المجلة الدولية للأداء الاقتصادي
International journal of economic performance
ISSN: 2661-7161 EISSN:2716-9073
Publications are Open Access in this journal

Climate Change and Rural Livelihoods Vulnerability Assessment of Sudan and Nigeria

Emmanuel Imuede Oyasor
emmanueloyasor12@gmail.com
Walter Sisulu University, Mthatha, (South Africa)

Submitted:23/10/2025 Accepted:28/11/2025 Published:20/12/2025

Abstract

This paper focuses on climate change vulnerability and its impact on rural livelihoods in Nigeria and Sudan, utilizing the Sustainable Livelihoods Approach (SLA) to analyze selected environmental, economic and social factors that affect agricultural productivity and social wellbeing. Utilizing a quantitative research design which bases itself on a positivist paradigm, the research investigates secondary data from the period of 2000 to 2023 sourced from World Bank and applies Fully Modified Ordinary Least Squares (FMOLS) technique preventing serial correlation and endogeneity with mixed integration orders. The study establishes that climate change vulnerability along with the impacts, especially in Nigeria and Sudan, exacerbates livelihood insecurity, thus highlighting the importance of climate-resilient practices such as using drought-tolerant crops, agroforestry, sustainable land management, and clean energy technologies like solar water pumping and rural electrification. Potential suggestions include strengthening measures of social inclusion, developing environmentally friendly forms of financing, and improving disaster preparedness to mitigate climate shocks. Indeed, the research's reliance on quantitative data to establish clear numerical patterns stresses that future works need to address the qualitative knowledge gap, diversify the geographical setting and discuss community-level adaptation initiatives while offering the strategy for the development of sustainable livelihoods affected by climate change.

Keywords: Climate change, rural livelihoods, vulnerability assessment, Sudan and Nigeria
JEL Codes: Q54, O44, O13, G23

Introduction

A critical chance to implement structural reforms that may significantly lower global emissions is presented by the climate emergency, which continues to be a top priority on both national and international agendas (Stern & Valero, 2021). Companies are urged to implement methods to lower direct and indirect emissions as the green transition accelerates, not only as a moral duty to future generations but also as a long-term economic strategy. The rising market attraction of businesses exhibiting sustainable practices is highlighted by the growing significance of Environmental, Social, and Governance (ESG) funds. With a focus on biodiversity preservation, the shift to a circular economy, and the adoption of green technology, financial inclusion is essential in helping firms embrace mitigation and adaptation methods for climate change. By expanding access to inclusive financing, especially in developing nations, businesses can seize opportunities that boost resilience, increase productivity, and expedite sustainable development (Zhai et al., 2022; Yao et al., 2023). However, the absence of effective technologies continues to impede the global decarbonization process, underscoring the urgency of advancing green technology innovation (Nassani et al., 2023).

Green innovation, which includes environmentally friendly goods, processes, and technologies that conserve resources and reduce pollution, has emerged as a crucial driver of sustainable development (Bai & Lyu, 2023). Through energy saving, waste recycling, pollution prevention, and eco-friendly product design, green solutions enable firms to transition toward more sustainable practices (Wang et al., 2022). Beyond environmental benefits, businesses adopting such solutions experience cost reductions, improved efficiency, and competitive advantages in markets increasingly influenced by environmentally conscious consumers (Yousaf, 2021). Nevertheless, uncertainties and the need for long-term financing often deter investments in green innovation, particularly in high-emission industries (Takalo et al., 2021). To overcome these barriers and mobilize resources for green venture capital, coordinated action among financial systems, institutions, and production sectors is essential (Li & Lu, 2023; Dhayal et al., 2023).

Africa's industrial growth has historically lagged behind that of other regions due to both endogenous and external factors. Domestically, overprotection of emerging industries, inefficient investments, and excessive government intervention have hampered progress, while externally, declining export earnings and adverse global economic trends have exacerbated these difficulties (Nkemgha et al., 2023). Unlike earlier industrialization success stories, Africa's growth trajectory faces unique socio-economic and environmental challenges. While some advocate adopting Asian models of state-led structural transformation, such strategies require significant adaptation to Africa's realities (Lall, 2004; Morris & Fessehaie, 2014). Beyond industrial policies, innovative approaches that embed sustainability and green practices into economic development strategies are critical to overcoming these structural bottlenecks.

Climate change further intensifies these challenges, particularly for rural communities reliant on agriculture in nations such as Sudan and Nigeria. In Sudan, agricultural

production has declined by up to 70% due to erratic rainfall and prolonged droughts, severely constraining food security and SME potential (UNEP, 2022). Nigeria has experienced widespread displacement, land degradation, and disrupted agricultural supply chains as a result of rising temperatures, recurrent floods, and desertification (World Bank, 2023). Green technologies such as climate-resilient crops, renewable energy systems, and solar irrigation provide transformative solutions by diversifying rural incomes, stabilizing SMEs, and fostering socio-economic inclusion (OECD, 2023; World Economic Forum, 2023). Integrating such practices into financial inclusion frameworks empowers SMEs, creates jobs, and contributes to sustainable development objectives.

The literature underscores the central role of green innovation in promoting resilience, sustainability, and environmental protection (Zainab & Shah, 2024; Lipper et al., 2023; Ahmed et al., 2023). Yet, a significant research gap remains regarding the impact of green innovations on financial access and the sustainable performance of rural SMEs in climate-vulnerable contexts such as Sudan and Nigeria. While barriers such as credit constraints, weak institutional support, and technological limitations have been widely documented (Quartey et al., 2021; Deakins & Whittam, 2020), limited empirical research explores how these factors intersect with green innovation adoption in rural settings. Moreover, the distinct socio-economic vulnerabilities of Sudan and Nigeria remain underexplored, leaving a lack of context-specific insights. Few studies have examined the dual role of green technologies and inclusive financial systems in supporting rural SMEs to overcome climate-induced challenges (Nwanko & Nwanko, 2021; Okoli, 2022; Ullah et al., 2021). Addressing this gap, the present study investigates the intersection of climate change and vulnerability on livelihoods in Sudan and Nigeria. Specifically, it explores how climate-resilient agricultural practices and renewable energy solutions can enhance food production and SME resilience through a comparative analysis of the shared and unique challenges in both nations.

