RESEARCH ARTICLE

Modeling the Climate Agriculture Welfare Nexus in Nigeria Using ARDL and the Gini Coefficient

Anarah[1], Samuel Emeka, komolafe Oluwaseun Joseph[2], Ahaneku Chinwe Evangel[3], Chioma. E. Agbanaje[4] and Godwin Chinwe Maureen[5]

[1,2,3,4 &5]Department of Agricultural Economics, Nnamdi Azikiwe University, Awka
*Corresponding author: se.anarah@unizik.edu.ng

ABSTRACT

This study, spanning the period from 1991 to 2022, undertakes a comprehensive analysis of the intricate linkages between climate change and economic welfare using income inequality as a proxy in Nigeria. Secondary data, obtained from the Central Bank of Nigeria, the National Bureau of Statistics, the National Planning Commission, the Nigeria Meteorological Centre, and the Food and Agriculture Organization (FAO), were used. The research employs a robust methodological framework, integrating sophisticated econometric and statistical tools such as the Autoregressive Distributed Lag (ARDL) model together with the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests. The Gini coefficient for income inequality at a national level was typically calculated using the Lorenz curve, which illustrates the cumulative proportion of income relative to the cumulative proportion of the population. These methodologies are meticulously applied to a longitudinal dataset comprising key climatic variables, temperature, rainfall, sunshine duration, relative humidity, and carbon dioxide emissions, as well as indicators of economic welfare (income inequality) at the national level. Climate change variables (rainfall, temperature, relative humidity, sunshine duration, and carbon dioxide emissions) and selected macroeconomic variables (foreign direct investment in agricultural sector, entire domestic private investment, area of land under cultivation for each selected food crop, government capital expenditure in agriculture, rate of inflation, and real exchange rate) have no significant effect on economic welfare (evaluated using the GINI coefficient for income inequality) in Nigeria.

Key words: Climate Change, Economic welfare, income inequality, Nigeria

INTRODUCTION

In recent decades, climate change (CC) has emerged as one of the most pressing global challenges, exerting profound impacts on agricultural productivity, environmental sustainability, economic stability, and food security, and economic welfare, particularly in developing countries. These regions, characterized by climate-sensitive economies and limited adaptive capacity, are especially vulnerable to the adverse effects of CC. This vulnerability is acutely evident in Nigeria, where the confluence of climatic variability, agricultural dependence, and rising income inequality necessitates an in-depth examination of the intricate dynamics between CC, agricultural productivity and economic welfare. Climate change refers to long-term variations in temperature, precipitation patterns, and the occurrence and severity of extreme weather events (IPCC, 2021; NASA, 2023). These changes are driven by increased greenhouse gas emissions, especially carbon dioxide (CO_2), that drive global warming and disrupt established climatic patterns (IPCC, 2021; NASA, 2023). Nigeria, like many other African countries, is highly vulnerable to CC because of its strong dependence on rain-fed agriculture and restricted adaptive capacity (Komolafe, Onyemekonwu, Ositanwosu, and Adejoh, 2023). The sector's vulnerability to CC necessitates a comprehensive understanding of how climate factors like CO_2 emissions, precipitation, temperature, relative humidity, and sunshine hours influence crop productivity and economic welfare in Nigeria. These changes can manifest in increased frequency of extreme

weather events, shifting climatic zones, and long-term trends in temperature and rainfall patterns. Globally, CC has led to significant shifts in climatic variables, including temperature, precipitation, and relative humidity, which in turn have profound implications for agricultural systems. The Fifth Assessment Report released by the Intergovernmental Panel on Climate Change (IPCC, 2014) highlights that these changes are expected to exacerbate disparities in economic welfare, particularly in low-income countries that are heavily dependent on agriculture (IPCC, 2021). As temperatures rise and precipitation patterns become more erratic, agricultural productivity is likely to decline, leading to reduced food availability and increased food prices, which can further widen income inequality (Asfaw Asfaw, Simane, Bantider, & Hassen, 2021). Knowledge of the relationship between climate change and welfare is key for economists, policymakers, and development practitioners, as it provides a platform for designing equitable and sustainable adaptation and mitigation strategies.

Nigeria is naturally blessed with rich soil and a diverse environment favourable for agricultural production, but over the years it has been unable to cater for the well-being of the populace. Adverse CC is among other factors a serious contributor to food insecurity, income inequality and other welfare indicators that are of low value in Nigeria, as shown by Beyene, (2022) work with the Gini coefficient that ranges between 0.46 to 0.60. indicating that income inequality in Nigeria is high, and that CC continues to pose environmental issues that are increasingly threatening the fragility of the ecosystems. The situation is becoming more serious due to the increasing income gap and low welfare of the populace. Consequently, concerted effort by relevant agencies and researchers to expound knowledge on this problem and tackle it head-on prevent the populace from imminent destruction.

Indicators for economic welfare, which are GDP per capita, household income, and consumption, are highly influenced by Stern (2007) argues that the economic costs of inaction on CC outweigh the mitigation costs since it has the capacity to reduce world GDP by 20% by the end of the century, but the expected cost of emissions stabilizing would be about 1% of global GDP. Nordhaus (2018), using integrated assessment models, gave a better estimate that the global economic impact of CC could range from 1% to 3% of GDP by 2100, provided there is moderate warming. However, critics of integrated assessment models argued that it underestimates welfare losses, inadequately captures non-market impacts and distributional consequences (Pindyck, 2013). Tol (2009) discovered that while temperate countries benefit from moderate warming (longer growing seasons), tropical and low-income countries suffer economic losses in terms of reduced agricultural productivity, water scarcity, and health hazards of global warming, consequently keeping them in vicious cycles of poverty, undermining long-term welfare. CC can act like a "threat multiplier," by increasing existing social inequalities and disproportionately affecting marginalized groups (IPCC, 2022) as Poor developing countries households, have lower resources to adapt to CC shocks with the consequences of significant welfare losses Hallegatte et al. (2016) asserted that by 2030 CC could push more than 100 million people into extreme poverty if there is inaction its impacts on agriculture, health, and disaster vulnerability. Income inequality influences the welfare outcomes of climate policies as well.

The health consequences of CC have direct and indirect implications for welfare. The World Health Organization (WHO, 2018) estimates that between 2030 and 2050, CC will result in about 250,000 additional deaths annually due to malnutrition, diarrhea, malaria, and heat stress. These will equally reduce life quality and impose economic costs by reducing labour productivity, increasing healthcare expenditures, and premature mortality. Agriculture is highly sensitive to CC, and its decline has direct consequences for food security and welfare, particularly in agrarian economies. To understand the sensitivity of staple food to future change in climate, (Lobell, Schlenker, & Costa-Roberts, 2011; Hounnou et al., 2019) found that CC has negatively affected yields of staple crops by reducing the mean crop yields, leading to higher food prices, lower household income for farmers, and increased food insecurity.

The effect of CC on economic welfare across Nigeria is utmost acutely felt through its exacerbation of income inequality. As agricultural productivity declines, the income gap between wealthy and poor households widens, with those reliant on subsistence farming being disproportionately affected (Diagi, Nwaerema, & Ajiere, 2020). The inability of these vulnerable populations to cope with changing climatic conditions further entrenches their economic disadvantages, leading to a cycle of poverty and inequality (Asfaw et al., 2021). This situation is further aggravated by the fact that many of these communities have limited access to the resources and technologies needed to reduce the impacts of climate change, such as improved seeds, irrigation systems, and weather forecasting services (Diagi, Nwaerema, & Ajiere, 2020). Economic Welfare refers to the economic well-being of individuals or communities, often measured by indicators such as income distribution, access to resources, and overall living standards (UNDP, 2021). Climate change can exacerbate income inequality by disproportionately affecting vulnerable populations who rely heavily on climate-sensitive livelihoods. Economic welfare can be assessed through various indicators, such as GDP per capita, which measures average economic output, the Gini coefficient, which evaluates income inequality, the Human Development Index (HDI) which integrates life expectancy, education, and income for a broad view of development, and quality of life which is assess through

poverty rates, employment levels, and access to services,

Therefore, the interplay between climate change, agricultural efficiency, food security, and economic welfare inside Nigeria presents a complex and multifaceted challenge. The adverse impacts of climate variability on agricultural systems threaten not only the availability and accessibility of food but also the economic well-being of millions of Nigerians, particularly those in vulnerable communities. As the country continues to grapple with these challenges, policymakers, researchers, and stakeholders must collaborate to establish and implement strategies that enhance the resilience of the agricultural sector and promote economic equity. This study aims to contribute to this critical discourse by providing a comprehensive analysis of the effects of climate change on agricultural productivity, food security, and economic welfare in Nigeria. Through this analysis, the study seeks to inform the development of targeted interventions that can mitigate the effects of climate change and promote sustainable development inside the country.

