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# Climate Change, Urbanisation, and Sustainability Outcomes in Sub-Saharan Africa

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**Competing Interests**

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**Data Availability**

All data used in this study were obtained from publicly available databases. The compiled dataset supporting the findings of this study is available from the corresponding author upon reasonable request. The data sources are explicitly referenced as follows:

World Development Indicators (WDI):
https://databank.worldbank.org/source/world-development-indicators
Climate Change Knowledge Portal (CCKP):
https://climateknowledgeportal.worldbank.org
Worldwide Governance Indicators (WGI):
https://info.worldbank.org/governance/wgi/
National Oceanic and Atmospheric Administration (NOAA) Climate Data:
https://www.ncei.noaa.gov

Environmental Performance Index (EPI):
https://epi.yale.edu
Human Development Index (HDI):
https://hdr.undp.org/data-center/human-development-index

**Ethical Compliance**

This study relies exclusively on secondary data obtained from publicly accessible databases and does not involve human participants, animals, or confidential personal information. Therefore, ethical approval was not required.

**Ethical Approval**

This study is based entirely on secondary data from publicly available sources. It does not involve human participants, personal data, or sensitive information. Consequently, ethical approval was not required in accordance with institutional and journal guidelines.

**Consent to Participate**

Not applicable.

**Consent to Publish**

Not applicable. All authors have read and approved the final manuscript and consent to its publication.

**Abstract**

This study examines the effects of climate change and urbanisation on sustainability outcomes in Sub-Saharan Africa using panel data for 32 countries over the period 1996–2023. The analysis focuses on economic, environmental, and social sustainability while incorporating temperature, precipitation, carbon emissions, and persistent drought conditions measured by the Palmer Drought Severity Index. To capture long-run relationships, nonlinear responses, distributional dynamics, and heterogeneity across countries, sectors, and subregions, the study employs Pooled Mean Group estimation, Common Correlated Effects estimators, Hansen threshold regression, and panel quantile regression techniques. The findings show that rising temperatures weaken economic, environmental, and social sustainability, while precipitation generally improves sustainability outcomes, particularly economic sustainability. Carbon emissions support economic sustainability in some economies but reduce environmental sustainability, revealing a trade-off between economic expansion and environmental protection. The threshold estimates indicate that the effects of climate change and urbanisation become increasingly adverse once critical climatic and urbanisation levels are exceeded. The results further reveal substantial heterogeneity across subregions and sectors, with West and East Africa displaying greater climate vulnerability, and agriculture emerging as the most climate-sensitive sector. Persistent drought conditions exert particularly strong negative effects on social sustainability and weaken economic performance in several parts of the region. These findings demonstrate that the sustainability consequences of climate change and urbanisation vary considerably across climatic conditions, sectors, and stages of development. The study underscores the importance of climate adaptation, sustainable urban planning, renewable energy transition, institutional strengthening, and climate-resilient infrastructure investment in supporting long-term sustainability and resilience across Sub-Saharan Africa.

**Keywords:** Carbon emissions; Climate change; sustainability; Persistent drought conditions; Threshold effects; Urbanisation.

## 1. Introduction

Climate change and rapid urbanisation have become central concerns in the pursuit of sustainable development, particularly in developing economies where environmental vulnerability and demographic pressures continue to intensify. Rising temperatures, changing precipitation patterns, prolonged drought conditions, and increasing carbon emissions affect economic performance, environmental quality, and social welfare through their influence on agricultural productivity, ecosystem stability, water resources, and household livelihoods (IPCC, 2023; Romanello et al., 2023; UNEP, 2023). Evidence indicates that climate-related pressures increasingly undermine sustainable development by reducing productivity, weakening food systems, degrading environmental resources, and constraining welfare improvements, especially in economies with limited adaptive capacity (Baloch et al., 2023; Khan et al., 2023; Wang et al., 2024).

At the same time, urbanisation continues to reshape development patterns across the Global South. Urban growth can support sustainability through infrastructure development, technological progress, labour mobility, and improved access to economic opportunities and public services (Henderson et al., 2017; Nathaniel & Bekun, 2021). However, when urban expansion outpaces infrastructure provision and institutional capacity, it may increase environmental degradation, congestion, pollution, inequality, and pressure on public services (Ezeh et al., 2017; Fox & Goodfellow, 2021). Consequently, urbanisation can either strengthen or weaken sustainability outcomes depending on the pace and quality of urban development.

These challenges are particularly pronounced in Sub-Saharan Africa, which remains highly exposed to climate variability while experiencing one of the fastest rates of urban expansion globally. Rising temperatures, rainfall variability, and persistent drought conditions continue to threaten agriculture, water availability, energy systems, and household welfare across the region (IPCC, 2023; World Meteorological Organization, 2023). Given the region's dependence on climate-sensitive sectors, these pressures weaken economic sustainability through lower productivity, food insecurity, income instability, and reduced long-term growth prospects (Serdeczny et al., 2017; Abidoye et al., 2022). Climate-related pressures also contribute to environmental degradation, biodiversity loss, and ecosystem deterioration, while social sustainability is affected through rising poverty, health risks, migration pressures, and unequal access to essential services (Diffenbaugh & Burke, 2019; Romanello et al., 2023).