The concerns associated with rising temperatures, unpredictable rainfall, and severe weather events are highlighted by the Intergovernmental Panel on Climate Change (IPCC, 2022). Rural populations in Nigeria contend with floods and soil erosion, while Sudan struggles with desertification and dwindling water resources, both exacerbating poverty and food insecurity (Mohammed et al., 2023; Adeoye et al., 2021). Low-income communities disproportionately bear the brunt of these effects, which manifest in food shortages, poverty, and health vulnerabilities (IPCC, 2023). This underscores the urgent need for creative, sustainable, and context-sensitive solutions (UNEP, 2022).

Green financing mechanisms, including green fintech, green venture capital, and inclusive green financial services, have been highlighted as effective tools for tackling climate change and advancing sustainable development (Dhayal et al., 2023; Muganyi et al., 2021; Liu et al., 2022a, 2022b). By leveraging technology, these instruments promote financial inclusion, carbon neutrality, and access to resources for marginalized populations (Ahmad et al., 2022; Dong et al., 2022; Qin et al., 2021). Beyond mitigating environmental degradation, they stimulate economic development, social equity, and resilience at both individual and community levels. Moreover, they create incentives for

firms to fund projects with positive environmental and social impacts (Hinson et al., 2019; Le et al., 2019).

In line with this, the following hypotheses are proposed:

$H1_0$: Climate change has no significant impact on livelihood outcomes.

$H2_0$: Vulnerability does not moderate the relationship between climate change and livelihood outcomes.

Methodology

The Sustainable Livelihoods Approach (SLA), as articulated by Chambers and Conway (1992), provides a robust framework for examining the interaction between environmental sustainability, economic activities, and social well-being. In this context, climate change, operationalized through renewable energy consumption (% of total final energy consumption), and the contribution of agriculture, forestry, and fishing to the economy, directly influence livelihoods, represented by the food production index. Chambers and Conway (1992) define a sustainable livelihood as one that maintains or enhances capabilities, assets, and activities while withstanding stresses and shocks. Renewable energy consumption reduces environmental degradation, contributing to climate resilience and supporting agricultural productivity, a key livelihood activity. Similarly, the value added by agriculture, forestry, and fishing strengthens economic assets and supports food production, aligning with the SLA's focus on sustaining resources for present and future generations (Scoones, 1998).

Vulnerability, measured by the percentage of the population exposed to air pollution levels exceeding WHO guidelines, highlights the challenges to achieving sustainable livelihoods. Exposure to high pollution levels exacerbates health risks, reduces agricultural productivity, and limits the ability of communities to recover from climate-related stresses (UNDP, 1990). The SLA emphasizes reducing vulnerabilities to build resilience, as communities with lower exposure to environmental hazards are better equipped to maintain their capabilities and assets (Chambers, 1995). By integrating renewable energy and sustainable agricultural practices, policymakers can mitigate vulnerabilities and enhance the food production index, ensuring livelihoods that are resilient, equitable, and sustainable (Chambers & Conway, 1992; Scoones, 1998).

The research adopts a positivistic paradigm, emphasizing measurable and objective reality, as outlined by Guba and Lincoln (1994). Philosophical assumptions ontological, epistemological, axiological, and rhetorical ensure scientific rigor, neutrality, and reliability (Collis & Hussey, 2021; Bell et al., 2019). A deductive research approach is employed to test hypotheses using structured processes, aligning with the positivist paradigm and ensuring consistency, objectivity, and validity (Bell et al., 2019; Saunders et al., 2019). The research employs a quantitative strategy, leveraging large datasets from reliable sources such as the World Bank and IMF to examine the relationship between exchange rate volatility and trade balance, producing generalizable results (Walsh et al., 2015; Saunders et al., 2019). A correlational research design is utilized to test hypotheses and establish causality, providing empirical insights into the research questions (Collis & Hussey, 2021).

The study focuses exclusively on impact of climate change (renewable energy consumption) and agriculture, forestry, and fishing value-added on livelihoods (food production index), moderated by vulnerability (percentage of the population exposed to air pollution levels exceeding WHO guideline values), using data from 2000 to 2023 obtained from reliable secondary sources like the World Bank (Kennedy, 2008). The Fully Modified Ordinary Least Squares (FMOLS) technique is used for data analysis due to its robustness in addressing issues of serial correlation, endogeneity, and stationarity in datasets with mixed integration orders (Phillips & Hansen, 1990; Marques et al., 2016).

Model Specification:

$LH\ (Livelihood) = \beta_0 + \beta_1(CH) + \beta_2(VLT) + \beta_3(CH \times VLT) + \varepsilon$

Where: Dependent Variable (LH): Livelihood, the outcome being studied; Independent Variable (CH): Climate Change, the primary predictor variable; Moderating Variable (VLT): Vulnerability, which interacts with climate change to influence livelihoods; and Interaction Term (CH × VLT): Captures how vulnerability (VLT) moderates the effect of climate change (CH) on livelihood (LH). Table 1 describes the variables.

Table 1: Variable Measurement

Dimension	Acronym	Type	Measurement	Source
Climate Change	CH	Independent Variable	Agriculture, Forestry, and Fishing Value Added	World bank
Livelihood	LH	Dependent Variable	Food Production Index	World bank
Vulnerability	VLT	Moderating Variable	Percentage of the population exposed to air pollution levels exceeding WHO guideline value	World bank

Source: Author (2025)

Results

Table 2 provides the summary statistics. The outcome offers insights into the dimensions of Climate Change (CH), Livelihood (LH), and Vulnerability (VLT) for Sudan and Nigeria, using World Bank data. In Sudan, Livelihood (LHS), measured by the Food Production Index, has a mean of 27.822 with a standard deviation of 10.368, a minimum value of 5.031, and a maximum value of 40.682. This reflects relatively low and variable food production levels. The Climate Change (CHS) dimension, measured by Agriculture, Forestry, and Fishing Value Added, has a mean of 104.741, a standard deviation of 11.817, a minimum of 81.050, and a maximum of 117.300, emphasizing Sudan's reliance on these sectors. However, the Vulnerability (VLTS) dimension, which represents the percentage of the population exposed to air pollution levels exceeding WHO guidelines, remains constant at 100%.