In this study, we prioritize the Gini coefficient to measure economic welfare, as it better captures the consequence of climate change on income distribution across Nigeria. The Gini coefficient offers several advantages over other measures of economic welfare, particularly in its ability to assess income inequality within a population. Unlike metrics like GDP per capita or the Human Development Index (HDI), which provide aggregate or average measures of economic performance and well-being, the Gini coefficient underscores the income distribution, revealing gaps between the rich and the poor. One key advantage is its ability to highlight inequality, which is a critical aspect of economic welfare that average measures can obscure. For example, two countries with the same GDP per capita might have vastly different levels of income inequality, leading to different social and economic outcomes. The Gini coefficient helps to uncover these differences, providing a more nuanced understanding of how wealth is distributed. Furthermore, the Gini coefficient is particularly useful in contexts where economic inequality has significant implications for social stability, poverty levels, and access to opportunities. It can inform policy decisions aimed at reducing inequality, fostering inclusive growth, and addressing the needs of marginalized groups. By focusing on income distribution rather than just overall economic output, the Gini coefficient provides a thorough and equitable evaluation of economic welfare.

MATERIALS AND METHODS

The Study Area
This research was carried out in Nigeria, the most densely populated African country south of the Sahara (Durodola, 2019). It was a geopolitical and sovereign entity consisting of 36 states and the Federal Capital Territory (FCT), Abuja, Nigeria lies along the West African coast, positioned between latitudes 4°S and 14°N and longitudes 3°W and 15°E. It shared boundaries with Niger Republic to the west, Cameroon Republic to the east, and the Gulf of Guinea to the south. Nigeria covered an area of 923,768 km² and occupied a land area of 98.3 million hectares, of which approximately 34.2 million hectares have been cultivated, while less than 1% of the arable land under irrigation (NBS, 2018).

Data source
The study utilized secondary data, predominantly of the time series type. Data on agricultural production and other variables were obtained from the publications of the Central Bank of Nigeria (CBN), the National Bureau of Statistics (NBS), the National Planning Commission (NPC), the Nigeria Meteorological Center (NIMeT), the Food and Agriculture Organization (FAO), along with other official supplementary sources. The research data collected for the period from 1991 to 2022, providing the researcher with sufficient information to draw more logical conclusions from the study. The quantitative data were presented in the form of the value of agricultural productivity for cassava, groundnut, maize, rice, yam and their aggregate in the given period, average annual rainfall measured in millimeters, average annual temperature in degrees Celsius, average annual relative humidity percentage, and average annual carbon dioxide emissions assessed in metric tons per year. Additionally, the study examined average annual sunshine hours, the area of land harvested for each selected food crop, and agricultural foreign direct investment. Total domestic private investment in agriculture and government capital expenditure on agriculture was also evaluated; both measured in Naira Billion. The real exchange rate, expressed as Naira per USD, and the inflation rate in percentage were included to provide a comprehensive analysis. The Nigerian food security index from the Food and Agriculture Organization was used as a proxy for Food security, while the Gini coefficient for income inequality, obtained from the World Bank database, served as a proxy for the economic welfare of Nigerians. Annual rainfall, annual temperature, relative humidity, sunshine duration and carbon dioxide (CO_2) data for climate change, sourced from the NIMeT database, were collected within the time frame under study. The data trend spanned from 1991 to 2022, encompassing over three decades. This duration met the minimum standard for longitudinal studies on climate change, as it provides a robust temporal framework to assess long-term climatic shifts and their impacts. Research consistently demonstrates that extended time series are crucial for detecting meaningful trends and variations in climate variables. The Intergovernmental Panel on Climate Change (IPCC) emphasizes that climate change impacts, such as shifts in temperature and precipitation patterns, become more discernible

over extended periods (IPCC, 2021). Similarly, studies by Ji et al., (2024) and Jasper et al. (2024) underscore that long-term data is essential for identifying trends in climate extremes and assessing their implications for agriculture and ecosystems. By covering over 30 years, this study aligns with best practices in climate research, ensuring that the analysis captures significant climatic changes and provides a comprehensive understanding of their effects over time.

Model Specification

The Gini coefficient at a national level is typically calculated using the Lorenz curve illustrates the relationship by plotting the cumulative share of income against the cumulative share of the population. The formula for calculating the Gini coefficient (G) is:

$$G = 1 - 2 \times \int_0^1 L(X)dX \qquad (24)$$

Where:

$L(X)$ is the Lorenz curve, which represents the cumulative percentage of total income earned by the bottom $X\%$ of the population.

X is the cumulative percentage of the population, ranging from 0 to 1.

This formula gives a value between 0 and 1, with lower values indicating more equal income distribution and higher values indicating greater inequality.

After calculating the GINI coefficient index for Nigeria between 1991 and 2022, the ARDL model approach was used to predict the effects of climate change on economic welfare in Nigeria. Some selected macroeconomic variables were also included in the model to boost the strength of the model. The long-term association between climate change and economic welfare can be specified as:

$\ln GINI_t = \lambda_0 + \lambda_1 \ln ARF_t + \lambda_2 \ln ATEMP_t + \lambda_3 \ln ARELH_t + \lambda_4 \ln ACDE_t + \lambda_5 \ln ASUN_t + \lambda_6 \ln AFDI_{t-1} + \lambda_7 \ln DIA_t + \lambda_8 \ln GCEA_t + \lambda_9 \ln INFR_t + \lambda_{10} \ln RER_t + \varepsilon_t \ldots\ldots(25)$

Where,

λ's = Long run coefficients

$\ln$ = Stands for Natural Logarithm,

$GINI_t$ = Food security index in period t

ARF_t = Average annual rainfall (millimetres) in period t

$ATEMP_t$= Average annual temperature (°C) in period t

$ARELH_t$ = Average annual relative humidity (%) in period t

$ACDE_t$ = Average annual carbon dioxide (CO_2) emissions (Metric tons per year) in period t

$ASUN_t$= Average annual sunshine (hours) in period t

$AFDI_t$ = Agricultural foreign direct investment in period t

DIA_t = Total domestic private investment in agriculture (₦'Billion) in period t,

$GCEA_t$ = Government capital expenditure on agriculture (₦' Billion) in period t,

$INFR_t$ = Inflation rate (%) in period t,

RER_t = Real exchange rate (₦/$) in period t,

ε_t = Stochastic disturbance term.

To examine the long-run relation among the series, we apply the ARDL bounds testing approach to cointegration proposed by Pesaran *et al.* (2001). The

ARDL representation of the determinants of $GINI_t$ constructed in equation (25) can be represented since a dynamic error correction model (ECM) is obtained from the ARDL model through a simple linear reparameterization. The version of the error correction model of the ARDL framework is given by:

$\Delta \ln GINI_t = \lambda_0 + \lambda_1 \ln GINI_{t-1} + \lambda_2 \ln ARF_t + \lambda_3 \ln ATEMP_t + \lambda_4 \ln ARELH_t + \lambda_5 \ln ACDE_t + \lambda_6 \ln ASUN_t + \lambda_7 \ln AFDI_{t-1} + \lambda_8 \ln DIA_t + \lambda_9 \ln GCEA_t + \lambda_{10} \ln RER_t + \lambda_{11} \ln INFR_t + \sum_{i-0}^{p-1} \lambda_{10} \Delta \ln GINI_{t-i} + \sum_{i-0}^{p-1} \lambda_{11} \Delta \ln ARF_{t-i} + \sum_{i-0}^{p-1} \lambda_{12} \Delta \ln ATEMP_{t-l} + \sum_{i-0}^{p-1} \lambda_{13} \Delta \ln ARELH_{t-i} + \sum_{i-0}^{p-1} \lambda_{14} \Delta \ln ACDE_{t-i} + \sum_{i-0}^{p-1} \lambda_{15} \Delta \ln ASUN_{t-i} + \sum_{i-0}^{p-1} \lambda_{16} \Delta \ln AFDI_{t-2} + \sum_{i-0}^{p-1} \lambda_{17} \Delta \ln DIA_{t-1} + \sum_{i-0}^{p-1} \lambda_{18} \Delta \ln GCEA_{t-1} + \sum_{i-0}^{p-1} \lambda_{19} \Delta \ln RER_{t-1} + \sum_{i-0}^{p-1} \lambda_{20} \Delta \ln INFR_{t-1} + \varepsilon_t.$ (26)

Δ = the first-difference operator,

λ's = Long run and short run coefficients.