Urbanisation further shapes these sustainability dynamics. Although urban centres support industrialisation, innovation, and structural transformation, many cities across Sub-Saharan Africa continue to face challenges associated with inadequate infrastructure, poor sanitation, waste management problems, overcrowding, and environmental stress (Lall et al., 2017; Ezeh et al., 2017; Fox & Goodfellow, 2021). Recent studies suggest that urbanisation can enhance sustainability through productivity growth and infrastructure development, but these benefits may diminish when urban growth exceeds environmental and institutional capacity (Acheampong et al., 2021; Wang et al., 2022; Rahman et al., 2024). This suggests that the sustainability effects of climate change may vary across different levels of urbanisation.

Although the literature on climate change and sustainability has expanded considerably, several important gaps remain. First, existing studies focus predominantly on environmental sustainability, particularly carbon emissions and ecological degradation, while giving less attention to economic and social sustainability dimensions (Ahmed et al., 2022; Baloch et al., 2023). Second, climate change and urbanisation are often examined separately despite their close interaction in shaping development outcomes, adaptive capacity, and environmental pressures (Pata & Isik, 2021; Usman & Makhdum, 2021). Third, evidence on whether climate effects vary across different stages of urbanisation remains limited, particularly in Sub-Saharan Africa, where urban transitions differ substantially across countries (Acheampong et al., 2021). Fourth, despite increasing concerns about drought across the region, relatively little attention has been devoted to the long-run sustainability implications of persistent drought conditions (Spinoni et al., 2021; IPCC, 2023). Finally, existing studies provide limited evidence on subregional and sectoral heterogeneity despite substantial differences in climate exposure, urban development, institutional quality, and productive structures across the region (Abidoye et al., 2022; Romanello et al., 2023).

This study addresses these gaps by examining the effects of climate change and urbanisation on sustainability outcomes in Sub-Saharan Africa over the period 1996–2023. Specifically, the study adopts a multidimensional sustainability framework that incorporates economic, environmental, and social sustainability; evaluates the joint effects of climate conditions and urbanisation; identifies urbanisation thresholds that alter climate–sustainability relationships; and examines the long-run effects of persistent drought conditions alongside subregional and sectoral heterogeneity. By doing so, the study contributes new evidence on the interaction between climate vulnerability, urban transition dynamics, and sustainable development in Sub-Saharan Africa.

## 2. Methods

This section describes the data, variables, and empirical methods used to examine the effects of climate change and urbanisation on sustainability outcomes in Sub-Saharan Africa. It presents the data sources and variable measurements, outlines the multidimensional sustainability framework adopted in the study, and discusses the

econometric techniques employed to analyse long-run relationships, threshold effects, and heterogeneity across subregions and sectors.

### *2.1 Data and Variables*

The study uses annual panel data for 32 Sub-Saharan African countries covering the period 1996–2023. The sample period was selected based on data availability and consistency across the variables included in the analysis. The dataset captures important changes in climate conditions, urbanisation, and sustainability outcomes across the region over nearly three decades.

Data were obtained from several international sources. Information on sustainability indicators, urbanisation, GDP per capita, renewable energy consumption, energy use, trade openness, population growth, gross fixed capital formation, agricultural value added, and carbon emissions was sourced from the World Bank's World Development Indicators (WDI). Temperature and precipitation data were obtained from the World Bank Climate Change Knowledge Portal and complementary climate databases where required. Data on persistent drought conditions, measured using the Palmer Drought Severity Index (PDSI), were obtained from the National Oceanic and Atmospheric Administration (NOAA). Government effectiveness data were sourced from the Worldwide Governance Indicators (WGI) database.

The study adopts a multidimensional sustainability framework comprising economic, environmental, and social sustainability dimensions. Climate change is represented by temperature, precipitation, carbon emissions, and persistent drought conditions, while urbanisation is measured by the share of the population residing in urban areas. Additional control variables include GDP per capita, renewable energy consumption, energy use, trade openness, population growth, gross fixed capital formation, agricultural value added, and government effectiveness. Table 1 presents the definitions, measurements, and sources of all variables used in the analysis.

The combination of these datasets provides a balanced panel suitable for examining long-run relationships, threshold effects, and heterogeneity in the climate–urbanisation–sustainability nexus across Sub-Saharan Africa.

### *2.2 Measurement of Sustainability Outcomes and Palmer Drought Severity Index (PDSI)*

#### *Sustainability Outcomes*

This study adopts a multidimensional approach to sustainability by examining economic, social, and environmental sustainability separately. This framework recognises that sustainable development extends beyond economic growth and requires the simultaneous improvement of economic resilience, social well-being, and environmental quality.

Economic sustainability (ES) is measured using Adjusted Net Savings per capita. This indicator reflects the capacity of an economy to sustain long-term wealth accumulation by accounting for investments in human and physical capital while adjusting for natural resource depletion and environmental damage (World Bank, 2022; Greiner & Semmler, 2021). Higher values indicate stronger economic sustainability and greater capacity to maintain future economic well-being.

Social sustainability (SOS) is proxied by the Human Development Index (HDI), which captures achievements in health, education, and income and is widely used as a measure of human welfare and social progress (UNDP, 2022). Higher HDI values indicate better social outcomes and improvements in living standards.

Environmental sustainability (EVS) is measured using the Environmental Performance Index (EPI). The EPI evaluates environmental quality and environmental management across countries by incorporating indicators related to ecosystem vitality, environmental health, and resource management (Wendling et al., 2020). Higher values reflect stronger environmental performance and greater environmental sustainability.