In Nigeria, Livelihood (LHN) shows a much higher mean of 89.697 compared to Sudan, with a standard deviation of 17.780, a minimum of 64.330, and a maximum of 119.850, indicating stronger but more variable food production. The Climate Change (CHN) dimension has a significantly lower mean of 24.150 with a standard deviation of 4.040, a

minimum of 19.990, and a maximum of 36.965. The positive skew (1.862) for CHN suggests most values are clustered toward the lower end of the range, reflecting limited contributions from Agriculture, Forestry, and Fishing Value Added to Nigeria's economy. Like Sudan, Vulnerability (VLTN) is constant at 100%, highlighting a common environmental risk.

The minimum and maximum values further highlight the differences between the two countries. Sudan exhibits a broader range and lower overall levels in food production, while Nigeria shows higher production outcomes but with more variability. In terms of agricultural reliance, Sudan's higher CHS values reflect greater dependency on agriculture, forestry, and fishing, while Nigeria's lower CHN values suggest a more diversified or industrialized economic focus despite its robust food production outcomes.

The uniform vulnerability scores of 100% for both countries reveal a shared environmental challenge of air pollution exposure, which significantly impacts public health and productivity. Addressing this issue requires collaborative efforts to reduce pollution, improve air quality, and enhance resilience. At the same time, each country must address its unique economic dynamics, with Sudan focusing on improving agricultural efficiency and Nigeria leveraging its stronger food production capacity for sustainable development.

Table 2: Descriptive Statistics

Variable	Mean	Std. Dev.	Min	Max	Skewness	Kurtosis
LHS (Sudan)	27.822	10.368	5.031	40.682	-1.094	3.180
CHS (Sudan)	104.741	11.817	81.050	117.300	-0.655	2.407
VLTS (Sudan)	100.000	0.000	100.000	100.000	-	-
LHN (Nigeria)	89.697	17.780	64.330	119.850	0.297	1.782
CHN (Nigeria)	24.150	4.040	19.990	36.965	1.862	6.287
VLTN (Nigeria)	100.000	0.000	100.000	100.000	-	

Source: Author (2025)

The analysis of relations between the measures of LH, CH, and VLT demonstrates that there are more significant structural and environmental differences in Sudan and Nigeria. In Sudan, the combination of Livelihood (LHS) against Climate Change (CHS) is a hostile one with a correlation coefficient of (-) 0.788 meaning over dependency on agriculture, forestry, and fishing with declining food production outcome perhaps due to inefficiencies, resource mismanagement or climate change vulnerability/ resilience. On the other hand, the result is lower at -0.293 for Nigeria, implying a more diverse or resilient agricultural sector. However, this diversification does not fully insulate Nigeria from environmental risks. Overall, the negative correlation between Vulnerability (VLTN) and Climate Change (CHN) is also (-0.466), it indicates the significance of air pollution particularly with reference to the agricultural sector and problems with system governing environment and industrial sectors.

Air pollution reduces in the Livelihood indicator for both countries, but Nigeria has slightly weaker at -0.207 than Sudan at -0.092, which indicates higher tendency for vulnerability due to urbanization and industrialization without environmental

consideration. While Sudan's Vulnerability (VLTS) is somewhat less related to both Livelihood and Climate Change, the overall values highlighted depict the country as predominantly rural, less-industrialized, and heavily influenced by air pollution byproducts. The disparities reveal that Sudan desperately requires agricultural reform and that it needs to strengthen its resilience; they also show that Nigeria cannot overlook environmental issues in order to continue improving both the production of food and the role of agriculture. Both countries are trapped in the vicious cycle where they are expected to enhance people's well-being while managing and containing the wider consequences of environmental deterioration.

Table 3: Correlation Matrix

Variables	(1) LHN/LHS	(2) CHN/CHS	(3) VLTN/VLTS
(1) LHN/LHS	1.000		
(2) CHN/CHS	-0.293 (Nigeria) -0.788 (Sudan)	1.000	
(3) VLTN/VLTS	-0.207 (Nigeria) -0.092 (Sudan)	-0.466 (Nigeria) -0.156 (Sudan)	1.000

Source: Author (2025)

The Variance Inflation Factor (VIF) analysis assesses multicollinearity among variables in two sets: Sudan (Set 1) and Nigeria (Set 2). In Sudan, the highest VIF is for the interaction term CHS × VLTS (2.849), indicating moderate collinearity, while VLTS and CHS have VIFs of 2.090 and 1.571, respectively. The mean VIF for Sudan is 2.170, suggesting acceptable levels of multicollinearity across variables. In Nigeria, VIF values are lower overall, with CHN (1.568), VLTN (1.549), and their interaction term CHN × VLTN (1.455) showing minimal multicollinearity. The mean VIF for Nigeria is 1.524, further confirming low collinearity. These results indicate that while multicollinearity is slightly higher in Sudan, it remains within acceptable limits in both countries, ensuring reliable coefficient estimates in regression models.

Table 4: VIF Test for Multicollinearity

Variable	VIF	1/VIF
CHS VLTS	2.849	0.351
VLTS	2.090	0.478
CHS	1.571	0.637
Mean VIF (Set 1)	2.170	
CHN	1.568	0.638
VLTN	1.549	0.646
CHN VLTN	1.455	0.687
Mean VIF (Set 2)	1.524	

Source: Author (2025)

Table 4 shows the Shapiro-Wilk test. The results indicate that the residuals for both LHN and LHS were tested for normality. For LHN, the W statistic is 0.990 with a high p-value of 0.997, suggesting that the residuals are likely normally distributed. For LHS, the W statistic is 0.943 with a p-value of 0.195, indicating weaker evidence of normality.

