The Nigerian Journal of Energy & Environmental Economics
Department of Economics,
Nnamdi Azikiwe University, Awka,
Anambra State, Nigeria.

Web:www.aeeeng.org *ISSN 2006-8395*

DYNAMICS OF CLIMATE CHANGE AND HUMAN DEVELOPMENT IN SUB-SAHARAN AFRICA

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Abstract

Africa is disproportionately affected by climate change despite contributing minimally to global greenhouse gas emissions. While existing studies largely focus on carbon emissions, other greenhouse gases, particularly methane, remain underexplored. This study investigates the nexus between climate change and human development in 30 Sub-Saharan African (SSA) countries using panel data from 2010 to 2022 obtained from the World Bank, Statista, and Country Economy. Human development was proxied by the Human Development Index (HDI), while climate change was captured using Average Annual Temperature (TEM), Carbon Emissions (CO_2), Methane Emissions (MET), Forest Depletion (FOR), and Average Precipitation (PRE). Institutional Quality (INQ) and Population Growth Rate (PGR) were included as control variables. Given cross-sectional dependence, the CIPS Second-Generation Unit Root test was applied. The study employed the Two-Step System Generalized Method of Moments (GMM), with robustness checks using Two-Step Difference GMM, Fixed Effects, and Random Effects models. Findings revealed that climate change significantly affects human development in SSA. CO_2 had mixed effects—positive under System GMM but negative under Difference GMM. TEM, MET, and FOR exerted negative and significant impacts on HDI, while PRE had a positive influence. The study recommends improved management of carbon and methane emissions and increased investment in climate resilience mechanisms to mitigate extreme weather impacts and safeguard human development in SSA.

Keywords: Climate Change, Human Development, CO_2 Emissions, Methane Emissions, Second Generation Unit Root, System GMM

JEL Classification Codes: Q54, Q56, R11

1.0 Introduction

Climate change is one of the most alarming developmental challenges that is confronting humanity in the twenty-first century. It is driven greatly by the concentration of carbon dioxide and other greenhouse gases depleting the ozone layer then increasing global warming, rising sea levels, and irregular weather conditions such as droughts and floods phenomena that significantly threaten food security, worsen health risks including the widespread of diseases and endangering the livelihoods of the people specifically in vulnerable areas of the population (National Oceanic & Atmospheric Administration, 2021).

Sub-Saharan Africa (SSA) is one of the most vulnerable regions to the negative effects of global greenhouse gas emissions. Even though its contribution to these emissions is minimal, the region suffers more from climate change than advanced countries with high emissions. For example, Figure 1.1 shows that the average carbon emissions in SSA from 2010 to 2022 are much lower, ranging from 0.04 to 7.75 metric tons. This is in contrast to countries in North America and Europe, such as the United States (15.5), Canada (15.5), Germany (8.88), Norway (7.56), and Australia (16.4). Additionally, Figure 1.2 indicates that average methane gas emissions (kt of CO_2 equivalent) from countries like the United States (701,467) and Australia (150,398) greatly exceed those from SSA countries during the same period (World Bank, 2023). From 2010 to 2022, Figure 1.1 also reveals that SSA countries are more affected by the consequences of global warming, despite their lower contributions. The average temperature in the African region is alarmingly higher, with some countries showing extreme averages—Nigeria (26.9°C), Sudan and Cameroon (31°C), Gabon (27°C), and Ghana (28°C). In comparison, advanced and industrialized countries, including the United States (11.87°C), Canada (9.9°C), Switzerland (7.4°C), Germany (8.7°C), and Norway (4.3°C) have lower average temperatures (World Bank Climate Change Knowledge Portal, 2023).