Examining these sustainability dimensions separately allows the analysis to capture the distinct channels through which climate change and urbanisation influence sustainable development outcomes in Sub-Saharan Africa. The definitions, measurements, and sources of all variables used in the analysis are presented in Table 1.

#### *Drought Intensity (PDSI)*

Drought intensity is measured using the Palmer Drought Severity Index (PDSI), obtained from the National Oceanic and Atmospheric Administration (NOAA). The PDSI is a widely used measure of long-term drought conditions derived from a climatic water balance framework that incorporates precipitation, temperature, evapotranspiration, runoff, and soil moisture conditions. The index is expressed as:

$$PDSI_t = \frac{Z_t}{\sigma_Z} \quad (1)$$

where $PDSI_t$denotes the Palmer Drought Severity Index in the period $t$, $Z_t$is the moisture anomaly index, and $\sigma_Z$The standard deviation is used to standardise moisture conditions. The moisture anomaly is determined as:

$$Z_t = f(P, T, ET, R, SM) \quad (2)$$

where $P$represents precipitation, $T$denotes temperature, $ET$is evapotranspiration, $R$represents runoff, and $SM$refers to soil moisture.

Negative PDSI values indicate drought conditions, while positive values indicate wetter-than-normal conditions. More negative values reflect greater drought severity and prolonged climate stress. Drought conditions reduce agricultural productivity, weaken food security, increase water scarcity, and accelerate ecosystem degradation, thereby affecting economic, social, and environmental sustainability (IPCC, 2021; Machado & Santos Silva, 2019). Accordingly, the expected relationship between drought conditions and sustainability outcomes is:

$$\frac{\partial SUS}{\partial PDSI} > 0 \quad (3)$$

where $SUS$denotes sustainability outcomes. Higher PDSI values indicate improved moisture conditions and are therefore expected to support sustainability performance. Annual PDSI values were obtained directly from the NOAA database and incorporated into the empirical analysis.

**Table 1: presents the definition, measurement, sources, and expected effects of the variables used in the study**.

| Variable Identifier | Variable | Measurement | Source | Expected Effect |
|---|---|---|---|---|
| ES | Economic Sustainability | Adjusted Net Savings per capita (%) | World Development Indicators (WDI) | Dependent Variable |
| EVS | Environmental Sustainability | Environmental Performance Index (EPI) | Environmental Performance Index Database | Dependent Variable |
| SOS | Social Sustainability | Human Development Index (HDI) | United Nations Development Programme (UNDP) | Dependent Variable |
| Temp | Temperature | Annual average temperature (°C) | Climate Change Knowledge Portal (CCKP) | Negative |
| Prec | Precipitation | Annual average precipitation (mm) | Climate Change Knowledge Portal (CCKP) | Ambiguous (+/−) |
| $CO_2$ | Carbon Emissions | $CO_2$ emissions (metric tons per capita) | World Development Indicators (WDI) | Negative |
| PDSI | Drought Intensity | Palmer Drought Severity Index | NOAA Climate Database | Positive (+)[1] |
| Urban | Urbanisation | Urban population (% of total population) | World Development Indicators (WDI) | Ambiguous (+/−) |
| GE | Government Effectiveness | Government Effectiveness Index | Worldwide Governance Indicators (WGI) | Positive |
| Trade | Trade Openness | Trade (% of GDP) | World Development Indicators (WDI) | Ambiguous (+/−) |
| GFCF | Gross Fixed Capital Formation | Gross fixed capital formation (% of GDP) | World Development Indicators (WDI) | Positive |
| Agric | Agriculture | Agriculture, forestry and fishing value added (% of GDP) | World Development Indicators (WDI) | Ambiguous (+/−) |

**Note:** *Higher PDSI values indicate improved moisture conditions and lower drought severity. Consequently, a positive coefficient implies that improved moisture conditions enhance sustainability outcomes, whereas more severe drought conditions reduce sustainability performance.*

### *2.3 Theoretical Foundation*

The study is grounded in the sustainability transition framework, which argues that long-term development depends on balancing economic progress, environmental protection, and social well-being (Markard et al., 2012; United Nations, 2015). Within this framework, climate change and urbanisation are important drivers of sustainability because they influence productive capacity, environmental quality, resource availability, and welfare outcomes. Climate conditions, including temperature, precipitation, carbon emissions, and drought, affect sustainability through their effects on agricultural productivity, ecological stability, and economic performance (IPCC, 2023; Romanello et al., 2023). Urbanisation also influences sustainability through infrastructure development, technological progress, labour mobility, and access to public services, although its effects may vary depending on the pace and quality of urban growth (Henderson et al., 2017; Ezeh et al., 2017).

Accordingly, sustainability outcomes may be represented as:

$$SUS_{it} = f(CC_{it}, URBAN_{it}, X_{it}) \quad (4)$$

where $SUS_{it}$denotes sustainability outcomes, $CC_{it}$represents climate conditions, $URBAN_{it}$denotes urbanisation, and $X_{it}$represents a vector of control variables, including government effectiveness, foreign direct investment, gross capital formation, trade openness, education, inflation, and other structural factors.

The expected relationship between sustainability and climate conditions is expressed as:

$$\frac{\partial SUS}{\partial CC} \neq 0 \qquad (5)$$

while the effect of urbanisation is represented as:

$$\frac{\partial SUS}{\partial URBAN} \neq 0 \qquad (6)$$

These relationships imply that changes in climate conditions and urbanisation influence sustainability outcomes. The theoretical framework, therefore, provides the basis for the empirical models used to examine the effects of climate change and urbanisation on economic, environmental, and social sustainability in Sub-Saharan Africa.

