim and Udo (2024) and Adamu and Hassan (2024), is supported by the demonstrated impacts of climate change on both vulnerability and resilience. Based on these findings, the following recommendations were made:

1. The management of manufacturing supply chains in Nigeria should proactively develop and implement climate change adaptation strategies. This includes conducting vulnerability assessments to identify specific risks and vulnerabilities posed by climate change. Based on these assessments, supply chain managers can develop targeted adaptation plans, such as implementing climate-resilient infrastructure, diversifying sourcing and production locations, and adopting technologies that enhance resilience to climate-related disruptions.
2. Collaboration among stakeholders should be strengthened to build resilient supply chains. Manufacturers, suppliers, logistics providers, government agencies and local communities should foster partnerships and knowledge sharing to collectively address the challenges of climate change. This can involve joint planning, information exchange and coordination to enhance the overall resilience of supply chains. Engaging with relevant industry associations and networks can also provide a platform for collaboration and sharing best practices.
3. Manufacturing organizations should invest in technology and innovation that can help in enhancing the resilience of manufacturing supply chains in Nigeria. Implementing advanced forecasting and risk management tools, utilizing real-time data monitoring and analysis and deploying smart logistics systems can improve supply chain visibility, responsiveness and adaptability. Furthermore, exploring sustainable and low-carbon technologies can help reduce the carbon footprint of supply chains, contributing to climate change mitigation efforts.
4. Capacity and awareness of supply chain stakeholders should be built. This can be achieved through training programmes, workshops and knowledge-sharing initiatives focused on climate change adaptation, risk management and sustainable practices. Raising awareness about the

potential impacts of climate change on supply chains and sharing best practices can empower stakeholders to make informed decisions and take proactive actions to strengthen resilience.

5. Government policies play a crucial role in creating an enabling environment for building resilient supply chains. Governments should therefore develop and enforce regulations that promote sustainable practices, climate change adaptation and resilience-building in the manufacturing sector. Integration of climate change considerations into national and sectoral policies, such as industrial development plans and infrastructure investment strategies can provide a holistic framework for addressing climate-related risks and vulnerabilities in supply chains.

Conclusion

Climate change poses significant challenges to the vulnerability and resilience of manufacturing supply chains in Nigeria. The findings of this study underscore the urgent need for strategic interventions, adaptive planning and collaborative efforts to mitigate the adverse effects of climate change and enhance the resilience of supply chains. By addressing these issues, stakeholders can ensure the sustainable development and continuity of manufacturing supply chains in Nigeria, ultimately contributing to the overall economic resilience and sustainability of the country.

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