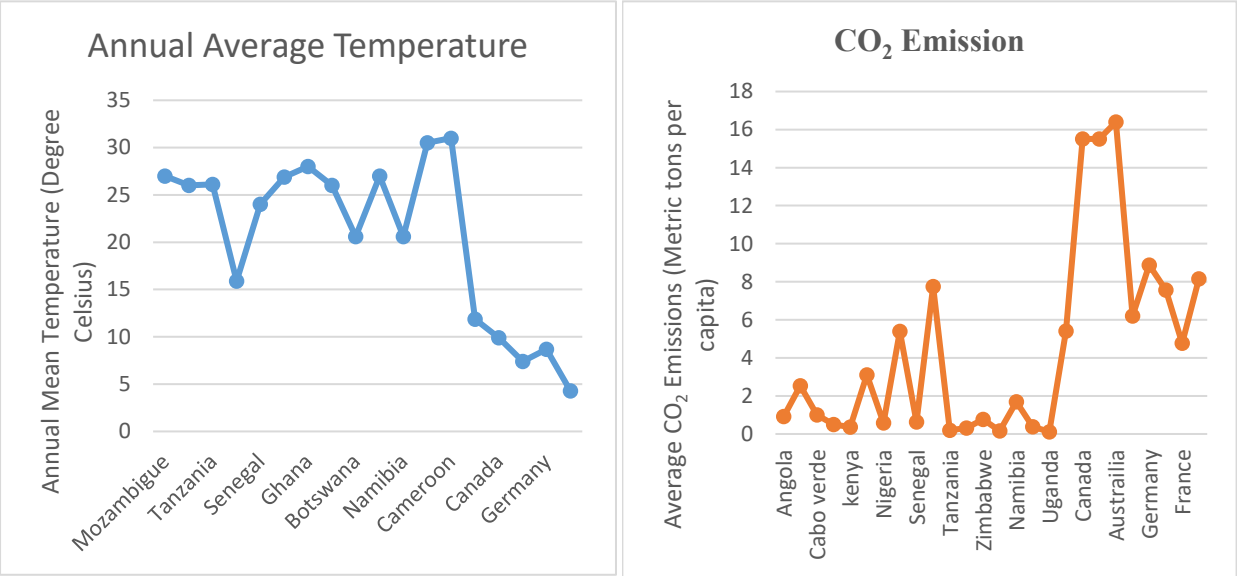


Figure 1.1: Average Annual Temperature (Degree Celsius) and $C0_2$ emissions of selected countries in Sub-Sahara Africa, North America, Europe, and Asia from 2010-2022.

Source: World Bank, 2023

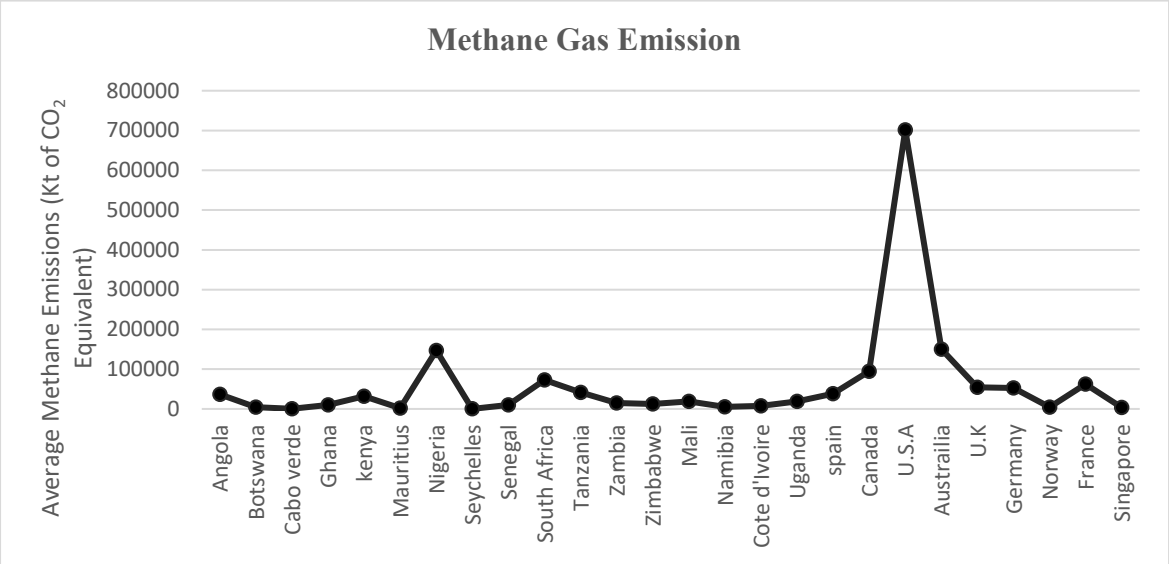


Figure 1.2: Average Methane Emissions (kt of CO_2 equivalent) of selected countries in SSA, North America, Europe, and Asia from 2010-2022.

Source: World Bank, 2023

The exposure of SSA countries to high temperatures, rise in sea level, and irregular rainfall often contributes to natural disasters like flooding, drought, and desertification. These events have a detrimental effect on the health of the population, availability of water both for domestic and agricultural use, and school absenteeism which ultimately slow the development process of the region (United Nations Climate Change, 2020). The United Nations Development Programme (UNDP, 2022) confirmed that poor climate change is responsible for low Human Development Index (HDI) score in the region, with the countries worrisomely ranked among the lowest of 191 countries that were studied in 2020 and 2021. It was noted by Fakomogbon (2022) that five of the ten most affected countries by climate change in 2019 were from SSA, and he also projected that by 2025, up to 250 million people in the region could face water scarcity and 55 million people stands to face hunger by 2050 due to climate-related issues.

Climate change has become a major barrier to educational progress in sub-Saharan Africa. Severe weather events reduce access to clean water and sanitation. They also increase the rates of diseases like malaria and diarrhoea, leading to more school absences, especially among girls (Zimbabwe Human Development Report, 2017). In Nigeria, flooding from July to October 2022 caused schools to close for up to 53 days. Catastrophic floods in 2024 disrupted the education of more than 2.2 million students (United Nations Children Emergency Fund [UNICEF], 2024). In Zimbabwe, Tropical Storm Ana in 2022 damaged 51 schools and displaced thousands of families, directly impacting access to learning (UNICEF, 2022). Similarly, in Malawi, Cyclone Freddy hit in March 2023, causing widespread school closures across ten southern districts and limiting educational opportunities (UNICEF, 2023). At a global level, estimates suggest that climate change interrupts the education of nearly 40 million children each year, with many of them living in sub-Saharan Africa (Wood, 2023). The Malala Fund (2021)

also projects that climate change could stop at least 12.5 million girls from finishing their education each year due to damage to infrastructure and pressures at home related to climate change.