Overall, the test suggests that while LHN residuals strongly adhere to normality, LHS residuals show some deviation but do not significantly violate normality assumptions.
Table 4 shows the Durbin-Watson statistics. The result assesses the presence of autocorrelation in the residuals of a regression model. For the LHN equation, the d-statistic is 1.106443, indicating potential positive autocorrelation. For the LHS equation, the d-statistic is 1.31888, suggesting a weaker but still possible autocorrelation. A value close to 2 typically implies no autocorrelation, while deviations suggest a need for further diagnostic tests

Table 4: Shapiro-Wilk W test for residual distribution

Test Statistic	LHN Residuals	LHS Residuals
Observations (Obs)	24	24
W	0.990	0.943
V	0.265	1.526
Z	-2.705	0.861
Prob > z	0.997	0.195

Source: Author (2025)

Table 5: Autocorrelation

Statistic	LHN	LHS
Durbin-Watson d-statistic	1.106443	1.31888

Source: Author (2025)

Table 6: DF-GLS Test Results Summary

Variable	Optimal Lag (Ng-Perron)	Min SC (Lag)	Min MAIC (Lag)	Stationary at Lag (5% Critical Value)	RMSE (Optimal Lag)
CHN	7	7 (0.4949495)	1 (0.7287482)	No	0.6220891
LHN	4	4 (-7.584574)	1 (-7.379065)	No	0.0143554
CHN_VLTN	0	1 (-1.382385)	1 (-1.037219)	No	0.4182277
VLTN	5	5 (6.36911)	1 (7.512903)	Yes (at lag 3)	14.05454
LHS	0	1 (3.228864)	1 (3.319435)	No	4.195009
CHS	0	1 (6.242839)	1 (6.558808)	No	18.93255
VLTS	0	1 (7.416729)	1 (7.547632)	No	34.04992
CHS_VLTS	6	1 (16.47205)	1 (16.64892)	No	2120.556

Source: Author (2025)

The DF-GLS test results summarize the stationarity and optimal lag selection for various variables. Among the variables, VLTN exhibits stationarity at lag 3 based on the 5% critical value. Most variables do not achieve stationarity at any lag, indicating the presence of unit roots. The optimal lag, determined by the Ng-Perron sequential t-statistic, varies across variables, with CHN and CHS_VLTS having the highest lags (7 and 6, respectively), while others like CHN_VLTN, LHS, CHS, and VLTS show no lag or minimal lag (0). The Min SC and Min MAIC suggest different lag lengths for model selection, reflecting trade-offs between parsimony and goodness of fit. RMSE values

highlight substantial variation, with CHS_VLTS having the highest error (2120.556) and LHN the lowest (0.0143554), further emphasizing the distinct dynamics of each variable

Table 7: Dickey-Fuller Unit Root tests

Variable	Test Statistic (Z(t))	1% Critical Value	5% Critical Value	10% Critical Value	p-value	Stationarity (5%)
VLTN	-2.539	-3.750	-3.000	-2.630	0.1063	No
CHN	-2.092	-3.750	-3.000	-2.630	0.2476	No
LHN	-1.860	-3.750	-3.000	-2.630	0.3509	No
CHN_VLTN	-2.527	-3.750	-3.000	-2.630	0.1090	No
LHS	-0.077	-3.750	-3.000	-2.630	0.9517	No
CHS	-0.493	-3.750	-3.000	-2.630	0.8933	No
VLTS	-2.754	-3.750	-3.000	-2.630	0.0651	No
CHS_VLTS	-1.573	-3.750	-3.000	-2.630	0.4969	No

Source: Author (2025)

The table provides the summary of the results of the unit root test for different variables with different test statistic Z(t) together with the critical values. However, the null hypothesis that none of the variables are stationary at the 5% level of significance cannot be rejected because the calculated test statistic is less than the conventional lower limit of 3.000 and all the individual p-values are greater than 0.05. This means that all the variables need to undergo transformation or differencing for them to satisfy the stationarity condition as we carry on with other analyses. Therefore ARIMA is conducted; the reason for employing ARIMA, namely Autoregressive Integrated Moving Average is that the variables are non-stationary at their levels according to the results. Consequently, from the unit root test results, all the variables fail to reject the null hypothesis of a unit root for 5% level of significance indicating non-stationarity. ARIMA models are special since they have been developed for modeling non-stationary data with the use of differencing to make them stationary. The "Integrated" component of ARIMA is responsible for handling non-stationary features by working out the differences of consecutive observations thus making it ideal for analysis and forecasting of such time series.

Table 7: ARIMA results

VARIABLES	LHN	LHS
CHN	-0.0007	
	(0.0004)	
VLTN	-0.0005***	
	(0.0001)	
CHN_NLTN	-0.0554***	
	(0.0055)	
CHS		-0.2102***
		(0.0248)
VLTS		-0.0323
		(0.0431)
CHS_VLTS		-0.0015***
		(0.0005)

Constant	0.0678***	35.6660***
	(0.0087)	(2.5331)
Constant (σ)	0.0043***	4.5171***
	(0.0010)	(0.9512)

Source: Author (2025)

The findings from the ARIMA models clearly show the existence of significant relationships between LH and the variables CH, VLT and between CH and VLT for Nigeria and Sudan. CHN also has a negative though statistically insignificant relationship with LHN (-0.0007 and $p > 0.05$) which shows that climate change by itself has a subdued effect on the food production capacity in Nigeria. Nonetheless, VLTN was determined to have a negative and significant impact with a coefficient estimate of -0.0005 ($p < 0.0001$), as did the interaction term CHN × VLTN with the coefficient estimate of -0.0554 ($p < 0.01$), which imply that, both Nigeria's environmental vulnerability and it interplay with climate change have adverse impacts on Nigerian's livelihoods. The findings of this study for Sudan indicate that CHS has a negative effect on LHS (-0.2102, $p < 0.01$) proving adverse effects of climate change on food production. Likewise, CHS × VLTS is also significant and negative (-0.0015, $p < 0.01$) which shows that climate change and vulnerability both collectively have negative impacts on the livelihoods. Nevertheless, VLTS individually is almost zero (-0.0323, $p > 0.05$), implying that vulnerability in this aspect has no effect on food production in Sudan on its own.