### *2.4 Empirical Model Specification*

Following the theoretical foundation, sustainability outcomes are modelled as a function of climate conditions, urbanisation, and other socioeconomic factors. The general empirical specification is expressed as:

$$SUS_{it} = \alpha + \beta_1 CC_{it} + \beta_2 URBAN_{it} + \gamma X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \qquad (7)$$

where $SUS_{it}$denotes sustainability outcomes, $CC_{it}$represents climate-related variables, $URB_{it}$denotes urbanisation, and $X_{it}$ is a vector of control variables. The terms $\mu_i$ and $\lambda_t$ capture country-specific and time-specific effects, respectively, while $\varepsilon_{it}$denotes the error term.

To capture the multidimensional nature of sustainability, the model is estimated separately for economic sustainability ($ES$), environmental sustainability ($EVS$), and social sustainability ($SOS$). Climate variables are introduced individually to isolate their effects and minimise potential multicollinearity among climate indicators.

#### *2.4.1. Economic Sustainability Model*

$$ES_{it} = \alpha_0 + \alpha_1 Temp_{it} + \alpha_2 Urban_{it} + \alpha_3 GE_{it} + \alpha_4 FDI_{it} + \alpha_5 GCF_{it} + \alpha_6 CPI_{it} + \alpha_7 Trade_{it} + \alpha_8 TSR_{it} + \alpha_9 EDUc_{it} + \mu_i + \lambda_t + \varepsilon_{it} \qquad (8)$$

$$ES_{it} = \alpha_0 + \alpha_1 Prec_{it} + \alpha_2 Urban_{it} + \alpha_3 GE_{it} + \alpha_4 FDI_{it} + \alpha_5 GCF_{it} + \alpha_6 CPI_{it} + \alpha_7 Trade_{it} + \alpha_8 TSR_{it} + \alpha_9 EDUc_{it} + \mu_i + \lambda_t + \varepsilon_{it} \qquad (9)$$

$$ES_{it} = \alpha_0 + \alpha_1 CO2_{it} + \alpha_2 Urban_{it} + \alpha_3 GE_{it} + \alpha_4 FDI_{it} + \alpha_5 GCF_{it} + \alpha_6 CPI_{it} + \alpha_7 Trade_{it} + \alpha_8 TSR_{it} + \alpha_9 EDUc_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (10)$$

***2.4.2. Environmental Sustainability Model***

$$EVS_{it} = \beta_0 + \beta_1 Temp_{it} + \beta_2 Urban_{it} + \beta_3 GE_{it} + \beta_4 FDI_{it} + \beta_5 GCF_{it} + \beta_6 CPI_{it} + \beta_7 Trade_{it} + \beta_8 TSR_{it} + \beta_9 EDUc_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (11)$$

$$EVS_{it} = \beta_0 + \beta_1 Prec_{it} + \beta_2 Urban_{it} + \beta_3 GE_{it} + \beta_4 FDI_{it} + \beta_5 GCF_{it} + \beta_6 CPI_{it} + \beta_7 Trade_{it} + \beta_8 TSR_{it} + \beta_9 EDUc_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (12)$$

***2.4.3. Social Sustainability Model***

$$SOS_{it} = \gamma_0 + \gamma_1 Temp_{it} + \gamma_2 Urban_{it} + \gamma_3 GE_{it} + \gamma_4 FDI + \gamma_5 GCF + \gamma_6 CPI_{it} + \gamma_7 Trade_{it} + \gamma_8 TSR_{it} + \gamma_9 EDU_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (13)$$

$$SOS_{it} = \gamma_0 + \gamma_1 Prec_{it} + \gamma_2 Urban_{it} + \gamma_3 GE_{it} + \gamma_4 FDI + \gamma_5 GCF + \gamma_6 CPI_{it} + \gamma_7 Trade_{it} + \gamma_8 TSR_{it} + \gamma_9 EDU_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (14)$$

$$SOS_{it} = \gamma_0 + \gamma_1 CO2_{it} + \gamma_2 Urban_{it} + \gamma_3 GE_{it} + \gamma_4 FDI + \gamma_5 GCF + \gamma_6 CPI_{it} + \gamma_7 Trade_{it} + \gamma_8 TSR_{it} + \gamma_9 EDU_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (15)$$

Where $ES_{it}$, $EVS_{it}$, and $SOS_{it}$ represent economic sustainability, environmental sustainability, and social sustainability, respectively, for the country $i$ at time $t$. In subsequent specifications, $SUST_{it}$ is used as a general notation representing the three sustainability indicators collectively. $Temp_{it}$ denotes temperature, $Prec_{it}$ denotes precipitation, and $CO2_{it}$ represents carbon emissions. $Urban_{it}$ captures urban growth, while $GE_{it}$ denotes government effectiveness. $Trade_{it}$, $CPI_{it}$, $GCF_{it}$, and $EDU_{it}$ trade openness, Consumer price index, gross capital formation, and school enrolment, respectively. $\mu_i$ captures country-specific effects, $\lambda_t$ captures time effects, and $\varepsilon_{it}$ represents the error term.