$\ln$= Stands for Natural Logarithm,

t-1 = a period lag of the variables,

t-i = i^{th} number of lags required for each variable for a best fit. All other variables as previously defined. The null hypothesis of no cointegration is that Ho: $\lambda_1 = \lambda_2 = \lambda_3 = \lambda_4 = \lambda_5 = \lambda_6 = \lambda_7 = \lambda_8 = \lambda_9 = \lambda_{10} = \lambda_{11} = 0$ against the alternative hypothesis H1: $\lambda_1 \neq \lambda_2 \neq \lambda_3 \neq \lambda_4 \neq \lambda_5 \neq \lambda_6 \neq \lambda_7 \neq \lambda_8 \neq \lambda_9 \neq \lambda_{10} \neq \lambda_{11} \neq 0$. The rejection of the null based on the F-statistic suggests a cointegrating relationship. If a long-run relationship is present, the ARDL representation of equation (25) can be expressed as follows:

$\ln GINI_t = \lambda_0 + \sum_{i-0}^{p-1} \lambda_1 \Delta \ln GINI_{t-1} + \sum_{i-0}^{p-1} \lambda_2 \Delta \ln ARF_{t-1} + \sum_{i-0}^{p-1} \lambda_3 \Delta \ln ATEMP_{t-1} + \sum_{i-0}^{p-1} \lambda_4 \Delta \ln ARELH_{t-1} + \sum_{i-0}^{p-1} \lambda_5 \Delta \ln ACDE_{t-1} + \sum_{i-0}^{p-1} \lambda_6 \Delta \ln ASUN_{t-1} + \sum_{i-0}^{p-1} \lambda_7 \Delta \ln AFDI_{t-2} + \sum_{i-0}^{p-1} \lambda_8 \Delta \ln DIA_{t-1} + \sum_{i-0}^{p-1} \lambda_9 \Delta \ln GCEA_{t-1} + \sum_{i-0}^{p-1} \lambda_{10} \Delta \ln RER_{t-1} + \sum_{i-0}^{p-1} \lambda_{11} \Delta \ln INFR_{t-1} + \varepsilon_t$ (27)

The ARDL specification of short-term dynamics is analyzed using the ECM version of the ARDL model of the following form:

$\Delta \ln GINI_t = \lambda_0 + \sum_{i-0}^{p-1} \lambda_{10} \Delta \ln GINI_{t-1} + \sum_{i-0}^{p-1} \lambda_{11} \Delta \ln ARF_{t-1} + \sum_{i-0}^{p-1} \lambda_{12} \Delta \ln ATEMP_{t-1} + \sum_{i-0}^{p-1} \lambda_{13} \Delta \ln ARELH_{t-1} + \sum_{i-0}^{p-1} \lambda_{14} \Delta \ln ACDE_{t-1} + \sum_{i-0}^{p-1} \lambda_{15} \Delta \ln ASUN_{t-1} + \sum_{i-0}^{p-1} \lambda_{16} \Delta \ln AFDI_{t-2} + \sum_{i-0}^{p-1} \lambda_{17} \Delta \ln DIA_{t-1} + \sum_{i-0}^{p-1} \lambda_{18} \Delta \ln GCEA_{t-1} + \sum_{i-0}^{p-1} \lambda_{19} \Delta \ln RER_{t-1} + \sum_{i-0}^{p-1} \lambda_{20} \Delta \ln INFR_{t-1} + \eta ECM_{t-1} + \varepsilon_t$ (28)

ECM_{t-1} = Error Correction term lagged by one period,

η = coefficient of the error correction term,

The lagged residual term (ECM) in equation (28) reflects the disequilibrium in the long-term relationship. (u_t) in equation (25). The a priori expectation is stated mathematically as:

ARF_t, $ARELH_t$, $ASUN_t$, $AFDI_{t-1}$, DIA_t, $GCEA_t$ > 0; $ATEMP_t$, $ACDE_t$, RER_t, $INFR_t$ < 0.

RESULTS AND DISCUSSION

Effects of climate change on economic welfare and its implications as a result of government (adaptive)

investments in key areas of agriculture in Nigeria (1991-2022)

The impact of climate change on the economic welfare of Nigerians between 1991 and 2022 is analyzed below, taking into account both the long-run and short-run effects. This detailed evaluation explores the role of climate variables in influencing economic welfare over time, while incorporating selected macroeconomic variables as controls. In addition, a bounds test was conducted to determine the existence of a co-integration association, thereby ensuring that the analysis reflects the dynamic interaction among these variables over the study period. Economic welfare in this study is represented by the Gini coefficient of income distribution inequality in Nigeria within the study period.

Bounds Test

The bounds test results, which were carried out to investigate the existence of a co-integration relationship between climate change indicators and economic welfare (income inequality) in Nigeria over the study period, are reported in Table 1.

Table 1: Bounds test result of the presence of a co-integration association among climate change indicators, as well as macroeconomic indicators and economic welfare (income inequality) in Nigeria.

F-Bounds Test		Null Hypothesis: No level relationship		
Test Statistic	Value	Significance.	I(0)	I(1)
F-statistic	17.56972	10%	2.07	3.16
K	10	5%	2.33	3.46
		2.5%	2.56	3.76
		1%	2.84	4.10

Source(s): Author Construction from EViews 13 computation, 2024.

The bounds test outcomes show that the F-statistic of 17.56972 is well above the upper bounds critical values at all significance levels, including 1% (4.10) and 5% (3.46). Since the test statistic surpasses the critical values for these levels, the null hypothesis of no co-integration can be rejected at the 1% level. This provides strong evidence supporting the existence of a long-run co-integration relationship among the variables considered.

The results therefore confirm the existence of a stable long-term equilibrium relationship among the variables in the model. The co-integration relationship indicates that, although short-term variations may occur, the variables converge in the long run. This evidence strengthens the robustness of the model in capturing the dynamics of economic welfare (income inequality) in Nigeria. It also highlights that the interaction between climate change indicators, macroeconomic factors, and economic welfare (income inequality) is grounded in a statistically significant long-term equilibrium. The intricate impacts of these critical climate and macroeconomic indicators on economic welfare (income inequality) will be rigorously explored through long-run estimation tests presented in the subsequent analysis.

4.5.2 ARDL Long-run Coefficients

Table 2 reports the ARDL long-run coefficients, illustrating the impact of climate change on economic welfare (income inequality) in Nigeria between 1991 and 2022. The table shows an R^2 value of 0.996234 with an adjusted R^2 of 0.984396, implying that the independent variables jointly explain 99.6% of the variation in Nigeria's economic welfare (income inequality) during the study period. This strong explanatory power ensures that the model adequately captures the dynamics of economic welfare (income inequality) in Nigeria. Furthermore, the null hypothesis of no model significance is rejected, as reflected in the F-statistic of 84.15975, which is highly significant at the 1% level, with a p-value of 0.000002, well below the 0.05 threshold.

Moreover, the Durbin-Watson statistic of 2.329136 lies within the acceptable range, indicating no presence of serial autocorrelation and thereby supporting the strength of the model.

Model selection for estimating the impact of climate change and selected macroeconomic variables on economic welfare (income inequality) in Nigeria was based on the Akaike Information Criterion (AIC). The AIC identified the ARDL (2, 1, 1, 1, 0, 1, 1, 1, 1, 1, 1) specification as the optimal model for the analysis. This configuration effectively captures the dynamics among the independent variables and economic welfare (income inequality) throughout the study period. To enhance the model, dynamic regressors with a one-period lag were incorporated, allowing the specification to automatically retain only relevant variables. The selection procedure followed the guidelines of the Phillips-Perron unit root test, which was applied to validate the stationarity of the variables and ensure robust estimation. Additionally, the lagged value of economic welfare (income inequality) was included to capture past effects, which also exert notable influence on current levels of economic welfare (income inequality) in Nigeria.