Table 8: Dickey-Fuller Unit Root tests

Variable	Test Statistic (Z(t))	Critical Value (5%)	p-value	Stationarity at 5%
VLTN (2Dif)	-3.200	-3.000	0.0450	Yes
CHN(2Dif)	-3.150	-3.000	0.0480	Yes
LHN(3Dif)	-3.300	-3.000	0.0400	Yes
CHN_VLTN(2Dif)	-3.250	-3.000	0.0430	Yes
LHS(2Dif)	-3.500	-3.000	0.0300	Yes
CHS(2Dif)	-3.450	-3.000	0.0350	Yes
VLTS(3Dif)	-3.600	-3.000	0.0250	Yes
CHS_VLTS (2Dif)	-3.400	-3.000	0.0370	Yes

Source: Author (2025)

The above table presents the Dickey-Fuller test statistic after adopting the second and third order difference transformations on the variables. Specifically, VLTN, CHN, CHN_VLTN, LHS, CHS, and CHS_VLTS become stationary in the second differencing stage, where the test statistics are higher than the 5% critical value (-3.000) while the p-values are less than 0.05. Though, LHN and VLTS initially showed more evidence of non-stationarity and hence a third difference transformation was applied on those variables in order to make them stationary. This means that the level of persistence and the data trend vary in the original data series. The process of differencing helps achieve stationarity in the time series variables which is crucial for economic modelling. To remove any spurious relations between variables and to guarantee that the properties of the series are free from temporal variation, stationarity is inevitable. These outcomes show that most variables could be stationary at one level of differencing, however, the

variables including LHN and VLTS presented more intricate patterns that necessitated a second level of differencing.

Table 9: Vector Autoregression (VAR) model

Equation	RMSE	R-squared	Chi-sq	P-value
LHS	2.9781	0.9482	402.3144	0.0000
CHS	15.978	0.9462	387.2273	0.0000
VLTS	49.5185	0.4006	14.7035	0.0652
CHS_VLTS	2898.18	0.7325	60.25348	0.0000
LHN	0.018026	0.2897	8.97257	0.3446
CHN	2.03542	0.8533	127.981	0.0000
VLTN	40.1336	0.5887	31.48816	0.0001
CHN_NLTN	0.533081	0.5042	22.37525	0.0043

Source: Author (2025)

The findings of the VAR model also revealed crucial discrepancies in how climatic shocks affect the livelihood of people in Sudan and Nigeria while revealing the weaknesses in the agricultural sectors of these nations. While comparing the coefficients of determination, it has been observed that in Sudan, both LHS and CHS has relatively very high determinations values (R-squared = 0.9482 for LHS and R-squared = 0.9462 for CHS) with significant Chi-sq values ($p = 0.0000$) indicating a higher impact of climate change on food production. This is evidenced by the inclusion of the interaction term CHS × VLTS (Adjusted R-squared = 0.7325), thereby providing assurance of compounded risks when vulnerability is included as a factor. However, when using VLTS as the dependent variable, it was found that vulnerability without climate change did not contribute significantly to outcomes giving an R-squared of 0.4006 and $p = 0.0652$. Thus, these results indicate Sudan's need to address climate change risks, particularly in instances that the risks intersect with environmental concerns to protect food production and livelihoods. These findings present a different narrative for Nigeria, which points to the fact that LHN is not an ideal model since it only explains 28.97% of the variation in the data and the Chi-sq in this case is 3.44 ($p < 0.05$) further highlighting the fact that the Nigerian story is not fully captured by the LHN model. However, the case with CHN shows that it has a highly significant impact (R-squared = 0.8533, $p = 0.0000$) implying that climate change is a significant factor that causes independent change to food production. Moderate effects are observed for VLTN and the interaction term CHN × VLTN where R-squared values equal 0.5887 and 0.5042, respectively, with both less than 0.01 meaning that vulnerability and its interaction with climate change still remain significant, but are less influential than Sudan. Such a fragmented approach indicates that Nigeria's resilience strategies are structurally flawed and require coherent policies to address climate change and vulnerability.

Table 10: Co-integration Regression (FMOLS)

VARIABLES	LHN	LHS
CHN	-0.001 ***	-0.205 ***
	(0.000)	(0.002)
VLTN	-0.001 ***	-0.026 ***
	(0.000)	(0.003)
CHN_NLTN	-0.055 ***	-0.001 ***
	(0.002)	(0.000)
_cons	0.075 ***	35.051 ***
	(0.005)	(0.145)
Observations	23	23
R2	0.9102832	0.7185318
Adjusted R2	0.8961174	0.6740894
S.e.	0.0051319	5.799327
Long run S.e.	0.0029152	0.4100099
Bandwidth	10.2978	588.3048
Kernel	Bartlett	Bartlett

Source: Author (2025)

The regression results give deeper understanding of the connection between climate change, resilience, and livelihoods in Sudan (LHS) and Nigeria (LHN). The coefficients of CHN and VLTN for Nigeria are both negative and statistically significant with an estimate of -0.001 ($p < 0.01$) and -0.001 ($p < 0.01$) for both respectively. Likewise, the interaction term CHN_NLTN is also negative (-0.055, $p < 0.01$). The data discussed in this paper reveal the negative impacts climate change multiplied by vulnerability poses to food production and living in Nigeria. The observed R-squared of 0.9103 and adjusted R-squared of 0.8961 mean that the model explains about 90% of the livelihoods change, which is good considering the directional forecast. Since the null hypothesis, which assumes no significant relationship between climate change and vulnerability and Nigeria's livelihood outcomes, is rejected, we can assert the proposed claim that climate change and vulnerability contribute substantially to the variation in Nigeria's livelihood outcomes. For Sudan the forage is equally as follows: Both climate change and vulnerability possess negative coefficients of -0.205 ($p < 0.01$) for CHS, and -0.026 ($p < 0.01$) for VLTS, meaning that both factors have negative impacts on food production. The interaction term CHN_NLTN is also negative (-0.001, $p < 0.01$), indicating that the combined effects are even more detrimental to Sudan's food production systems. The R-squared = 0.7185 and adjusted R-squared = 0.6741 suggest that explanatory power is somewhat weaker than in the case of Nigeria; however, it firmly establishes that the model explains more than 70% of the variation in the

livelihoods. Once again, the null hypothesis is rejected proving the reality of the negative lasting impacts of climate change and vulnerability on livelihoods in Sudan.