The income of the individuals can also be severely affected due to climate change. The World Bank warns that climate change could push over 100 million people into extreme poverty by 2030. In SSA, with more than 41% of the population living below the $1.90 poverty line, SSA is already one of the poorest regions globally. In fact, it was estimated that by 2030, 87% of the world's poorest people will reside in SSA (Hallegatte et al., 2015). This is concerning given that about 80% of climate related damages are from Africa despite having less contribution to global greenhouse emissions (World Bank, 2023). This has ignited scholars to examine the true relationship between climate changes and human development in SSA countries. While a few studies (e.g., Elkouk et al., 2022; Igbokwe-Ibeto, 2019) have explored the impact of climate change on human development in SSA, the findings remain inconclusive. Malpede and Percoco (2015), for instance, found temperature to have negatively affected human development while average precipitation had a negligible effect. This inconsistency in the literature underlines the need for further empirical investigation into the climate change–human development nexus in SSA.

This study is a significant contribution to knowledge in three aspects. First, it examined the nexus between climate change and human development in SSA using HDI that captures income, education and health, which have often been neglected among extant studies on economic growth (Zhao & Liu, 2023; Khan & Rashid, 2022; Adejumo, 2021). Economic growth is just a necessary condition for development; it is not sufficient enough for development to take place. Secondly, this study captured the effect of methane gas emissions and forest depletions which have received little to no attention in academic literatures. Methane gas is one of the most potent greenhouse gases (Neumann, 2024). Similarly, extant studies have failed to examine the role of forest depletion on human development except for Ogbuabor and Egwuchukwu (2017) howbeit within the Nigerian context. Lastly, this study employed the two-step system Generalized Method of Moments (GMM) to address endogeneity issues inherent in a dynamic model. Majority of the extant studies employed commonly used ARDL method that does not account for endogeneity (e.g., Kurshid et al., 2022; Maino & Emrullahu, 2022; Alagidede et al., 2014).

The remainder of this study is organized as follows: Section two delves into the review of related literature; Section three encompasses the methodology and theoretical framework. Section four discusses the empirical results and the last section concludes the study with key policy recommendations.

2.0 Literature Review

While a growing body of literatures has examined the relationship between climate change and economic growth, relatively few studies have actually focused explicitly on human development, particularly within the context of SSA (Malpede & Percoco, 2015; Elkouk et al., 2022; Igbokwe-Ibeto, 2019). The few extant literatures found the effect of climate change to be detrimental to human development. Malpede and Percoco (2015) conducted a global study that includes 1,564 regions to explore the relationship between climate desertification and local human development using a fixed effects regression model. The impact of an increase in average precipitation was negligible on human development whereas high temperatures were

associated with lower levels of development due to reduction in educational attainment and lower life expectancy.

Elkouk et al. (2022) investigated the implications of climate change for human development in sub-Saharan Africa (SSA) by analysing soil moisture and drought frequency from ISIMIP multi-model simulations. Using a multi-model ensemble drought analysis combined with Human Development Index (HDI) data, they found that a shift toward high greenhouse gas emission scenarios is associated with reduced human development outcomes in the region. Similarly, Igbokwe-Ibeto (2019) analysed Nigerian data using descriptive statistical analysis and identified climate change as the main driver of food insecurity and reduced human development, underlining the urgent need for mitigation strategy to avoid further deteriorations.

The stream of literatures on economic growth yielded mixed findings. The ARDL technique was employed in most of the studies. Generally, increased annual rainfall or average precipitation was found to be impactful, while the impact of high temperatures was detrimental to growth. Alagidede et al., (2014) and Maino and Emrullahu (2022) both employed the panel ARDL model and they found high temperature to be a significant impediment to economic progress among selected countries in SSA. Similar, result was reported by Kurshid et al., (2022) in Pakistan, where they found average precipitation to be positive and significant on growth, while extreme temperature retards growth.

In Nigeria, Adejumo (2021) used the ARDL technique and also found the effect of annual rainfall to be positive and significant on economic growth. At the global level, Khan and Rashid (2022) analysed data for 179 countries between 1990 and 2020 and found poor climate change to have negatively and significantly affected their economic performance. Interestingly, they found sea-level pressure to be beneficial to economic growth. Within the African context, Abidoye and Odusola (2015) found high temperatures to be a major impediment to the economic growth of 31 African countries using the simple correlation, descriptive statistics, and sensitivity analysis. They also found Nigeria and South Africa as targeted countries in addressing the negative impact of climate change in the region. While most findings found a positive relationship between rainfall and growth, the effects of temperature remain debatable. In Asia, for example, Akram (2012) utilized a panel fixed effects model and found both temperature and average precipitation to be positive and significant on economic growth contradicting other dynamic studies (Abidoye & Odusola, 2015; Maino & Emrullahu, 2022; Alagidede et al., 2014) who found a negative connection between temperature and economic growth. The study by Taher (2019) is in agreement with the positive effect of temperature on economic growth in Lebanon but the author found forest area to have negative impact on growth.

The impact of carbon emissions, a key driver of climate change has generated mixed findings. Using the ARDL model, Adejumo (2021) found Nigeria's growth to have been positively and significantly impacted by carbon emissions. In contrast, Kurshid et al. (2022) reported a negative and significant relationship in Pakistan. Studies employing static models, such as Ogbuabor and Egwuchukwu (2017) utilized the Ordinary Least Squares (OLS) and they showed that both carbon emissions and forest depletion are detrimental to the growth of the Nigerian economy. Similarly, Taher (2019) found carbon emissions to be detrimental to the growth of the Lebanon's economy. Zhao and Liu (2023) found climate

change to have positively impacted the coastal regions in a study involving 44 African countries and six climatic zones using the panel vector autoregression and fixed effects. They however found the influence to be negligible in the inland areas.