***2.5. Estimation Strategy***

The study employs multiple panel estimation techniques to account for cross-sectional dependence, slope heterogeneity, and long-run relationships across countries. The baseline analysis employs the Common Correlated Effects Mean Group (CCEMG) estimator and the pooled Common Correlated Effects (CCEP) estimator developed by Pesaran (2006). These estimators are appropriate because they account for cross-sectional dependence arising from common shocks, regional spillovers, and interconnected economic structures across African economies. The study further employs Driscoll–Kraay fixed effects estimation as a robustness approach because the estimator produces standard errors that remain robust to heteroskedasticity, serial correlation, and cross-sectional dependence (Driscoll & Kraay, 1998).

The selected estimators are particularly appropriate for Sub-Saharan Africa because countries within the region are interconnected through trade integration, climate variability, commodity price movements, migration patterns, and regional economic linkages. Ignoring these interdependencies may produce biased and inconsistent estimates. The CCEMG estimator further allows slope coefficients to vary across countries, making it suitable for heterogeneous regional conditions. The pooled CCEP estimator captures unobserved common factors that may simultaneously affect countries within the region, while the Driscoll–Kraay approach improves robustness by correcting for heteroskedasticity, autocorrelation, and cross-sectional dependence. Employing these complementary estimation techniques therefore improves the reliability, consistency, and robustness of the empirical findings.

***2.5. Threshold Modelling Framework***

To examine whether the sustainability effects of climate change vary across different stages of urbanisation, the study employs the Hansen (1999) panel threshold model. Urban growth serves as the threshold variable because the environmental and socioeconomic effects of climate conditions may differ depending on the pace and intensity of urban transition. Separate threshold models are estimated for economic sustainability, environmental sustainability, and social sustainability.

$$SUST_{it} = \theta_0 + \theta_1 Climate_{it} I(Urban_{it} \leq \tau) + \theta_2 Climate_{it} IUrban_{it} \quad (16)$$

Where $SUST_{it}$represents the sustainability indicators, $\tau$represents the estimated threshold level, and $I(.)$denotes the indicator function. $Climate_{it}$captures temperature, precipitation, and carbon emissions, while $X_{it}$represents the vector of control variables. The threshold framework allows the study to determine whether climate effects on sustainability change after urban growth exceeds a critical level.

### *2.6. Persistent Drought and Sustainability Analysis*

To investigate the long-run effect of persistent drought conditions on sustainability, the study employs panel quantile regression using the Palmer Drought Severity Index (PDSI). Quantile regression is appropriate because the sustainability effects of drought conditions may differ across countries with varying sustainability levels. The estimator also captures distributional heterogeneity that may not be identified under mean-based estimation approaches (Koenker & Bassett, 1978). Quantile models are estimated for economic sustainability, environmental sustainability, and social sustainability.

$$SUST_{it}(\tau) = \phi_0 + \phi_1 PDSI_{it} + \phi_2 GE_{it} + \phi_3 CV_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (17)$$

Where $SUST_{it}(\tau)$ represents the conditional quantiles of sustainability indicators, $PDSI_{it}$ captures persistent drought conditions, $GE_{it}$ denotes government effectiveness, and $CV_{it}$ represents the vector of control variables. This framework captures how persistent drought conditions affect sustainability across different points of the sustainability distribution.

### *2.7. Subregional Analysis and Diagnostic Tests*

The study further examines heterogeneity across Sub-Saharan African subregions comprising West Africa, East Africa, Central Africa, and Southern Africa. This analysis is important because climate exposure, urbanisation patterns, institutional quality, and productive structures differ substantially across subregions. Estimating separate regional models, therefore, provides additional insight into whether the sustainability effects of climate change and urbanisation vary across different regional contexts.

Several diagnostic tests are conducted before estimation to ensure the reliability of the empirical analysis. Cross-sectional dependence is examined using the Pesaran CD test, while panel unit root properties are examined using the Maddala–Wu Fisher panel unit root test. These tests help determine the suitability of the selected estimation techniques and improve the robustness of the empirical findings.

## 3. Results

This section presents the empirical findings on the effects of climate change and urbanisation on sustainability outcomes in Sub-Saharan Africa. The analysis begins with descriptive statistics and correlation analysis, followed by diagnostic tests to assess cross-sectional dependence and slope heterogeneity. The main results are then presented using the Common Correlated Effects Mean Group (CCEMG) and pooled Common Correlated Effects (CCEP) estimators, with additional robustness checks based on Driscoll–Kraay standard errors. The section concludes with the threshold, subregional, and sectoral analyses to examine potential nonlinearities and heterogeneity in the climate–urbanisation–sustainability relationship.

### *3.1 Descriptive Statistics and Preliminary Analysis*

Table 1 presents the descriptive statistics for the variables used in the study. The sustainability indicators display considerable variation across countries, highlighting differences in economic, environmental, and social sustainability performance within Sub-Saharan Africa. Economic sustainability (ES) records a mean value of 1.2105, while social sustainability (SOS) and environmental sustainability (EVS) record mean values of 0.5063 and 43.3848, respectively. The relatively wide ranges observed across the sustainability indicators suggest substantial heterogeneity in development outcomes across the region.

Urbanisation records an average value of 34.81%, indicating that many countries remain in the early stages of urban transition. Temperature averages 24.58°C, while precipitation exhibits substantial variability across countries, reflecting differences in climatic conditions and environmental exposure. Carbon emissions also vary considerably across the sample, suggesting differences in production structures and environmental pressures. Government

effectiveness records a negative average value, indicating persistent institutional challenges across many countries. The Palmer Drought Severity Index (PDSI) records a slightly negative mean value, suggesting the prevalence of mild drought conditions during the study period.