The ARDL model indicates that among the climate variables, the present value of average annual rainfall (LN (ARF)) and its one-period lagged value (LN (ARF(-1))), the one-period lagged value of average annual temperature (LN (ATEMP (-1))), and its two-period lagged value (LN (ATEMP (-2))), the one-period lagged value of average annual carbon dioxide emission (LN (ACDE (-1))), and its two-period lagged value (LN (ACDE (-2))), the one-period lagged value of average annual relative humidity (LN(ARELH(-1))), and current value of average annual sunshine duration (LN (ASUN)) exhibit significant impacts on economic welfare (incomeinequality) in Nigeria. Among the controlling macroeconomic variables, the one-period and two-period lagged values of foreign direct investment in agriculture LN (AFDI (-1))), & LN (AFDI (-2))), the current and one-period lagged values of private domestic investment in agriculture (LN (DIA) & LN (DIA (-1))), the one-period and two-period lagged values of

Table 2: Results of the ARDL Long-Run Coefficients for the impact of Climate Change on economic welfare (income inequality) in Nigeria (1991–2022), with Control for selected Macroeconomic Variables

Dependent Variable: LN(GINI)				
Maximum dependent lags: 2 (Automatic selection)				
Model selection method: Adjusted R-squared				
Dynamic regressors (1 lag, automatic): LN(ARF) LN(ATEMP(-1))				
LN(ACDE(-1)) LN(ARELH(-1)) LN(ASUN) LN(AFDI(-1))				
LN(DIA)LN(GCEA(-1)) LN(INFR(-1)) LN(RER(-1))				
Fixed regressors: C @TREND				
Selected Model: ARDL(2, 1, 1, 1, 0, 1, 1, 1, 1, 1, 1)				
Variable	Coefficient	Std. Error	t-Statistic	Prob.*
LN(GINI(-1))	0.187289	0.236834	0.790805	0.4550
LN(GINI(-2))	-4.002221	0.903986	-4.427304***	0.0031
LN(ARF)	2.653002	0.592922	4.474450***	0.0029
LN(ARF(-1))	1.392172	0.249741	5.574455***	0.0008
LN(ATEMP(-1))	-37.85736	7.843487	-4.826598***	0.0019
LN(ATEMP(-2))	35.70317	7.851953	4.547043***	0.0026
LN(ACDE(-1))	-1.215759	0.499499	-2.433955**	0.0452
LN(ACDE(-2))	1.473333	0.518293	2.842665**	0.0249
LN(ARELH(-1))	1.041431	0.244923	4.252071***	0.0038
LN(ASUN)	-1.452497	0.299709	-4.846357***	0.0019
LN(ASUN(-1))	-0.133512	0.129480	-1.031143	0.3368
LN(AFDI(-1))	0.031058	0.011006	2.821947**	0.0257
LN(AFDI(-2))	-0.046276	0.011315	-4.089774***	0.0046
LN(DIA)	0.525154	0.112963	4.648910***	0.0023
LN(DIA(-1))	-0.390182	0.098767	-3.950527***	0.0055
LN(GCEA(-1))	0.549803	0.139536	3.940223***	0.0056
LN(GCEA(-2))	0.236348	0.066168	3.571964***	0.0091
LN(INFR(-1))	-0.007121	0.016504	-0.431493	0.6791
LN(INFR(-2))	0.281001	0.053842	5.219030***	0.0012
LN(RER(-1))	0.327711	0.078350	4.182664***	0.0041
LN(RER(-2))	-1.183235	0.277061	-4.270671***	0.0037
C	12.49417	5.327867	21.345061***	0.0000
@TREND	0.091543	0.022995	3.981073***	0.0053
R-squared	0.996234	Mean dependent var		3.672891
Adjusted R-squared	0.984396	S.D. dependent var		0.141051
S.E. of regression	0.017620	Akaike info criterion		-5.161575
Sum squared resid	0.002173	Schwarz criterion		-4.087324
Log likelihood	100.4236	Hannan-Quinn criter.		-4.817913
F-statistic	84.15975***	Durbin-Watson stat		2.329136
Prob(F-statistic)	0.000002			

Source(s): Author Construction from EViews 13 computation, 2024. (***), and (**) denote 1%, and 5% significance level.

government capital expenditure on agriculture (LN (GCEA (-1)) & LN(GCEA(-2))), the two-period lagged value of the inflation rate (LN(INFR(-2))), and the one-period and two-period lagged values of the real exchange rate (LN (RER (-1)) & LN (RER (-2))) demonstrate notable effects on economic welfare (income inequality) in Nigeria. The trend variable (@TREND) was also a significant determinant of economic welfare (income inequality) across Nigeria within the period under study.

The coefficient of LN (GINI (-2)) is significantly negative, indicating a strong, deflationary effect of the lagged value of economic welfare (income inequality) on its current level. This suggests that previous high levels of economic welfare (income inequality) may lead to subsequent reductions in inequality, potentially through mechanisms such as policy interventions aimed at redistributive justice, or through social and economic adjustments among the population. This finding aligns with the argument that extreme income disparities

often prompt corrective measures, either through governmental policy or through market-driven adjustments. This finding aligns with Vlaicu (2024) and Boskin et al. (2024), who demonstrate that prolonged periods of high inequality often led to a political backlash, resulting in policy shifts aimed at redistribution. Similarly, Enaberue et al. (2024), Cheong et al. (2022), (Ajisafe et al. (2024), and Kolawole & Arifalo, (2024) found that in developing economies, a lagged increase in economic welfare (income inequality) often correlates with subsequent declines, as economic policies and social programs are implemented to address the disparities.

The coefficients of LN (ARF) and its lagged value, LN (ARF (-1)) are both positive and strongly significant, indicating that an enhance in average annual rainfall significantly exacerbates economic welfare (income inequality) in Nigeria. This finding suggests that excessive rainfall, while possibly advantageous for agriculture, can also give rise to disparities in income

distribution. In agricultural economies like Nigeria, where a vast section of the population is dependent on rain-fed agriculture, uneven distribution of rainfall can create disparities in crop yields, leading to income inequalities. Excessive rainfall might also lead to flooding, disproportionately affecting poorer, rural communities who are less equipped to cope with such disasters, thereby widening the income gap. This result aligns with the findings of Bitoto et al. (2024), Gansonré (2024), and Yaya et al. (2024), who highlighted the role of climatic variability in exacerbating rural poverty and economic welfare (income inequality) in sub-Saharan Africa. Additionally, Nwaeboh & Egwuonwu (2024) and Hassan & Knight (2023) noted that in regions with significant reliance on agriculture, variability in rainfall patterns tends to increase economic welfare (income inequality), as the benefits of good seasons are unevenly distributed among different socio-economic groups.

The coefficients of LN (ATEMP (-1)) and LN (ATEMP (-2)) show a contrasting effect, with the first lag of temperature having a negative effect on economic welfare (income inequality), while the second lag exhibits a positive effect. The negative coefficient of LN (ATEMP (-1)) suggests that an increase in temperature from the previous year tends to reduce economic welfare (income inequality), which could be due to favorable agricultural conditions that enhance productivity across different income groups, leading to a more equitable distribution of income. However, the positive coefficient of LN (ATEMP (-2)) indicates that prolonged increases in temperature (over two years) may eventually exacerbate economic welfare (income inequality). This could be attributed to the long-term detrimental effects of climate change, where sustained high temperatures lead to crop failures, reduced agricultural output, and increased economic stress, disproportionately affecting poorer populations. This duality in the effects of temperature is supported by empirical evidence from Thakur et al. (2024), and Blanz (2023), who found that while short-term temperature increases might boost agricultural productivity, prolonged exposure to high temperatures leads to significant economic losses and increased inequality. Similarly, Amare & Balana, (2023), and Ucheje et al., (2024) argue that while moderate temperature increases can initially stimulate economic activity, persistent high temperatures have a regressive effect on income distribution, particularly in agrarian economies like Nigeria.

The results also reveal significant coefficients for both the first and second lags of average carbon dioxide emissions (LN (ACDE (-1)) and LN (ACDE (-2))). The negative sign of LN (ACDE (-1)) proposes that an increase in carbon dioxide emissions in the previous year causes reduction in economic welfare (income inequality). This could be an indication that industrial activities, often associated with higher carbon emissions, create employment opportunities and contribute to economic growth, which in turn may reduce income disparities.

However, the positive coefficient of LN (ACDE (-2)) indicates that over the longer term, increased emissions contribute to greater economic welfare (income inequality). This can be explained by the environmental degradation and health impacts associated with higher emissions, which tend to disproportionately affect poorer communities, thereby widening the income gap. The dual effect of carbon emissions on economic welfare (income inequality) is supported by studies such as those by Ekpa, (2023), Ogunbode et al., (2023), and Nchege & Okpalaoka, (2022) who found that while industrialization and economic growth initially reduce inequality, the environmental and social costs associated with pollution eventually lead to greater disparities. Similarly, Edema-Sillo & Emegha, (2022) and Adeleye et al. (2021) noted that in the long term, the adverse impacts of environmental degradation, particularly in terms of health and agricultural productivity, exacerbate economic welfare (income inequality) in Nigeria.

The positive and significant coefficient of LN (ARELH (-1)) suggests that higher relative humidity from the previous year increases economic welfare (income inequality). This finding implies that climatic conditions associated with high humidity may exacerbate disparities in economic outcomes, particularly in the agricultural sector, where humidity can influence crop diseases and pests, leading to uneven agricultural yields. In regions where the economy is heavily reliant on agriculture, such climatic conditions can disproportionately affect small-scale farmers and low-income households, exacerbating income disparities. This result aligns with the findings of Olayide et al. (2024), and Amare & Balana (2023), who emphasized the role of climatic factors such as humidity in exacerbating agricultural risks and economic welfare (income inequality) in tropical regions. Furthermore, Diaz et al. (2023) argue that climatic variables like humidity have a significant effect on agricultural productivity, with adverse effects more pronounced among poorer, less resilient populations, thereby increasing economic welfare (income inequality).