Overall, the extant literatures have predominantly emphasized on the role of climate change on economic growth with limited attention given to human development. A general consensus exists on the positive relationship between average precipitation and economic growth, whereas the impact of temperature and carbon emissions remains inconclusive. Some studies reported a positive relationship, while others found a negative or insignificant relationship necessitating further investigation.

Additionally, studies have predominantly focused on variables such as carbon emissions, temperature, and precipitation (Malpede & Percoco, 2015; Maino & Emrullahu, 2022; Alagidede et al., 2014; Kurshid et al., 2022; Adejumo, 2021). Only a few studies, such as Ogbuabor and Egwuchukwu (2017), have included forest depletion as an explanatory variable. Furthermore, the focus has largely been on carbon emissions, while other variant of greenhouse gases like methane have been ignored. Most studies also employed the ARDL model, with limited exploration of a more sophisticated econometric techniques capable of addressing the issue of endogeneity inherent in a dynamic panel data analysis. To fill this methodological gap, the present study employed the Generalized Method of Moments (GMM) capable of mitigating endogeneity.

3.1 Data

In a bid to explore the relationship between climate change and human development in SSA, this study employed secondary data involving a panel of 30 SSA countries including Angola, Burundi, Gambia, Sierra Leone, Congo, Cameroon, Zambia, Eswatini, Cabo Verde, Ghana, Kenya, Mauritius, Nigeria, Seychelles, Rwanda, Senegal, Botswana, South Africa, Guinea, Mozambique, Zimbabwe, Mali, Burkina Faso, Namibia, Niger, Togo, Malawi, Benin, Cote d'Ivoire and Uganda spanning from 2010 to 2022. The 30 countries were selected based on available data as we were unable to get data for all the countries within the region. The data on the dependent variable proxied by Human Development Index (HDI) were sourced from Country economy and Statista while the explanatory variables - Average Annual Temperature (TEM), Carbon Emissions (CO_2), Methane Emission (MET), Forest Depletion (FOR), Average Precipitation (PRE) and control variables - Institutional Quality (INQ), and Population Growth Rate (PGR) were sourced from World Bank.

3.2 Theoretical Framework and Methodology

This study utilized the Environmental Kuznets Curve (EKC) as its theoretical framework. The EKC provides the lens through which we can explore the relationship between climate change and human development. It drew its roots from Simon Kuznets's theory on income inequality and economic growth in 1955. The theory states that the relationship between environmental degradation and economic development is an inverted U-shape as shown in Figure 3.1.

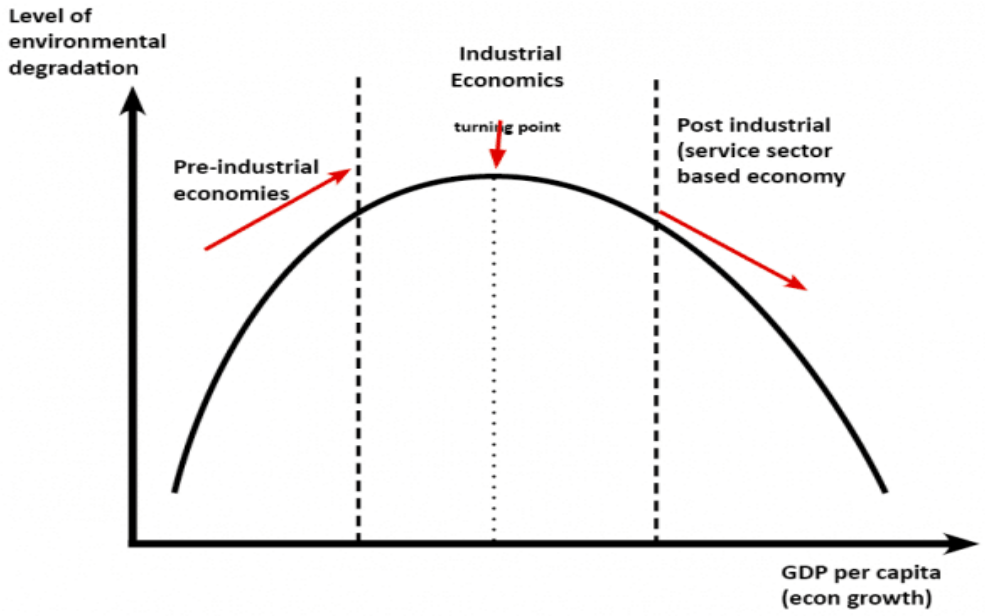


Figure 31: Environmental Kuznets Curve

At early stages of economic growth, there is an increase in environmental degradation; however, as income increases, subsequent levels of economic development leads to improvements in environmental quality due to better technology, stronger institutions and increased environmental awareness.

Although, the EKC traditionally examined the impact of economic development on environmental outcomes, recent adaptations of the theory reverse this relationship, exploring how environmental degradation affects the human development. This bi-directional relationship is relevant in the face of accelerating climate change and its documented consequences for health, education, and income which are all components of the Human Development Index (HDI).