Appendix Table 1A reports the correlation matrix and Variance Inflation Factor (VIF) results. The correlation coefficients indicate moderate relationships among the variables, while the VIF estimates remain well below conventional thresholds. The mean VIF value of 1.954 confirms the absence of multicollinearity concerns.

Appendix Table 2A presents the Fisher–ADF panel unit root results. The findings indicate that the variables are integrated of order zero, I(0), and order one, I(1). This mixed order of integration supports the use of the selected panel estimation techniques and confirms the suitability of the empirical framework adopted in the study.

**Table 1: Summary Statistics**

| Variable | Observation | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| Economic sustainability | 896 | 1.2105 | 3.8942 | -14.3866 | 14.0586 |
| Social sustainability | 896 | 0.5063 | 0.1115 | 0.2660 | 0.8530 |
| Environmental sustainability | 896 | 43.3848 | 4.0468 | 34.5304 | 58.0517 |
| Urbanisation | 896 | 34.8075 | 3.9931 | 28.0245 | 39.9656 |
| Precipitation | 896 | 1092.4270 | 712.6451 | 123.7100 | 5401.2900 |
| Temperature | 896 | 24.5816 | 4.2774 | 12.1400 | 31.9700 |
| $CO_2$ emissions | 896 | 2.6148 | 0.8148 | 0.4911 | 7.2223 |
| Government effectiveness | 896 | -0.7246 | 0.6053 | -1.9775 | 1.1556 |
| Foreign direct investment | 896 | 9.4113 | 5.4464 | -17.2921 | 103.3374 |
| Total resource rent | 896 | 15.3449 | 18.8762 | 0.0024 | 135.2796 |
| Gross capital formation | 896 | 20.6995 | 10.1742 | 5.2479 | 68.4064 |
| Consumer price index | 896 | 106.1996 | 93.2636 | 0.1966 | 645.9986 |
| Palmer drought severity index | 896 | -0.0420 | 0.9825 | -2.8548 | 4.7511 |

### 3.2 Effects of Climate Change on Sustainability Outcomes

Table 4 presents the long-run estimates obtained from the Pooled Mean Group (PMG) estimator for the effects of climate variables on economic, environmental, and social sustainability in Sub-Saharan Africa. The error correction terms (ECTs) are negative and statistically significant across all specifications, confirming the existence of stable long-run relationships among the variables and convergence towards equilibrium following short-run deviations.

Temperature records negative and statistically significant effects across all sustainability dimensions. A one-unit increase in temperature reduces social sustainability by 0.0250%, economic sustainability by 0.0022%, and environmental sustainability by 0.126%. The magnitude of the coefficient is largest for environmental sustainability, indicating a stronger response of environmental conditions to changes in temperature.

Precipitation exerts positive and statistically significant effects on all sustainability outcomes. A 1% increase in precipitation increases social sustainability by 0.0551%, economic sustainability by 1.398%, and environmental sustainability by 0.298%. The effect is strongest for economic sustainability, suggesting greater responsiveness of economic activities to rainfall conditions.

The results for $CO_2$ emissions differ across sustainability dimensions. A one-unit increase in $CO_2$ emissions increases economic sustainability by 1.398%, while reducing environmental sustainability by 0.935%. The coefficient for social sustainability is statistically insignificant. These findings indicate that the effects of carbon emissions vary across the three dimensions of sustainability.

Education records positive and statistically significant coefficients across the sustainability models. Trade openness and gross fixed capital formation also exert positive effects in several specifications. In contrast, the consumer price index records a negative and statistically significant effect on social sustainability, indicating that inflation is associated with weaker social sustainability outcomes.

**Table 4: Pool Mean Group Estimations [PMG]: Dependent Variable: Sustainability**

| | Social sustainability | | | Economic sustainability | | | Environmental sustainability | | |
|---|---|---|---|---|---|---|---|---|---|
| Variable | M1 (PMG) | M2 (PMG) | M3 (PMG) | M1 (PMG) | M2 (PMG) | M3 (PMG) | M1 (PMG) | M2 (PMG) | M3 (PMG) |
| Temperature | -0.0250** | | | -0.002** | | | -0.126** | | |
| | (0.0120) | | | (0.001) | | | (0.062) | | |
| ln_Precipitation | | 0.0551*** | | | 1.398** | | | 0.298** | |
| | | (0.0072) | | | (0.451) | | | (0.145) | |
| CO2 emissions | | | -0.0137 | | | 1.398** | | | -0.935*** |
| | | | (0.0479) | | | (0.451) | | | (0.260) |
| Foreign direct investment | 0.0043 | 0.0022 | 0.0040 | 0.061*** | 0.063*** | 0.056*** | 0.007 | 0.0050 | 0.0033 |
| | (0.0031) | (0.0030) | (0.0031) | (0.015) | (0.015) | (0.015) | (0.017) | (0.0171) | (0.0169) |
| Trade | 0.0046*** | 0.0044*** | 0.0043*** | -0.010 | -0.009 | -0.004 | 0.008 | 0.0091 | 0.0156*** |
| | (0.0011) | (0.0010) | (0.0011) | (0.006) | (0.006) | (0.006) | (0.006) | (0.0058) | (0.0060) |
| Gross capital formation | 0.0136*** | 0.0128*** | 0.00136** | 0.002 | -0.004 | 0.004 | 0.046*** | 0.045*** | 0.0499*** |
| | (0.0022) | (0.0021) | (0.0022) | (0.013) | (0.013) | (0.013) | (0.012) | (0.012) | (0.0122) |
| Consumer price index | -0.0014*** | -0.0010*** | -0.0013*** | -0.001 | -0.001 | -0.006 | -0.0012 | 0.0047 | 0.0057 |
| | (0.00002) | (0.0002) | (0.0002) | (0.001) | (0.001) | (0.001) | (0.0098) | (0.0093) | (0.0091) |
| Total resource rent | 0.0061** | 0.0056** | 0.0064** | 0.045*** | 0.043*** | 0.041*** | 0.053*** | 0.051*** | 0.0540*** |
| | (0.0030) | (0.0028) | (0.0029) | (0.013) | (0.013) | (0.013) | (0.016) | (0.016) | (0.0159) |
| Education | 0.0680*** | 0.00677*** | 0.0680*** | 0.054*** | 0.054*** | 0.046** | 0.128*** | 0.128*** | 0.137*** |
| | (0.0036) | (0.0035) | (0.0037) | (0.019) | (0.019) | (0.018) | (0.020) | (0.020) | (0.020) |
| Observation | 864 | 864 | 864 | 864 | 864 | 864 | 864 | 864 | 864 |
| ECT | -0.321*** | -0.535*** | -0.267*** | –0.29*** | –0.33*** | -0.230** | -0.476*** | -0.511*** | -0.509*** |
| | (0.007) | (0.OO4) | (0.003) | (0.090 | (0.10) | (0.089) | (0.004) | (0.012) | (0.005) |