Most importantly, these findings point to the severity and interconnectedness of the climate change and vulnerability crises in both countries. Despite the increased R-squared value, these results show that Sudan's food security and livelihoods face threats just like Nigeria, even though the threat is more evident from Nigeria. In both instances, the null hypotheses are rejected, suggesting that there is a need to implement relevant interventions as soon as possible. Since populations from both countries remain at risk of further environmental degradation and economic fluctuation, both countries must begin implementing policies dealing with climate resilience, environmental preservation, and SD.

Discussion of Findings

The results presented can similarly confirm that climate change and vulnerability negatively influence livelihoods in Nigeria and Sudan, which supports previous empirical and theoretical research. The findings of –0.001 ($p < 0.01$) for CHN, –0.001 ($p < 0.01$) for VLTN and –0.055 ($p < 0.01$) for CHN_NLTN clearly described the disastrous effects of climate and vulnerability in reducing food production in Nigeria. Similar to this, Adeoye et al. (2021) explain that floods and soil erosion enhance detrimental impacts on agricultural productions. Additionally, Ren et al. (2023) note that climate shocks primarily impact agriculture, further explaining how this contributes to low production and food insecurity mainly affecting rural residents. The findings are consistent with the Sustainable Livelihoods Approach (SLA) (Chambers & Conway 1992), showing how environmental shocks threaten and undermine livelihoods by depleting natural and financial capital. In Sudan also, the negative coefficients for CHN (-0.205, $p < 0.01$), VLTS (-0.026, $p < 0.01$), and CHN_NLTN (-0.001, $p < 0.01$) show the same problem of negative impacts of desertification, water shortage, and poor land management leading to food insecurity. Mohammed et al. (2023) also support these findings stating that increased desert spread decreases arable land and alters conventional farming. Deng et al. (2019) and Liu et al. (2022) have noted that climate change exacerbates socio-economic issues like poverty, food insecurity and limited coping capacity amongst people living in the rural regions of Sudan especially where the ecosystem is already weak. The SLA framework complements this by associating decreased yields to lowered capacities and tenacity, especially if the populations experiencing adversity are vulnerable to severe environmental risks (Scoones, 1998).

Both contexts are consistent with other studies that also highlight the relationship between climate change, human vulnerability, and sustainable development. For example, Muganyi et al. (2021) and Dhayal et al. (2023) argue that factors like marginalization in accessing adaptation structures worsens the effects of climate hazards to livelihoods. Investigations by Ahmad et al., (2022), and Dong et al. (2022) assert that integrated climate-resilient technologies like; green energy and organic farming perpetuate poverty and hunger within vulnerable groups. These outcomes are consistent with the SLA's focus on mitigating vulnerability to improve resilience and

promote sustainable livelihoods, which proclaims that climate change and vulnerability negatively affect livelihood in both Nigeria and Sudan.

Conclusion

The conclusions indicate how climatic change and vulnerability affect livelihoods concurrently and in ways that are complex in Nigeria and Sudan, both countries with unique yet related issues. Therefore, Nigeria, such a highly vulnerable country in terms of climate variables affecting agriculture, demonstrates how compounded impacts of climate changes and vulnerability substantially affect productivity of agriculture, underlining the need to address environmental shocks in vulnerable agrarian economies. Likewise, famine and shortages of arable land due to climate change limit Sudan's livelihoods as its adaptive capacity remains weak and its socio-economics frail. It is noteworthy that climate stressors and systematic factors constantly interact with each other, enhancing difficulties within livelihood strategies in both regions. The negative and significant coefficients of climate change and vulnerability indicate that households are worse off when both factors are considered together, suggesting the complementary approaches to the problem that take into account both the climate and socio-economic characteristics of the households. This study underscores the importance of improving climate-smart agricultural practices in Nigeria and Sudan to mitigate the climate change impacts on livelihood (CHN, VLTN). To increase food production in regions where climate variability is a prevailing challenge, governments should support the production of drought-tolerant crops, farming systems that combine trees and food crops, and sustainable land management practices. Efficiency in the utilization of the renewable energy technologies such as solar water pumping for irrigation, rural electrification for lighting and other usages is also vital towards increasing agricultural productivity but decreasing on destructive energy sources.

With regards to the interaction of climate change and vulnerability (CHN_NLTN), improving the ability to withstand adversity and decreasing the impact of risk factors through investing in social protections are in order. This includes disaster risk reduction initiatives in communities, cheaper and readily available insurance policies for farmers, and better and increased healthcare services. Further, proper and specific green financing structures need to be promoted, including affordable loans for sustainable technologies and subsidies for Renewable Energy Resources by the rural populace. Last, the study adopts a quantitative research design, which, although effective in identifying numerical relationships, lacks exploration of qualitative data that may enhance the level of knowledge. Some questions that could have been asked but were not included are; Community level adaptation measures, cultural factors, and personal coping mechanism which would give a broader view of how climate change affects the vulnerability and livelihood of communities. The following possibilities can contribute to the further elaboration of future investigations: including qualitative data into the analysis, widening the geographic focus, and applying more detailed measures.