Analysing it from the context of SSA, different countries are often found at different points along the EKC. Many nations are situated at the early stages of development, where industrial growth and resource exploitation lead to increased emissions, deforestation, and environmental degradation. This in turn exacerbates vulnerabilities in health, education systems, and livelihoods, thereby stalling progress in human development. The EKC framework suggests that, unless these countries reach a turning point which is facilitated by improved institutional quality, environmental regulation and technological adaptation, environmental degradation will continue to suppress development outcomes.

Adapting the EKC to a human development context allows for the following model:

$$HDI_{it} = \alpha_o + \beta_i E_{it} + \gamma Z_{it} + \mu_i \quad [3.1]$$

Where:
HDI_{it} denotes the human development index,
E_{it} is a vector of climate change indicators (average temperature, CO_2 emissions, methane emissions, forest depletion, and precipitation),
Z_{it} represents vector of control variables which may include institutional quality and population growth rate.

Apart from adapting to the Kuznets theory, the functional form of the model for this study was adapted from the work of Alagidede et al., (2016) where temperature and precipitation were used as proxy for climate change and Ogbuabor and Egwuchukwu (2017) that used forest depletion and carbon emission as proxy for climate change.

The functional form of the model is stated in equation 3.2:

HDI = f (TEM, CO2, MET, PRE, FOR, INQ, PGR) *[3.2]*

Equation 3.1 can be expanded to capture the model in a dynamic form as seen in Equation 3.3:

$$HDI_{it} = \alpha_0 + \beta_1 HDI_{it-1} + \beta_2 TEM_{it} + \beta_3 CO2_{it} + \beta_4 LogMET_{it} + \beta_5 LogPRE_{it} + \theta_1 FOR_{it} + \theta_2 INQ_{it} + \theta_3 PGR_{it} + \mu_t + \varepsilon_{it} \quad [3.3]$$

Where:

All variables are as previously explained (see section 3.1). In addition, μ_i is the individual country specific effect, and ε_{it} is the remainder disturbance term. α is the constant term, β_1 to β_5 are the coefficients of the explanatory variables and θ_1 to θ_3 are the coefficients of the controlled variables.

Table 3.1: Description of Variables and A priori

	Var.	Description	A priori	Source
Dependent Variable	HDI	A composite index that captures education, health and living standards	-	**Country Economy & Statista**
Independent Variables	TEMP	The degree of hotness and coldness	Negative	**World Bank (2023)**
	PRE	Any form of water, liquid or solid, that falls from the atmosphere and reaches the Earth's surface	Positive	**World Bank (2023)**
	CO_2	The release of carbon dioxide gas into the atmosphere	Negative	**World Bank (2023)**
	MET	The release of methane gas into the atmosphere	Negative	**World Bank (2023)**
	FOR	The reduction or loss of forests over time	Positive	**World Bank (2023)**
Control Variables	IQ	A measure of a country's political and economic institutions	Positive	**World Bank (2023)**
	PGR	Percentage change in the population of a country between two periods	Negative	**World Bank (2023)**

Source: Author's Compilation, 2025

Justification for Choice of Variables

The dependent variable, HDI was used to proxy human development because it captures education, health and living standard which are the components of a country development.

Climate change on the other hand was proxied by five variables - Average Temperature, CO_2 Emissions, Methane Emissions, Forest Depletion and Average Precipitation. Temperature is the main variable for climate changes as supported by previous studies (Maino & Emrullahu, 2022; Kurshid et al., 2022; Abidoye & Odusola, 2015). Carbon Emission (CO_2) is the most prevalent greenhouse gas and a key driver of climate change as supported by previous studies (Kurshid et al., 2022; Adejumo, 2021). Methane Emissions (MET) was used in the study as another variant of greenhouse gas. The novel employment of methane emission as an explanatory variable stems from the fact that methane gas is more potent in terms of its impact on greenhouse effect over shorter time frames than $C0_2$ (Neumann, 2024). The use of Forest Depletion (FOR) is silent in literatures as the closest study that captured forest depletion was Ogbuabor and Egwuchukwu (2017). Forest are crucial carbon sinks and their depletion accelerates climate change. In addition, Average Precipitation (PRE) was used to capture rainfall in line with some extant literatures (Kurshid et

al., 2022; Adejumo, 2021; Taher, 2019; Akram, 2012).

In addition to the explanatory variables, control variables were also captured in the model. These includes institutional quality and Population growth rate. Institutions shape how effectively countries can respond to climate change. Strong institutions help implement adaption policies, allocate resources efficiently and protect vulnerable populations making them essential for sustaining human development under climate change (Akram, 2012; Acemoglu & Robinson, 2012). Population dynamics on the other hand influence both the demand for natural resources and the pressure on infrastructure, health and education systems. High growth can worsen the effects of climate stress unless matched by development gains.

3.3. Estimation Technique

The aim of this paper is to examine the relationship between climate changes and human development among 30 selected countries in SSA. The empirical analysis follows a dynamic approach since most economic variables are dynamic in nature with their current values dependent on their past values. We were able to analyse the dynamic nature of the relationship by including the lag of the dependent variable as an explanatory variable in the model.

The study employed the Generalized Method of Moments propounded by Arellano and Bond (1991). The GMM was employed because of its ability to control for endogeneity of the lagged dependent variable and the unobserved panel heterogeneity. This is done by using instrumental variables. The GMM uses the lags of the endogenous variable (i.e. HDI) as instrument. In addition, the GMM was also employed because the number of cross-sections (30) is larger than the time period (15). It is also relevant to make use of the GMM to account for the problem of auto-correlation and heteroscedasticity.