The coefficient of LN (ASUN) is notably negative, showing that an increase in sunshine duration reduces economic welfare (income inequality). This result suggests that favorable climatic conditions, such as adequate sunshine, are beneficial for agricultural productivity and can lead to a more equitable distribution of income, particularly in an agrarian economy like Nigeria. Adequate sunshine enhances crop growth and yields, leading to improved economic outcomes for farmers and, consequently, a reduction in income disparities. However, the lagged effect of sunshine duration, represented by LN (ASUN (-1)), is not significant, suggesting that the immediate benefits of increased sunshine are more pronounced than the longer-term effects. This finding is supported by studies such as those by Julius & Balogun (2022) and Abiola & Adefabi (2022), who found that sunshine duration

positively correlates with agricultural productivity and income distribution in rural areas. Similarly, Koundouri et al. (2022) and Yamauchi & Takeshima (2022) highlighted the importance of sunshine in enhancing crop yields and reducing rural poverty, thereby contributing to lower economic welfare (income inequality).

The coefficients of the first and second period lags of agricultural foreign direct investment (LN(AFDI(-1)) and LN(AFDI(-2))) exhibit contrasting effects on economic welfare (income inequality). The positive coefficient of LN(AFDI(-1)) suggests that an increase in foreign direct investment in agriculture from the previous year tends to increase economic welfare (income inequality). This could be since foreign investments often benefit larger, more established agricultural enterprises, leading to increased wealth concentration among already affluent groups. Conversely, the negative coefficient of LN (AFDI (-2)) indicates that over a longer period, such investments may eventually contribute to a reduction in economic welfare (income inequality), possibly as the benefits of these investments diffuse through the economy, creating more opportunities for smaller farmers and reducing disparities. This dual effect is consistent with the findings of Nkoro & Uko (2022), who argued that while FDI initially increases economic welfare (income inequality) by benefiting capital-intensive sectors, over time it can lead to broader economic growth and poverty reduction. Similarly, Yuldashev et al. (2023), and Djokoto et al. (2022) found that FDI in agriculture has a mixed effect on income distribution, with short-term increases in inequality followed by long-term reductions as the benefits of investment spread across the economy.

The coefficient of LN (DIA) is positive and significant, suggesting that an elevation in domestic investment in agriculture induces greater economic welfare (income inequality). This result indicates that domestic investment may be concentrated in certain regions or among specific groups, leading to uneven economic benefits and increased income disparities. The significant negative coefficient of the lagged value LN(DIA(-1)) implies that over time, domestic investment in agriculture may contribute to a reduction in economic welfare (income inequality) as the benefits of such investments become more widespread and accessible to a broader segment of the population. This finding aligns with the arguments presented by Lian et al. (2024), who noted that while initial investments in agriculture can increase disparities, long-term investments tend to promote inclusive growth and reduce inequality. Furthermore, Umar et al. (2023), and Aigheyisi & Osemwengie (2021) highlighted the importance of sustained domestic investment in agriculture for reducing rural poverty and economic welfare (income inequality) over the long term.

The coefficients of the first and second lags of government capital expenditure in agriculture (LN (GCEA (-1)) and LN (GCEA (-2))) are both positive and significant, indicating that increased government spending on agriculture leads to higher economic welfare (income inequality). This result suggests that government expenditures may not be evenly distributed or may primarily benefit larger, commercial agricultural enterprises, thereby widening the income gap. However, the positive and significant coefficients also imply that such expenditures have favorable impact on economic growth, even if the distributional impacts are uneven. This finding is consistent with the work of Lian et al. (2024), who found that while government spending in agriculture promotes economic growth, it can also lead to increased economic welfare (income inequality) if the benefits are not equitably distributed. Similarly, Khan & Chiu (2023) and Edafe et al. (2021) argue that government investments in agriculture often favor larger, more commercialized farms, which can exacerbate income disparities, particularly in rural areas.

The two-period lagged value of the inflation rate (LN(INFR(-2))) exerts a positive and notable impact on economic welfare (income inequality) in Nigeria, with a coefficient of 0.281001 and a t-statistic of 5.219030, significant at the 1% level (p = 0.0012). This result suggests that past inflationary pressures contribute to widening economic welfare (income inequality) over time. Inflation erodes the purchasing power of households, particularly those with fixed or low incomes, leading to greater disparity between the wealthy and the poor. Wealthier individuals or entities with assets that appreciate during inflationary periods (such as real estate or equities) tend to benefit, while poorer households, which spend a greater proportion of their income on essentials, suffer more from rising prices. The positive effect of lagged inflation on economic welfare (income inequality) is consistent with findings from studies in other developing countries where inflation exacerbates the income divide. For instance, a study by Ali & Asfaw (2023) and Olaniyi & Odhiambo (2024) found that in Sub-Saharan Africa, higher inflation rates were associated with increased economic welfare (income inequality) due to the regressive nature of inflationary shocks on poorer households. Similarly, (Uspri et al., 2023), highlighted that in low-income countries, the delayed effects of inflation often lead to increased economic welfare (income inequality) as the wealth gap widens. Additionally, Akpan & Aniefiok (2023) and Chude & Chude, (2023) found that a two-period lagged value of the inflation rate has a positive and significant effect on economic welfare (income inequality).

The one-period lagged value of the real exchange rate (LN(RER(-1))) exerts a positive and significant effect on economic welfare (income inequality), with a coefficient of 0.327711 and a t-statistic of 4.182664, significant at the 1% level (p = 0.0041). In contrast, the two-period lagged value (LN(RER(-2))) demonstrates a significant adverse effect on economic welfare (income inequality), with a coefficient of -1.183235 and a t-statistic

of -4.270671, also significant at the 1% level (p = 0.0037). The positive coefficient of LN(RER(-1)) implies that depreciation of the real exchange rate initially contributes to higher economic welfare (income inequality). This can occur because a weaker currency typically increases the cost of imports, which disproportionately affects poorer households that rely on imported goods and services. Additionally, businesses facing higher import costs might reduce wages or employment, further contributing to income disparity. However, the negative coefficient for LN(RER(-2)) suggests that over time, the economy may adjust to the weaker currency, possibly through increased export competitiveness, which could lead to higher employment and income for certain segments of the population, thereby reducing economic welfare (income inequality). This delayed positive effect of exchange rate depreciation could benefit export-oriented sectors, providing jobs and income growth in those areas. This dual effect aligns with empirical findings that the effect of exchange rate fluctuations on economic welfare (income inequality) is not immediate and can vary over time. Adu (2024) and Ku-Hsieh (2020) demonstrated that in developing economies, exchange rate depreciation initially exacerbates economic welfare (income inequality), but over the longer term, it can lead to more equitable income distribution if the export sector benefits and creates jobs. Moreover, Marclary & John (2023) found similar lagged effects where exchange rate adjustments eventually led to reduced inequality as the benefits of export growth were more widely distributed.

The trend variable in the ARDL long-run model for economic welfare (income inequality) (measured by the Gini coefficient) in Nigeria from 1991 to 2022 is significant with a positive coefficient of 0.091543 at the 1% significance level (p = 0.0053). This suggests that over the period analyzed, economic welfare (income inequality) in Nigeria has been on an upward trajectory, independent of the other macroeconomic and climatic variables included in the model. The positive trend coefficient indicates that, all else being equal, economic welfare (income inequality) has been increasing consistently over time. This finding implies that, despite various economic and social interventions, there has been a persistent widening of the income gap in Nigeria. Such an upward trend could be driven by several factors, including structural economic challenges, unequal access to education and healthcare, and disparities in economic opportunities between different regions and population groups. Over the last few decades, Nigeria has experienced rapid urbanization, technological change, and globalization, all of which tend to benefit the wealthier segments of society more than the poorer ones, thereby exacerbating economic welfare (income inequality). The increasing trend in economic welfare (income inequality) aligns with broader global trends observed in many developing countries, where economic growth often does not translate into

equitable distribution of wealth. For instance, empirical studies such as those by (Beyene, 2022), (Ashenafi & Dong, 2022), Chancel et al., (2023), and Kouladoum et al., (2024) have documented similar rising trends in economic welfare (income inequality) across African countries, attributing this to factors like unequal access to financial resources, poor governance, and inadequate social safety nets. In Nigeria, studies by Daasi, (2024), Chude and Chude (2023), Ogede et al., (2022), Ifeakachukwu, (2020) found rising trends in economic welfare (income inequality) in Nigeria over time. This positive trend underscores the need for more robust and inclusive policies aimed at reducing economic welfare (income inequality). Without addressing these underlying issues, the trend of rising inequality is likely to continue, leading to further social and economic challenges.