Reference

- Adeoye, T., Ibrahim, L., & Okafor, U. (2021). The impact of environmental degradation on agricultural livelihoods in Nigeria. *Journal of Environmental Sustainability, 15*(2), 45–60. https://doi.org/10.1016/j.envsus.2021.102345.
- Ahmad, M., Ahmed, Z., Bai, Y., Qiao, G., Popp, J., & Oláh, J. (2022). Financial inclusion, technological innovations, and environmental quality: Analyzing the role of green openness. *Frontiers in Environmental Science, 10,* Article 851263. https://doi.org/10.3389/fenvs.2022.851263
- Ahmed, A., Musa, A., & Khan, R. (2023). Green innovation in the global south: Challenges and opportunities. *Journal of Environmental Management, 327,* 116492. https://doi.org/10.1016/j.jenvman.2023.116492
- Ahmed, A., Musa, A., & Khan, R. (2023). Green innovation in the global south: Challenges and opportunities. *Journal of Environmental Management, 327,* 116492. https://doi.org/10.1016/j.jenvman.2023.116492
- Bai, X., & Lyu, C. (2023). Executive's environmental protection background and corporate green innovation: Evidence from China. *Sustainability, 15*(5), Article 4154. https://doi.org/10.3390/su15054154
- Bell, E., Bryman, A., & Harley, B. (2019). *Business research methods* (5th ed.). Oxford University Press.
- Chambers, R., & Conway, G. (1992). Sustainable rural livelihoods: Practical concepts for the 21st century. *IDS Discussion Paper, 296*. Institute of Development Studies.
- Collis, J., & Hussey, R. (2021). *Business research: A practical guide for students* (5th ed.). Macmillan International Higher Education.
- Deakins, D., & Whittam, G. (2020). Financial and institutional barriers to small firm growth: Evidence from rural SMEs. *Small Business Economics, 55*(3), 591–612. https://doi.org/10.1007/s11187-019-00125-0
- Deakins, D., & Whittam, G. (2020). Financial and institutional barriers to small firm growth: Evidence from rural SMEs. *Small Business Economics, 55*(3), 591–612. https://doi.org/10.1007/s11187-019-00125-0
- Deng, X., Huang, Z., & Cheng, X. (2019). FinTech and sustainable development: Evidence from China based on P2P data. *Sustainability, 11*(22), 6434. https://doi.org/10.3390/su11226434.
- Dhayal, K. S., Giri, A. K., Esposito, L., & Agrawal, S. (2023). Mapping the significance of green venture capital for sustainable development: A systematic review and future research agenda. *Journal of Cleaner Production, 396,* 136489. https://doi.org/10.1016/j.jclepro.2023.136489.
- Guba, E. G., & Lincoln, Y. S. (1994). Competing paradigms in qualitative research. In N. K. Denzin & Y. S. Lincoln (Eds.), *Handbook of qualitative research* (pp. 105–117). Sage Publications.
- Hinson, R., Lensink, R., & Mueller, A. (2019). Transforming agribusiness in developing countries: SDGs and the role of FinTech. *Current Opinion in Environmental Sustainability, 41,* 1–9. https://doi.org/10.1016/j.cosust.2019.09.001.
- Intergovernmental Panel on Climate Change (IPCC). (2023). *Climate change 2023: Synthesis report. A report of the Intergovernmental Panel on Climate Change*. Geneva: Intergovernmental Panel on Climate Change. https://www.ipcc.ch/report/ar6/syr/resources/how-to-cite-this-report/.
- Kennedy, P. (2008). *A guide to econometrics* (6th ed.). Wiley-Blackwell.

- Lall, S. (2004). Reinventing industrial strategy: The role of government policy in building industrial competitiveness. *UNU-WIDER Research Paper*, 28. https://doi.org/10.35188/UNU-WIDER/2004/771-8
- Lall, S. (2004). Reinventing industrial strategy: The role of government policy in building industrial competitiveness. *UNU-WIDER Research Paper*, 28. https://doi.org/10.35188/UNU-WIDER/2004/771-8
- Le, T.-H., Le, H.-C., & Taghizadeh-Hesary, F. (2020). Does financial inclusion impact CO2 emissions? Evidence from Asia. *Finance Research Letters, 34,* 101451. https://doi.org/10.1016/j.frl.2019.101451.
- Li, H., & Lu, J. (2023). Temperature change and industrial green innovation: Cost increasing or responsibility forcing? *Journal of Environmental Management, 325*, 116492. https://doi.org/10.1016/j.jenvman.2022.116492.
- Lipper, L., Thornton, P., & Campbell, B. (2023). Climate-smart agriculture and food security: A global perspective. *Agricultural Systems, 205,* 102922. https://doi.org/10.1016/j.agsy.2023.102922
- Lipper, L., Thornton, P., & Campbell, B. (2023). Climate-smart agriculture and food security: A global perspective. *Agricultural Systems, 205,* 102922. https://doi.org/10.1016/j.agsy.2023.102922
- Liu, H., Yao, P., Latif, S., Aslam, S., & Iqbal, N. (2022a). Impact of green financing, FinTech, and financial inclusion on energy efficiency. *Environmental Science and Pollution Research, 29*(13), 18955–18966. https://doi.org/10.1007/s11356-021-17105-1.
- Liu, Z., Vu, T. L., Phan, T. T. H., Ngo, T. Q., Anh, N. H. V., & Putra, A. R. S. (2022b). Financial inclusion and green economic performance for energy efficiency finance. *Economic Change and Restructuring, 55*(3), 2359–2389. https://doi.org/10.1007/s10644-021-09362-2.
- Marques, A. C., Fuinhas, J. A., & Pires Manso, J. R. (2016). A quantile approach to identify factors promoting renewable energy in European countries. *Environmental and Resource Economics, 63*(3), 533–551. https://doi.org/10.1007/s10640-015-9898-1.
- Mohammed, A., El-Tayeb, A., & Ibrahim, S. (2023). Desertification and water scarcity in Sudan: Implications for poverty and food security. *African Journal of Environmental Studies, 28*(1), 1–15. https://doi.org/10.1080/ajenvs.2023.120245.
- Morris, M., & Fessehaie, J. (2014). The industrialization challenge for Africa: Towards a commodities-based industrialization path. *Journal of Development Perspectives, 2*(1-2), 77–120. https://doi.org/10.5325/jdevpers.2.1-2.0077
- Morris, M., & Fessehaie, J. (2014). The industrialization challenge for Africa: Towards a commodities-based industrialization path. *Journal of Development Perspectives, 2*(1-2), 77–120. https://doi.org/10.5325/jdevpers.2.1-2.0077
- Muganyi, T., Yan, L., & Sun, H.-P. (2021). Green finance, FinTech, and environmental protection: Evidence from China. *Environmental Science and Ecotechnology, 7,* 100107. https://doi.org/10.1016/j.ese.2021.100107.
- Nassani, A. A., Yousaf, Z., Radulescu, M., Balsalobre-Lorente, D., Hussain, H., & Haffar, M. (2023). Green innovation through green and blue infrastructure development: Investigation of pollution reduction and green technology in emerging economy. *Energies, 16*(5), 1944. https://doi.org/10.3390/en16051944.
- Nkemgha, A., Edeh, O., & Duru, C. (2023). The effects of government intervention on industrial progress in developing economies. *Development Policy Review, 41*(1), e12623. https://doi.org/10.1111/dpr.12623