**Note:** *Entries are coefficients with standard errors in parentheses. Significance: *** p<0.001, ** p<0.01, * p<0.05, . p<0.1*

### *3.3 Effects of Climate Change on Sustainability across Subregions*

Tables 5 and 6 present the Pooled Mean Group (PMG) subregional estimates for social sustainability, economic sustainability, and environmental sustainability across Central Africa, West Africa, Southern Africa, and East Africa. The results indicate considerable heterogeneity in the sustainability effects of climate change across the four subregions.

Temperature generally exerts negative effects on sustainability outcomes, although the magnitude and significance vary across regions. For social sustainability, temperature records statistically significant negative effects in West Africa and Southern Africa, where a one-unit increase reduces social sustainability by 0.0057% and 0.0048%, respectively. In the economic sustainability models, the largest negative effect is observed in West Africa, where a one-unit increase in temperature reduces economic sustainability by 0.334%. The coefficients for other subregions are smaller and less consistent across the specifications.

Precipitation records positive and statistically significant effects across several subregions, particularly for social and economic sustainability. In West Africa, a 1% increase in precipitation increases social sustainability by 0.0464%, while reducing economic sustainability by 0.164%. In contrast, precipitation improves economic sustainability in Southern Africa, where a 1% increase raises economic sustainability by 0.113%. These results suggest that the sustainability effects of precipitation differ across subregions.

The results for $CO_2$ emissions also vary across regions. For social sustainability, $CO_2$ emissions record negative and statistically significant effects in Southern Africa and East Africa. In the economic sustainability models, $CO_2$ emissions increase economic sustainability by 2.002% in Central Africa and 1.991% in West Africa. By contrast, the environmental sustainability models show negative and statistically significant coefficients in Southern Africa and East Africa, indicating adverse environmental effects associated with rising emissions.

Education records positive and statistically significant effects across many of the specifications, particularly in Central Africa, Southern Africa, and East Africa. Trade openness and gross capital formation also exert positive effects in several models. In contrast, the consumer price index records negative coefficients in a number of the social and environmental sustainability specifications, indicating weaker sustainability outcomes under higher inflationary conditions.

**Table 5: Pool Mean Group Estimations [PMG]: Dependent Variable: Sustainability across Subregions**

| | **PANEL A:** SOCIAL SUSTAINABILITY | | | | **PANEL B**: ECONOMIC SUSTAINABILITY | | | |
|---|---|---|---|---|---|---|---|---|
| **Variable** | Model 1 **Central Africa** | Model 2 **West Africa** | Model 3 **Southern Africa** | Model 4 **East Africa** | Model 1 **Central Africa** | Model 2 **West Africa** | Model 3 **Southern Africa** | Model 4 **East Africa** |
| Temperature | -0.0034 | -0.0057** | -0.0048** | -0.068 | -0.042 | -0.334** | -0.195 | -0.294 |
| | (0.0029) | (0.0025) | (0.0016) | (0.038) | (0.352) | (0.133) | (0.240) | (0.180) |
| ln_Precipitation | 0.0105 | 0.0464*** | 0.0246 | 0.0350 | -0.703 | -0.164*** | 0.113*** | 0.015 |
| | (0.0090) | (0.0102) | (0.0186) | (0.0189) | (0.427) | (0.029) | (0.032) | (0.009) |
| $CO_2$ Emissions | -0.0048 | -0.0006 | -0.008** | -0.009*** | 2.002* | 1.991** | 0.120 | -0.749 |
| | (0.0035) | (0.0004) | (0.003) | (0.002) | (1.088) | (0.908) | (5.461) | (0.824) |
| Foreign direct | -0.011*** | 0.0014** | -0.0022** | 0.001 | -0.042** | 0.003 | 0.007 | 0.030*** |
| investment | (0.002) | (0.0005) | (0.0008) | (0.006) | (0.021) | (0.009) | (0.018) | (0.009) |
| Trade | 0.0003 | 0.0009*** | 0.0005** | 0.003 | 0.017 | 0.024 | 0.049** | 0.044** |
| | (0.0002) | (0.0001) | (0.0002) | (0.002) | (0.037) | (0.022) | (0.018) | (0.019) |
| Gross capital | 0.0006 | 0.0007** | -0.0007 | 0.0026*** | -0.006 | -0.007** | -0.010 | 0.002* |
| formation | (0.0003) | (0.0003) | (0.0005) | (0.0004) | (0.005) | (0.002) | (0.010) | (0.001) |
| Consumer price | -0.002*** | -0.0001** | -0.0003** | -0.002*** | 0.111*** | -0.034 | 0.020 | -0.046* |
| index | (0.0001) | (0.00001) | (0.0001) | (0.0001) | (0.028) | (0.023) | (0.194) | (0.026) |
| Total resource | 0.001*** | 0.0007** | 0.0038*** | 0.014*** | 0.001 | 0.062*** | 0.001 | 0.041** |
| rent | (0.0002) | (0.0003) | (0.0007) | (0.003) | (0.010) | (0.016) | (0.019) | (0.016) |
| Education | 0.0106*** | 0.0065*** | 0.0037*** | 0.0040*** | 0.083 | 0.022 | 0.054*** | 0.037* |
| | (0.0007) | (0.0005) | (0.0005) | (0.0004) | (0.088) | (0.035) | (0.004) | (0.019) |
| Observation | 896 | 896 | 896 | 896 | 896 | 896 | 896 | 896 |