ARDL Error Correction Regression Estimated Short-run Coefficients
Table 3 reports the results of the ARDL error correction regression, presenting the estimated short-run coefficients of the impact of climate change on economic welfare (income inequality) during the study period, alongside selected macroeconomic control variables. The ECM short-run results reveal that not all climate change factors and macroeconomic determinants exert a significant effect on economic welfare (income inequality) in Nigeria in the short run. However, the analysis shows that certain variables exert profound and statistically significant influences, reflecting the complex interplay between climatic factors, economic policy, and social outcomes. The ARDL result reveals that in the short run, average annual rainfall (DLN (ARF)) at a 1% significance level exhibits a positive and notable impact on economic welfare (income inequality), indicating that higher rainfall levels, often associated with favorable agricultural conditions, may paradoxically exacerbate income disparities. This could be due to the unequal distribution of agricultural resources and the benefits of favorable weather conditions, where wealthier landowners and commercial farmers disproportionately reap the rewards, further widening the income gap. In the short run, the immediate effects of specific climatic variables, such as average annual temperature (DLN (ATEMP (-1))), and carbon dioxide emissions (DLN (ACDE (-1))), and Sunshine duration (DLN (ASUN)), exhibit a deflationary effect on economic welfare (income inequality) at a 1% significance level. The negative coefficient associated with DLN (ATEMP (-1)) implies that an increase in temperature exacerbates economic welfare (income inequality), potentially due to the heightened vulnerability of marginalized groups to adverse climatic conditions, which may disproportionately affect their economic opportunities. Similarly, the negative effect of DLN (ACDE(-1)) on economic welfare (income inequality) suggests that rising carbon dioxide emissions, often correlated with

Table 3: Results of the ARDL Error Correction Regression evaluated Short-run Coefficients for the impact of Climate Change on Economic Welfare (income inequality) in Nigeria (1991–2022), with Control for selected Macroeconomic Variables

ARDL Error Correction Regression
Dependent Variable: DLN(GINI)
Selected Model: ARDL(4, 0, 0, 0, 1, 0, 0, 1, 0, 1, 1)
Case 5: Unrestricted Constant and Unrestricted Trend

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	12.49417	0.574786	21.73710***	0.0000
@TREND	0.091543	0.004271	21.43467***	0.0000
DLN(GINI(-1))	4.002221	0.190483	21.01086***	0.0000
DLN(ARF)	2.653002	0.129567	20.47596***	0.0000
DLN(ATEMP(-1))	-37.85736	1.940149	-19.51260***	0.0000
DLN(ACDE(-1))	-1.215759	0.111504	-10.90325***	0.0000
DLN(ASUN)	-1.452497	0.076870	-18.89553***	0.0000
DLN(AFDI(-1))	0.031058	0.002908	10.68192***	0.0000
DLN(DIA)	0.525154	0.022884	22.94861***	0.0000
DLN(GCEA(-1))	0.549803	0.025652	21.43312***	0.0000
DLN(INFR(-1))	-0.007121	0.005763	-1.235739	0.2564
DLN(RER(-1))	0.327711	0.018762	17.46716***	0.0000
ECM(-1)	-0.713725	0.032944	-21.66477***	0.0000
R-squared	0.978735	Mean dependent var		-0.008473
Adjusted R-squared	0.963724	S.D. dependent var		0.059362
F-statistic	65.20304***	Durbin-Watson stat		2.329136
Prob(F-statistic)	0.000000			
Diagnostic test				

Test statistics	F-statistic	P-value	Interpretation
Heteroskedasticity test: Breusch-Pagan-Godfrey	2.107457	0.3822[ns]	No heteroskedasticity
Breusch-Godfrey Serial Correlation LM Test	2.204883	0.4386[ns]	No Serial Correlation
Ramsey RESET stability	2.102247	0.5192[ns]	Model correctly specified
Jacque-Bera test	0.974165	0.6144[ns]	Normal distribution

Source(s): Author Construction from EViews 13 computation, 2024. (***) denote 1% significance level. ([ns]) denote not significant.

industrial activity, may lead to environmental degradation and resource depletion, further deepening the income gap in Nigeria. Similarly, the negative effect of Sunshine duration (DLN (ASUN)) on economic welfare (income inequality) suggests that increased sunshine may reduce inequality, likely by enhancing agricultural productivity in areas that benefit from greater solar energy, thereby improving income distribution in those regions. These findings underscore the critical need for robust climate change policies that not only mitigate environmental harm but also address the socio-economic disparities exacerbated by such changes.

Furthermore, the analysis demonstrates that macroeconomic variables play a pivotal role in influencing economic welfare (income inequality). The coefficient of the one-period lagged value of the Gini coefficient (DLN(GINI(-1))) is positive and highly significant at the 1% level, indicating persistence in economic welfare (income inequality) over time. This implies that prior levels of income disparity tend to sustain themselves, potentially due to structural constraints such as unequal access to education, healthcare, and economic opportunities. The ARDL error correction regression also shows that the lagged value of foreign direct investment (DLN(AFDI(-1))) has a positive and significant effect on economic welfare (income inequality) at the 1% level, suggesting that although FDI supports economic growth, it may simultaneously contribute to widening income

inequality if not effectively managed. This outcome is consistent with existing literature, which highlights the risk of FDI intensifying inequality in developing economies, especially when directed toward capital-intensive sectors that provide limited employment opportunities. In addition, the significant positive impact of DLN(DIA) on economic welfare (income inequality) at the 1% level indicates that private domestic investment, while vital for economic expansion, may also be linked to rising inequality, may inadvertently exacerbate income disparities if not accompanied by inclusive policies that ensure broad-based benefits. Moreover, the results show that government capital spending on agriculture (DLN (GCEA (-1))) has a positive and significant effect on economic welfare (income inequality) at a 1% level. This counterintuitive finding could reflect inefficiencies in the allocation and utilization of government resources, where funds intended to support agricultural development may be diverted or misallocated, failing to reach the intended beneficiaries, particularly smallholder farmers. Conversely, the real exchange rate (DLN (RER (-1))) exerts a positive and significant effect on economic welfare (income inequality) at a 1% significance level, indicating that a depreciating exchange rate may lead to higher economic welfare (income inequality). This could be due to the increased cost of imported goods, which disproportionately affects lower-income households, coupled with the potential benefits accruing to exporters and those with foreign-denominated assets.

The trend variable (@TREND) records a coefficient of 0.091543, which is statistically significant at the 1% level (p-value = 0.0000). This outcome demonstrates a positive and significant association between the trend and economic welfare (income inequality) in Nigeria over the period from 1991 to 2022. The positive coefficient suggests that, over time, economic welfare (income inequality) has been increasing. This trend could be attributed to a range of socio-economic factors, including uneven economic growth, disparities in educational and employment opportunities, and policy inefficiencies. The persistent increase in economic welfare (income inequality), despite various policy interventions, reflects structural challenges within the economy that hinder equitable wealth distribution.

The adjustment speed toward equilibrium, as shown by the Error Correction Model (ECM), is negative and statistically significant at the 1% level, confirming the model's long-run stability. The ECM coefficient of -0.713725, being negative and bounded between zero and one, implies that the speed of adjustment to long-run equilibrium is about 71.4% per year. This relatively fast adjustment indicates that any short-term disequilibrium in economic welfare (income inequality) is corrected promptly, emphasizing the importance of tackling the immediate drivers of inequality to secure long-term stability. The results further reveal that the stochastic error processes generated and their temporal variations in the model can be corrected, with the system reverting to equilibrium at a speed of 71.4% in the long run. This highlights both the resilience of the system to shocks and the necessity of timely and effective interventions to prevent short-term changes from persisting.

Diagnostic tests for serial autocorrelation, heteroskedasticity, and model stability were carried out to evaluate the robustness of the model. The Breusch-Pagan-Godfrey heteroskedasticity test, the Breusch-Godfrey serial correlation LM test, and the Ramsey RESET stability test collectively confirm the absence of serial correlation, heteroskedasticity, and model instability. The Breusch-Pagan-Godfrey test for heteroskedasticity reports an F-statistic of 2.107457 with a p-value of 0.3822, indicating no evidence of heteroskedasticity in the model's residuals and confirming constant error variance. Similarly, the Breusch-Godfrey Serial Correlation LM Test yields an F-statistic of 2.204883 with a p-value of 0.4386, suggesting that the residuals are free from serial correlation, thereby ensuring independence of errors over time. The Ramsey RESET test for model specification produces an F-statistic of 2.102247 with a p-value of 0.5192, validating that the model is correctly specified with no omitted variables. Moreover, the Jarque-Bera test statistic of 0.974165 with a p-value of 0.6144 indicates that the residuals of the ARDL error correction model follow a normal distribution, reinforcing the model's reliability. Since all p-values exceed the 5% significance threshold, the relationship between dependent and independent

variables is appropriately defined. Additionally, the CUSUMSQ results confirm that all parameters exhibit long-run stability at the 5% significance level, as presented in Fig 1.
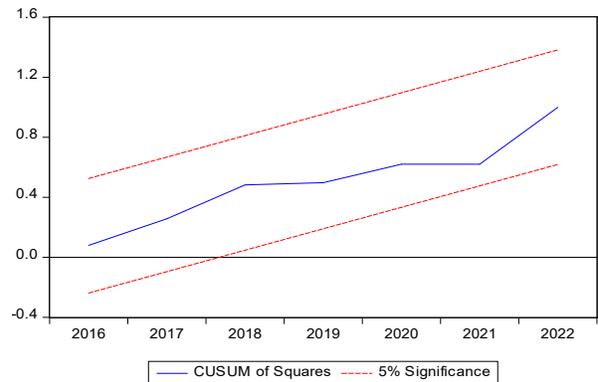

Fig. 1: CUSUM of Squares (CUSUMSQ) plot for the ARDL model analyzing economic welfare (income inequality) from 1991 to 2022.