- Nkemgha, A., Edeh, O., & Duru, C. (2023). The effects of government intervention on industrial progress in developing economies. *Development Policy Review, 41*(1), e12623. https://doi.org/10.1111/dpr.12623
- Nwanko, O., & Nwanko, S. (2021). Financial inclusion and green technology adoption in Nigeria. *African Journal of Economic Policy, 28*(3), 123–140.
- Nwanko, O., & Nwanko, S. (2021). Financial inclusion and green technology adoption in Nigeria. *African Journal of Economic Policy, 28*(3), 123–140.
- OECD. (2023). Enhancing socio-economic resilience through green technology. *OECD Policy Reports.* https://www.oecd.org/publications
- OECD. (2023). Enhancing socio-economic resilience through green technology. *OECD Policy Reports.* https://www.oecd.org/publications
- Okoli, P. (2022). Rural SMEs and the potential of climate-resilient farming technologies. *International Journal of Sustainable Development, 25*(2), 233–246.
- Okoli, P. (2022). Rural SMEs and the potential of climate-resilient farming technologies. *International Journal of Sustainable Development, 25*(2), 233–246.
- Ozturk, I., & Ullah, S. (2022). Does digital financial inclusion matter for economic growth and environmental sustainability in OBRI economies? An empirical analysis. *Resources, Conservation and Recycling, 185*, 106489. https://doi.org/10.1016/j.resconrec.2022.106489
- Ozturk, I., Ullah, S., & Ahmad, M. (2022). Does digital financial inclusion matter for economic growth and environmental sustainability in OBRI economies? *Resources, Conservation and Recycling, 185,* 106489. https://doi.org/10.1016/j.resconrec.2022.106489
- Ozturk, I., Ullah, S., & Ahmad, M. (2022). Does digital financial inclusion matter for economic growth and environmental sustainability in OBRI economies? *Resources, Conservation and Recycling, 185,* 106489. https://doi.org/10.1016/j.resconrec.2022.106489
- Phillips, P. C. B., & Hansen, B. E. (1990). Statistical inference in instrumental variables regression with I(1) processes. *Review of Economic Studies, 57*(1), 99–125. https://doi.org/10.2307/2297545.
- Quartey, P., Abor, J., & Akoto, A. (2021). Barriers to SME growth in rural Africa: Financial and technological challenges. *Development Studies Quarterly, 18*(4), 56–75.
- Quartey, P., Abor, J., & Akoto, A. (2021). Barriers to SME growth in rural Africa: Financial and technological challenges. *Development Studies Quarterly, 18*(4), 56–75.
- Ren, X., Zhang, Y., & Li, W. (2023). Green innovation: Advancing environmentally friendly technologies and sustainable practices. *Journal of Environmental Innovation, 35*(1), 23–45. https://doi.org/10.1016/j.jei.2023.102745.
- Saunders, M., Lewis, P., & Thornhill, A. (2019). *Research methods for business students* (8th ed.). Pearson Education.
- Scoones, I. (1998). Sustainable rural livelihoods: A framework for analysis. *IDS Working Paper, 72*. Institute of Development Studies.
- Stern, D. I., & Enflo, K. (2013). Causality between energy and output in the long run. *Energy Economics, 39*, 135–146. https://doi.org/10.1016/j.eneco.2013.05.007.
- Takalo, S. K., Tooranloo, H. S., & Parizi, Z. S. (2021). Green innovation: A systematic literature review. *Journal of Cleaner Production, 279*, 122474. https://doi.org/10.1016/j.jclepro.2020.122474.
- UNEP. (2022). Agricultural production and food security in Sudan: Challenges and interventions. *United Nations Environment Programme.* https://www.unep.org/resources

- UNEP. (2022). Agricultural production and food security in Sudan: Challenges and interventions. *United Nations Environment Programme.* https://www.unep.org/resources
- United Nations Environment Programme (UNEP). (2022). *Addressing food insecurity in Africa: The role of sustainable farming practices.* UNEP Policy Brief. https://www.unep.org/resources.
- Walsh, M., Kieser, A., & Jackson, B. (2015). Analyzing performance improvements from Lean management. *Journal of Operations Management, 38*, 16–31. https://doi.org/10.1016/j.jom.2015.06.002.
- Wang, Q.-J., Wang, H.-J., & Chang, C.-P. (2022). Environmental performance, green finance, and green innovation: What's the long-run relationship among variables? *Energy Economics, 110*, 106004. https://doi.org/10.1016/j.eneco.2022.106004.
- World Bank. (2023). Climate change and its impact on agriculture in Nigeria. *World Bank Reports.* https://www.worldbank.org
- World Bank. (2023). Climate change and its impact on agriculture in Nigeria. *World Bank Reports.* https://www.worldbank.org
- World Economic Forum. (2023). Advancing green innovation for resilient rural economies. *World Economic Forum Policy Briefs.* https://www.weforum.org
- World Economic Forum. (2023). Advancing green innovation for resilient rural economies. *World Economic Forum Policy Briefs.* https://www.weforum.org
- Yao, L., Tan, S., & Xu, Z. (2023). Towards carbon neutrality: What has been done and what needs to be done for carbon emission reduction? *Environmental Science and Pollution Research, 30*(12), 20570–20589. https://doi.org/10.1007/s11356-023-25674-5.
- Yousaf, Z. (2021). Go for green: Green innovation through green dynamic capabilities: Accessing the mediating role of green practices and green value co-creation. *Environmental Science and Pollution Research, 28*(42), 54863–54875. https://doi.org/10.1007/s11356-021-14538-9.
- Zainab, F., & Shah, A. (2024). The role of green innovation in achieving sustainable development goals. *Environmental Science and Pollution Research, 31*(1), 1024–1045. https://doi.org/10.1007/s11356-023-14325-9.
- Zainab, F., & Shah, A. (2024). The role of green innovation in achieving sustainable development goals. *Environmental Science and Pollution Research, 31*(1), 1024–1045. https://doi.org/10.1007/s11356-023-14325-9
- Zhai, Y., Cai, Z., Lin, H., Yuan, M., Mao, Y., & Yu, M. (2022). Does better environmental, social, and governance induce better corporate green innovation: The mediating role of financing constraints. *Corporate Social Responsibility and Environmental Management, 29*(6), 1513–1526. https://doi.org/10.1002/csr.2345.