For the sake of our estimation, the system GMM was selected over the Difference GMM. This is because the difference GMM only helps to remove the unobserved fixed effects. The problem of endogeneity still persists. With the two-step system GMM method, the problem of endogeneity and unobserved fixed effect would be eliminated by introducing more instruments to improve efficiency (Arellano & Bover, 1995; Blundell & Bond, 1998). In addition, System GMM makes use of more moment conditions and there are gains in precision and small sample bias is reduced when the System GMM is applied. Furthermore, a two-step system GMM estimator is more appropriate in the presence of autocorrelation and heteroscedasticity (Roodman, 2009).

4.0 Presentation and Discussion of Results

Table 4.1 Descriptive Statistics

Variables	Units	Obs.	Mean	Std. Dev.	Min.	Max.
Human Development Index	0 – 1	360	0.57	0.1121	0.38	0.81
Annual Average Temperature	Degree Celsius	360	28^0C	4.101	25^0C	48^0C
Annual Average Precipitation	mm per year	360	1113.8	668.62	220	2391
CO_2 Emissions	Metric Tons Per Capita	360	1.057	1.389	0.0342	6.224
Methane Emissions	Thousand Metric Tons of CO_2 Equivalent	360	13483	18529	83	94645
Forest Depletion	% of GNI	360	4.741	5.761	0.0006	24.797
Institutional Quality	-2.5 to +2.5	360	-0.454	0.650	-1.555	0.870
Population Growth Rate	Annual %	360	2.28	0.917	-2.63	4.68

Source: Author's Compilation, 2025

From Table 4.1, the mean human development index of the selected countries within the SSA during the study period is 0.57, a value significantly lower than what is obtainable in advanced countries in Europe and America. In terms of climate changes, the mean annual average temperature in SSA is 28° Celsius with a minimum of 25° Celsius and maximum of 48° Celsius indicating how bad the selected countries within the SSA have been affected by climate change. Also, the mean annual average precipitation of the SSA Countries is 1113.8. The average CO_2 emissions is 1.057 mm per year while that of methane emissions is 13483 metric tons of CO_2 equivalent. The mean forest depletion is 4.741% of GNI. In addition, average index of institutional quality is -0.454, a value that is significantly below the world average. The mean growth rate of the population in SSA is 2.28%.

Table 4.2 Correlation Matrix and Variance Inflation Factor

	HDI	TEM	CO2	MET	FOR	PRE	INQ	PGR
HDI	1							
TEM	0.31	1						
CO_2	0.86	0.32	1					
MET	-0.30	-0.03	-0.30	1				
FOR	-0.56	0.30	-0.45	0.10	1			
PRE	0.26	-0.31	0.37	-0.18	0.36	1		
INQ	0.77	-0.23	0.64	-0.35	-0.43	0.02	1	
PGR	-0.62	0.12	-0.51	0.36	0.35	-0.06	-0.64	1
VIF	-	2.83	3.83	1.37	2.5	2.6	3.57	2.45
1/VIF	-	0.35	0.26	0.79	0.4	0.38	0.28	0.41
Mean VIF	**2.74**							

Source: Author's Compilation, 2025

From Table 4.2, there is a strong positive correlation between CO_2 emissions and Human Development Index among the selected countries in SSA. However, Methane emissions have a weak negative correlation. This shows that the emission of CO_2 has a strong influence on human development of SSA countries. Also, Institutional Quality has a strong positive correlation with Human Development Index among SSA countries. This highlights the role that good institution plays in enhancing human development. The mean Variance inflation Factor of 2.74 which is below the threshold of 5 is an indication of no multi-collinearity in the model. This is also evident in the correlation coefficients among the explanatory variable with all the variables showing a weak relationship among each other.

Table 4.3 Cross-Section Dependence Test

Variables	Cross-Section Dependence			Variables	Cross-Section Dependence		
Level	**CD-test**	**Corr**	**Abs (Corr)**	**First Diff.**	**CD-test**	**Corr**	**Abs (Corr)**
HDI	38.22***	0.80	0.80	ΔHDI	2.83***	0.06	**0.267**
TEM	-	-	-	ΔTEM	-	-	**-**
CO_2	5.24***	0.120	0.546	ΔCO_2	3.29***	0.075	**0.306**
LogMET	8.69***	0.199	0.588	ΔLogMET	1.96*	0.045	**0.291**
FOR	12.91***	0.296	0.515	ΔFOR	16.87***	0.387	**0.421**
LogPRE	-	-	-	ΔLogPRE	-	-	**-**
INQ	4.13***	0.205	0.453	ΔINQ	3.22***	0.040	**0.42**
PGR	**11.73*** **	**0.257**	**0.571**	**ΔPGR**	**3.86*** **	**0.019**	**0.308**

***, **, & * denote statistical level of significance @ 1%, 5%, and 10% respectively

Source: Author's Compilation, 2025.

From Table 4.3, all the variables have cross section dependence at both levels and first difference at 1% level of significance except for the first difference of LogMET that indicate cross-section dependence at 5%. In the presence of cross-section dependence among observations, the first-generation unit-root test (Ims, Pesaran & Shin, 2003; Levin, Lee & Chu, 2002; Hadri, 2000; Madala & Wu, 1999 among others) will not provide a reliable result (Pesaran, 2007). Hence, we conducted the second-generation unit root test using the CIPS second generation unit root test by Pesaran (2007).