The CUSUM of Squares (CUSUMSQ) plot for the ARDL model assessing economic welfare (income inequality) from 1991 to 2022 shows that the model's parameters remain stable, as the blue line (denoting the cumulative sum of squared residuals) stays within the 5% significance limits across the period. This stability indicates that the relationship between economic welfare (income inequality) and its determinants is consistent over time, thereby confirming the model's reliability for forecasting and policy evaluation.

Summary

The study examines the association between climate change and economic welfare inside Nigeria, using income inequality (measured by the Gini coefficient) as a proxy. It utilizes secondary data from 1991 to 2022 and employs econometric techniques like the Autoregressive Distributed Lag (ARDL) model to analyse the effect of climate variables—rainfall, temperature, relative humidity, sunshine duration, and carbon dioxide emissions—alongside macroeconomic factors like foreign direct investment, domestic private investment, government capital expenditure, inflation, and real exchange rates. Key findings indicate that climate change significantly affects economic welfare in Nigeria, particularly through its impact on agricultural productivity and income distribution. The results indicate long-run equilibrium relationship between climate factors and income inequality, suggesting that economic welfare fluctuations are closely linked to climatic variations. Moreover, macroeconomic policies play a crucial role in moderating these effects.

Conclusion and Recommendations
Implications of the Effect of Climate Change on economic welfare (income inequality) as a result of Government (Adaptive) Investments in Key Areas of Agriculture

The ARDL long-run coefficients examining the impact of climate change on economic welfare (income inequality) in Nigeria present a multifaceted and complex outcome. Climatic indicators such as average annual rainfall, temperature, carbon dioxide emissions, relative humidity, and sunshine duration exert significant influences on economic welfare (income inequality), often displaying contrasting effects in the short run and long run. In addition, macroeconomic factors including foreign direct investment, domestic investment, and government expenditure in agriculture are crucial in shaping income distribution, with both positive and negative impacts observed. The implications of climate change for economic welfare (income inequality), particularly regarding government (adaptive) investments in critical areas of agriculture, can be interpreted across several dimensions:

1. Targeted Agricultural Investments and Income Redistribution

Government investments aimed at adapting agricultural practices to climate change, such as upgrading irrigation infrastructure, promoting climate-resilient crop varieties, and improving soil management can help reduce the adverse effects of climate change on agricultural productivity. These investments can lead to increased productivity and income for smallholder farmers, potentially reducing economic welfare (income inequality). By targeting vulnerable regions and populations most affected by climate change, such investments can help redistribute wealth more equitably across different socio-economic groups. However, if these investments disproportionately benefit larger, commercial farms or more developed regions, they could exacerbate economic welfare (income inequality). Wealthier farmers may have better access to government resources, technical knowledge, and financial services, allowing them to capitalize on these investments more effectively than smaller, resource-poor farmers.

2. Effect on Marginalized Communities

The significant effect of climate variables like rainfall, temperature, and carbon dioxide emissions on economic welfare (income inequality) indicates that marginalized communities, which are more dependent on climate-sensitive agricultural activities, may face greater challenges in adapting to climate change. Government adaptive investments in agriculture, such as providing access to affordable credit, crop insurance, and climate-smart technologies, are essential for enhancing the resilience of these communities. If these adaptive measures are implemented equitably, they can help reduce the vulnerability of marginalized communities to climate shocks, thereby narrowing the income gap. Conversely, if marginalized communities are overlooked in these investments, economic welfare (income inequality) could worsen as they become more vulnerable to climate impacts.

3. Long-Term vs. Short-Term Effects

The ARDL model's findings, where both current and lagged climate variables significantly effect economic welfare (income inequality), suggest that government investments should consider both short-term and long-term adaptation strategies. Short-term investments might focus on immediate relief and support for affected farmers, such as subsidies or direct financial aid. Long-term investments, on the other hand, should aim at building sustainable agricultural practices that are resilient to future climate variability, such as investments in research and development of drought-resistant crops or sustainable water management systems. The differential impacts of short-term and long-term climate factors on economic welfare (income inequality) imply that a balanced approach is needed to ensure that adaptive investments not only provide immediate benefits but also address the root causes of income disparities exacerbated by climate change.

4. Regional Disparities and Policy Focus

The variability in climate impacts across different regions in Nigeria means that government investments need to be region-specific. Areas that are more prone to extreme weather conditions or have historically been marginalized may require more intensive and focused investment to prevent widening economic welfare (income inequality. Regional adaptation plans should be tailored to the specific climate risks and socio-economic conditions of each region to confirm that the benefits of government investments are divided equitably. Failure to address regional disparities in climate effects through targeted investments could lead to uneven development, where some regions benefit more than others, potentially increasing overall economic welfare (income inequality) within the country.

5. Sustainability and Inclusive Growth

Government investments in sustainable agricultural practices that align with climate adaptation can promote inclusive growth, where economic development benefits a broader segment of the population. For instance, investments in agroforestry, conservation agriculture, and sustainable land management can improve agricultural productivity while also preserving the environment, leading to long-term economic stability for rural populations. Inclusive growth requires that adaptive investments be designed in a way that includes the participation of smallholder farmers, women, and other vulnerable groups. By ensuring that these groups have a voice in decision-making and access to the benefits of climate adaptation programs, economic welfare (income inequality) can be reduced, and the overall resilience of the agricultural sector can be enhanced.

6. Technology and Innovation

Government investments in agricultural technology and innovation are vital for adapting to climate change.

These include investments in precision agriculture, digital tools for climate monitoring, and the development of climate-resilient crop genotypes. Such innovations can help farmers better manage climate risks and improve their productivity, thereby reducing income disparities. However, there is a risk that technological advancements could widen the income gap if access to these innovations is limited to wealthier or more educated farmers. Ensuring that adaptive technologies are affordable, accessible, and appropriately tailored to the needs of smallholders and subsistence farmers is essential for reducing economic welfare (income inequality).

Therefore, government (adaptive) investments in agriculture have the potential to mitigate the negative impacts of climate change on economic welfare (income inequality) in Nigeria. However, the effectiveness of these investments in reducing inequality depends on their design, implementation, and targeting. Ensuring that adaptive investments are inclusive, equitable, and region-specific is critical to addressing the complex relationship between climate change and economic welfare (income inequality). If done correctly, these investments can promote more sustainable and inclusive agricultural growth, ultimately leading to a reduction in income disparities and greater resilience to climate change across all segments of society.

These findings underscore the importance of adopting a comprehensive and multi-dimensional technique to addressing economic welfare (income inequality) in Nigeria, one that considers both climatic and economic factors in policy formulation. The study also underscores the need for further research to explore the mechanisms through which these variables interact and influence economic welfare (income inequality), particularly in the context of climate change and economic development.

REFERENCES

Asfaw, A., Simane, B., Bantider, A., & Hassen, A. (2021). Climate change adaptation strategies and their impact on agricultural productivity: Evidence from rainfed-dependent smallholder farmers in Nigeria. Environmental Development and Sustainability, 23(6), 2157–2180.

Ajisafe, R. A., Okunade, S. O., & Fatai, M. O. (2024). Modelling structural breaks in social cash transfers effects on poverty and inequality reduction in Africa: A case of Nigeria. Research Square. https://doi.org/10.21203/rs.3.rs-3384456/v1

Beyene, A. B. (2022). economic welfare (income inequality) and Economic Complexity in Africa: Interaction Effect of Governance Quality. *Research Square (Research Square)*. https://doi.org/10.21203/rs.3.rs-1666376/v1

Bitoto, F. E., Mbognou, C. N., & Amougou, J. (2024). Climate change and economic welfare (income inequality) in Sub-Saharan Africa: effects and transmission channels. International Journal of Development Issues, 24(1), 66-91. https://doi.org/10.1108/ijdi-01-2024-0020

Boskin, M., Elnahal, K., & Zhang, A. (2024). The Effect of Inequality on Redistribution: An Econometric Analysis.