Table 4.4 Second Generation (CIPS) Unit Root Test (Lag 1)

Variables	Levels	Variable	First Difference	Order of Integration
	CIPS (Z_t bar)		**CIPS (Z_t bar)**	
HDI	0.528	ΔHDI	-4.79a***	**I (1)**
TEM	4.32b***	ΔTEM	4.12b***	**I (0)**
CO_2	-2.691b***	ΔCO_2	-1.75a**	**I (0)**
LogMET	0.642	ΔMET	-2.93a***	**I (1)**
FOR	2.074	ΔFOR	-4.27a***	**I (1)**
LogPRE	17.724	ΔPRE	-4.33***	**I (1)**
INQ	-1.342	ΔINQ	-1.754b**	**I (1)**

PGR	**-0.342**	**ΔPGR**	**-2.49b*****	**I (1)**

***, **, & * denote statistical level of significance @ 1%, 5%, and 10% respectively
Source: Author's Compilation, 2025

Table 4.4 shows that only TEM and CO_2 emissions are stationary at levels without trend. However, after differencing, the remaining variables HDI, LogMet, FOR, LogPRE, INQ are stationary with trend while PGR is stationary without trend. The result therefore shows a mixed order of integration of I (0) and I (1) variables which necessitated the adoption of a dynamic model. The Generalized Method of Moment was employed to get estimates of the relationship between climate change variables and human development index (see Table 4.5).

4.1. Model Estimation

Dynamic Two-Step System GMM Estimation

With the number of cross-section (N) greater than the time (T). The appropriate estimator for the study is the Generalized method of moment (GMM). The estimates based on the two-step GMM estimator are provided in Table 4.5.

Table 4.5 Two-Step System GMM Estimates

Variables	Coefficients	T-statistics
L.HDI	0.9157	**47.78*****
TEM	-0.0530	**-2.08****
CO_2	0.0299	**4.67*****
LogMET	-5.865	**-2.23****
FOR	-0.0671	**-3.67*****
LogPRE	3.995	**5.22*****
INQ	0.0416	**2.53****
PGR	-0.0108	**-1.74***
F-statistics = 92137.86, Prob.=0.000 **AR (1) in first differences: z = -3.64 Prob. = 0.000** **AR (2) in first differences: z = 0.39 Prob. = 0.698** **Sargan = 21.54, Prob. = 0.028** **Hansen = 17.94, Prob. = 0.183**		

***, **& * indicate statistical significance at 1%, 5% and 10% respectively, robust option was used; estimation was carried out using xtabond2 option in Stata.
Source: Author's Computation, 2025.

From Table 4.5, the one-year lag of HDI has a significant impact on the current value with a unit increase causing 0.9157unit increase in current HDI.

The table also revealed that the explanatory variables, Temperature, Methane emissions and Forest depletion have a negative and significant impact on HDI with a unit increase in Temperature and Forest depletion respectively causing 0.0530 and 0.0671 unit decrease in the mean of HDI. On the other hand, one percent increase in Methane emissions decreases HDI by 0.0587 unit. On the other hand, CO_2

emissions and Annual average precipitation both have a significant positive impact on HDI with a unit increase in CO_2 emissions causing 0.0299 unit increase in HDI and a one percent increase in annual average precipitation causing HDI to increase by 0.03995 units.

In addition, the influence of the controlled variables is also significant on HDI. For instance, there is a positive and significant impact of institutional quality on HDI with a unit increase causing 0.0416 unit increase in HDI. However, Population growth rate was negative and insignificant on HDI with a unit increase in PGR causing 0.0108 unit decrease in HDI.

The probability of AR (2) of 0.0698 indicate that we cannot reject the null hypothesis of no second-order serial correlation. Hence, we can conclude that the model does not suffer from second-order serial correlation. Also, given the p-value of the Hansen statistic of 0.183, we cannot reject the null hypothesis that all the instruments are jointly valid. Hence, we can conclude that the instruments used are not over-identified.

4.2 Robustness Check

This section discusses the robustness of the GMM estimates by comparing its result with results from other estimation techniques to see if our estimates are robust.

Table 4.6 Two-step Differences GMM, Fixed Effects and Random Effects Regression

Variables	Two-step Difference GMM	Fixed Effect	Randon Effects
L.HDI	0.9583***	-	-
TEM	-0.0343***	-0.0224***	0.0212***
CO_2	-0.142***	-0.110**	-0.237***
LogMET	-5.2333**	-4.2414	-4.4828
FOR	-0.0303***	-0.0265***	-0.0356***
LogPRE	4.4432***	2.2275**	5.2857 **
INQ	0.0275***	0.0265**	0.0211***
PGR	-0.0868***	-0.0323 *	-0.0437***

***, **& * indicate statistical significance at 1%, 5% and 10% respectively
Source: Author's Computation, 2025.

From Table 4.6, the estimations carried out using the Difference GMM, Fixed effect and Random effect method showed that the coefficients of all the explanatory variables exhibit the same sign as the two-step System GMM estimation except the CO_2 emissions that showed a negative coefficient from all the three estimations. This is an indication that the relationship between carbon emission and human development is mixed in SSA. The negative relationship could be due to the detrimental impact that CO_2 emission has on health and education of the population which in turn reduces the level of development. Importantly, Methane Emission was negative in all the three estimations. However, only the two-step Difference GMM estimation showed a statistically significant relationship.