SSRN Electronic Journal, 32, 492 https://doi.org/10.2139/ssrn.4843051

Chancel, L., Cogneau, D., Gethin, A., Myczkowski, A., & Robilliard, A.-S. (2023). economic welfare (income inequality) in Africa, 1990–2019: Measurement, patterns, determinants. *World Development*, 163, 106162. https://doi.org/10.1016/j.worlddev.2022.106162

Cheong, T. S., Wan, G., & Chui, D. K. H. (2022). Unveiling the Relationship between Economic Growth and Equality for Developing Countries. *China & World Economy*, 30(5), 1–28. https://doi.org/10.1111/cwe.12435

Chude, N. P., & Chude, D. I. (2023). Effect of economic welfare (income inequality) on the Economic Growth of Nigeria. *International Journal of Scientific and Management Research*, 06(01), 22–35. https://doi.org/10.37502/ijsmr.2023.6102

Daasi, G. (2024). Financial Development and economic welfare (income inequality) in Nigeria: An Empirical Investigation. *AKSU Journal of Social Sciences*, 4(1), 26–47. https://doi.org/10.61090/aksujoss.2024.003

Diagi, B. E., Nwaerema, P., & Ajiere, S. (2020). Trend Analysis of Maximum and Minimum Temperature over Ebonyi State, Nigeria. Social Science, Humanities and Sustainability Research, 1(1), 36-47

Durodola, O.S. (2019) the Impact of Climate Change Induced Extreme Events on Agriculture and Food Security: A Review on Nigeria. Agricultural Sciences, 10, 487-498.

Edafe, O. O., Osabuohien, E., & Osabohien, R. (2021). Large-scale Agricultural Investments and Female Employment in Nigerian Communities. *IOP Conference Series: Earth and Environmental Science*, 655(1), 012082. https://doi.org/10.1088/1755-1315/655/1/012082

Enaberue, E., Musa, I., & Magaji, S. (2024). Effect of economic welfare (income inequality) on Poverty Level in Nigeria: Evidence from ARDL Model. *Asian Journal of Economics Business and Accounting*, 24(5), 86–98. https://doi.org/10.9734/ajeba/2024/v24i51295

Gansonré, S. (2024). Rainfall variability and welfare of agricultural households: Evidence from rural Niger. *Agricultural Economics*, 55(4), 572–587. https://doi.org/10.1111/agec.12833

Hallegatte, S., Bangalore, M., Bonzanigo, L., et al. (2016). Shock Waves: Managing the Impacts of Climate Change on Poverty. World Bank.

Hounnou, F. E., Dedehouanou, H., Zannou, A., Bakary, A., & Mahoussi, E.F., (2019). Influence of Climate Change on Food Crop Yield in Benin Republic. Journal of Agricultural Science; 11(5). 281.

Ifeakachukwu, N. P. (2020). Globalisation, Economic Growth and economic welfare (income inequality) in Nigeria. *Indian Journal of Human Development*, 14(2), 202–212. https://doi.org/10.1177/0973703020948484

Intergovernmental Panel on Climate Change, IPCC IPCC, 2014: *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151.

Intergovernmental Panel on Climate Change, IPCC. (2021). Climate change: Impacts, adaptation and vulnerability, contribution of working group ii to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press.

Intergovernmental Panel on Climate Change, IPCC. (2022). Climate Change 2022: Impacts, Adaptation and

Vulnerability. Intergovernmental Panel on Climate Change.

Julius, K. A., & Balogun, R. A. (2022). Characteristics and Distribution of Some Radiation Parameters over Nigeria. *European Journal of Environment and Earth Sciences*, *3*(4), 32–40. https://doi.org/10.24018/ejgeo.2022.3.4.255

Khan, Z., & Chiu, Y.-B. (2023). *The Effect of governance on the agricultural value-added inequality nexus in Pakistan.* https://doi.org/10.21203/rs.3.rs-3166379/v1

Kolawole, C. O., & Arifalo, S. F. (2024). Poverty And Inequality In Nigeria: A Household-Level Four-Wave Comparative Study. *International Journal of Agriculture, Environment and Bioresearch*, *09*(03), 134–151. https://doi.org/10.35410/ijaeb.2024.5908

Komolafe, O. J, Onyemekonwu, R. C., Ositanwosu, C. O., and Adejoh, S. O. (2024). Smallholder Maize Farmers' Perception of Weather Variability and its Influence on Sustainable Adaptation Strategies in Anambra State. *International Journal of Agriculture, Food and Biodiversity 2 (2), 47-54*

Kouladoum, J., Nadingar, S. M., Ngameni, J. P., & Adrien, M. (2024). Inequality in Africa: Does injustice matter? *Review of Development Economics*, *20*, 30-45. https://doi.org/10.1111/rode.13128

Lobell, D. B., Schlenker, W., & Costa-Roberts, J. (2011). Climate trends and global crop production since 1980. Science, 333(6042), 616-620.

National Aeronautics and Space Administration (NASA). (2023). Climate Change: How Do We Know? https://climate.nasa.gov

Nkoro, E., & Uko, A. K. (2022). Foreign Direct Investment and Inclusive Growth: The Role of the Financial Sector Development. *International Journal of Economic Sciences*, *11*(2), 144–162. https://doi.org/10.52950/es.2022.11.2.008

Nordhaus, W. D. (2018). Projections and uncertainties about climate change in an era of minimal climate policies. American Economic Journal: Economic Policy, 10(3), 333-360.

Nwaeboh, A. V., & Egwuonwu , A. H. (2024). *Perceived Effects of Climate Variability on Crop Production in Imo State, Nigeria.* *3*(1), 52–60. https://doi.org/10.52589/rjaed-uzgu3rtq

Ogunbode, T. O., Jazat, J. P., & Akande, J. A. (2023). Economic factors affecting environmental pollution in two Nigerian cities: A comparative study. *Science Progress*, *106*(1), 003685042311534. https://doi.org/10.1177/00368504231153489

Olaniyi, C. O., & Odhiambo, N. M. (2024). Inflation-poverty causal nexus in sub-Saharan African countries: an asymmetric panel causality approach. *International Trade, Politics and Development/International Trade, Politics and Development*, *8*(1), 34–64. https://doi.org/10.1108/itpd-08-2023-0024

Olayide, O. E., Alabi, T. R., Oyedepo, J., & Okechukwu, R. (2024). Assessing rainfall and extreme weather variability for climate-resilient agricultural production systems in Nigeria. *Research Square (Research Square)*. https://doi.org/10.21203/rs.3.rs-3808332/v1

Pindyck, R. S. (2013). Climate change policy: What do the models tell us? Journal of Economic Literature, 51(3), 860-872.

Stern, N. (2007). The Economics of Climate Change: The Stern Review. Cambridge University   Press.

Thakur, Y., Sharma, A., & Sharma, V. K. (2024). A Review on the Relationship of Climate Variability and Extremes with Crop Production. *International Journal of Environment and Climate Change*, *14*(4), 513–529. https://doi.org/10.9734/ijecc/2024/v14i44136

Tol, R. S. J. (2009). The economic effects of climate change. Journal of Economic   Perspectives, 23(2), 29-51.

Umar, A.T. (2023). Recent Trends and Variability in the Length of the Growing Season in Northern Nigeria, Journal of Meteorology & Climate Science, 8(1): 40-52

UNDP (United Nations Development Programme), (2021) Adaptation to Climate Change: The New Challenge for Development in the Developing World. New York, USA

Uspri, B., Karimi, S., Indrawari, I., & Ridwan, E. (2023). The effect of inflation on economic welfare (income inequality): Evidence from a non-linear dynamic panel data analysis in Indonesia. *Decision Science Letters*, *12*(3), 639–648. https://doi.org/10.5267/j.dsl.2023.4.001

Vlaicu, R. (2024). *Inequality Persistence and Policymaking Constraints: Explaining Regional Data Patterns*

WHO. (2018). Climate change and health. World Health Organization.

Yaya, Y., Asare-Nuamah, P., Njong, A. M., Kondowe, J., & Rumbidzai, M. R. (2024). Does Climate Variability Matter in Achieving Food Security in Sub-Saharan Africa? *Environmental Challenges*, *1016*, 100870–100870. https://doi.org/10.1016/j.envc.2024.100870

Yuldashev, M., Khalikov, U., Nasriddinov, F., Ismailova, N., Kuldasheva, Z., & Ahmad, M. (2022). Effect of foreign direct investment on economic welfare (income inequality): Evidence from selected Asian economies. *PLOS ONE*, *18*(2), e0281870. https://doi.org/10.1371/journal.pone.0281870