4.3. Discussion of Findings and Policy Implications

This study examined the impact of climate change on human development in selected countries in SSA. Employing the two-step GMM estimator the

study highlighted noteworthy findings. In line with the study of Adejumo (2021), CO_2 emissions showed a mixed result in the study with the two-step GMM showing a positive and significant impact on human development suggesting the need for more industrialization and energy production to drive economic growth and development. The robustness check done using the two-step difference GMM and fixed and random effect regression however showed a negative and significant impact on human development similar to extant studies (Ogbuabor & Egwuchukwu, 2017; Taher, 2019; Kurshid et al., 2022). It is therefore crucial to ensure that the increase in CO_2 emissions is sustainable and does not compromise the environment. In other words, policy makers should strike a balance between fostering human development and safeguarding the environment. Promoting green technologies and encouraging industries to adopt sustainable practices can be instrumental in striking the balance.

The negative and significant effect of methane gas emissions on human development based on the two-step system and difference GMM suggests the need to reduce methane gas emissions particularly from sources like agriculture and waste management. This may involve promoting sustainable agricultural practices and improving waste disposal methods. In addition, policymakers should focus on policies that promote sustainable livestock management practices to reduce methane emissions from enteric fermentation.

In line with some extant studies (Kurshid et al., 2022; Maino & Emrullahu, 2022; Alagidede et al., 2014), annual average temperature is detrimental to human development. The negative impact of temperature suggests the need for policy makers to prioritize the development and implementation of climate resilience strategies to mitigate the effect of rising temperatures on key sectors like agriculture, water resources and public health. There should be investment in infrastructure that can withstand extreme weather events.

Average rainfall/precipitation also showed a significant positive impact on human development in line with extant studies (Maino & Emrullahu, 2022; Alagidede et al., 2014). The positive impact of average annual precipitation on human development highlights the importance of adequate rainfall on human development in SSA. This suggests the need for proper water resource management to ensure reliable access to clean water for agriculture, industries and household.

In line with Ogbuabor and Egwuchukwu (2017), our findings showed a negative and significant of forest depletion on human development. The negative impact of forest depletion of human development emphasized the importance of addressing deforestation for sustainable development. Policymakers should focus on policies that promote forest conservation and reforestation projects to counteract the negative impact of depletion. Policies should prioritize the conversation of biodiversity within the forests. Protecting diverse ecosystems contributes not only to environmental sustainability but also to the resilience of communities dependent on forest resources.

Our findings are similar to the findings of Elkouk et al. (2022) where poor climate change was responsible for the low level of human development of SSA countries. It is however against the findings of Malpede and Percoco (2015) where average precipitation was insignificant on human development among different regions in the world.

Looking at the influence of the controlled variables, the positive impact of institutional quality on human development underscores the pivotal role that effective governance and strong institutions play in fostering socio-economic

development. Measures should be put in place to strengthen the legal and regulatory framework that create a conducive environment for development. Anti-corruption measures should be put in place to combat corruptions within public institutions.

The negative impact of population growth rate on human development underscores the need for policies that address population dynamics. Policies that promote access to family planning and reproductive health services should be prioritized. Policies should be focused on empowering women through education and economic opportunities. When women have access to education and employment, it often correlates with low fertility rates contributing to effective population management.

The similarity in results from different estimation techniques suggest that our model is robust and the validity of the instruments used, based on the Hansen statistic shows that the GMM estimates are robust and reliable for predictions.

5.0 Conclusions and Policy Recommendations

This study examined how climate change affects human development in selected sub-Saharan African (SSA) countries. Unlike most earlier studies that mainly focused on economic growth, this research used the Human Development Index (HDI) as a broader measure. This approach captures not just income but also the health and education aspects of development. Using HDI is a key strength of the study because it offers a clearer picture of how climate change impacts quality of life and well-being in the region, rather than solely its economic output. By applying the two-step system GMM estimation technique, the study produced several important findings.

The analysis showed that carbon dioxide (CO_2) emissions are linked to human development in SSA. This finding highlights the role of industrialization and energy production in driving economic and social progress. However, it also points out a significant challenge: while CO_2-related industrial activities may aid development, they bring environmental costs that could threaten long-term sustainability. In contrast, methane emissions, rising temperatures, and deforestation were found to have notable negative effects on human development. These results stress the vulnerability of SSA's development path to environmental damage and climate-related stress. The study also found that average precipitation positively contributes to HDI. Adequate rainfall boosts agricultural productivity, improves food security, and supports better health outcomes. Additionally, better institutional quality enhances human development, while rapid population growth decreases it, highlighting the importance of governance and population management in affecting development outcomes.

Taken as a whole, these findings show that climate change affects not only economic indicators but also wider aspects of human development. This supports the choice to use HDI as a more complete measure of welfare. The study concluded that effectively managing climate-related factors, alongside strong institutions and sustainable population policies, is crucial for promoting human development in SSA. Based on these findings, the study suggests that for SSA countries to enhance their human development, regional governments must properly manage CO_2 emissions. They also need to invest in infrastructure that can withstand extreme weather events. Additionally, there should be efforts to cut methane emissions, especially from agriculture and waste management sources. Reliable water resource management is necessary to ensure access to clean water for agriculture, industries, and households. Finally, promoting forest conservation and reforestation projects is essential to counter the negative effects of deforestation.

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