**Note**: *Entries are coefficients with standard errors in parentheses. Stars denote significance levels: * p<0.05, ** p<0.01, *** p<0.001*

**Table 6: Pool Mean Group Estimations [PMG]: Dependent Variable: Sustainability across Subregions**

| **PANEL C**: ENVIRONMENTAL SUSTAINABILITY | | | | |
|---|---|---|---|---|
| | Model 1 | Model 2 | Model 3 | Model 4 |
| **Variable** | **Central Africa** | **West Africa** | **Southern Africa** | **East Africa** |
| Temperature | -0.0034 | -0.0057** | -0.0048** | -0.0068 |
| | (0.0029) | (0.0025) | (0.0016) | (0.0038) |
| ln_Precipitation | 0.0105 | 0.0464*** | 0.0246 | 0.0350 |
| | (0.0090) | (0.0102) | (0.0186) | (0.0189) |
| $CO_2$ Emissions | -0.0048 | -0.0006 | -0.0008*** | -0.0009*** |
| | (0.0035) | (0.0004) | (0.0001) | (0.0002) |
| Foreign direct | -0.0011*** | 0.0014*** | -0.0022*** | 0.0010 |
| investment | (0.0002) | (0.0005) | (0.0008) | (0.0006) |
| Trade | 0.0003 | 0.0009*** | 0.0005** | 0.0003 |
| | (0.0002) | (0.0001) | (0.0002) | (0.0002) |
| Gross capital | 0.0006 | 0.0007** | 0.0007 | 0.0026*** |
| formation | (0.0003) | (0.0003) | (0.0005) | (0.0004) |
| Consumer price | -0.0002*** | -0.0001** | -0.0003** | -0.0002*** |
| index | (0.0000) | (0.0000) | (0.0001) | (0.0000) |
| Total resource rent | 0.0010*** | 0.0007** | 0.0038*** | 0.0014*** |
| | (0.0002) | (0.0003) | (0.0007) | (0.0003) |
| Education | 0.0106*** | 0.0065*** | 0.0037*** | 0.0040*** |
| | (0.0007) | (0.0005) | (0.0005) | (0.0004) |
| Observation | 216 | 216 | 216 | 216 |

**Note**: *Entries are coefficients with standard errors in parentheses. Stars denote significance levels: * p<0.05, ** p<0.01, *** p<0.001*

***3.4 Effects of Climate Change on Sustainability across Sectors***

Tables 7 and 8 present the Pooled Mean Group (PMG) estimates for the effects of climate variables on social, economic, and environmental sustainability across the agriculture, industry, manufacturing, services, and tourism sectors. The results reveal considerable variation in the sustainability effects of climate change across sectors.

Precipitation records positive and statistically significant effects across several sectoral specifications. For social sustainability, precipitation improves sustainability outcomes in agriculture, manufacturing, and tourism, with the largest effect observed in agriculture, where a 1% increase in precipitation increases social sustainability by 4.668%. In the economic sustainability models, precipitation exerts positive and significant effects in agriculture, manufacturing, services, and tourism, with the strongest effects recorded in manufacturing and services. Positive precipitation effects are also observed in the environmental sustainability models for agriculture and tourism.

The effects of $CO_2$ emissions differ across sectors. In the social sustainability models, $CO_2$ emissions increase sustainability in agriculture by 0.040% but reduce sustainability in manufacturing by 0.020%. In the environmental sustainability models, $CO_2$ emissions record a negative and statistically significant effect in the services sector, where a one-unit increase in emissions reduces environmental sustainability by 0.286%. The remaining coefficients vary in both magnitude and significance across sectors.

Temperature also produces heterogeneous effects across the sectoral models. In the social sustainability specifications, temperature increases sustainability in industry by 0.011% but reduces sustainability in tourism by 0.024%. In the economic sustainability models, temperature records negative and statistically significant effects in agriculture, industry, and services, reducing economic sustainability by 0.312%, 0.146%, and 0.118%, respectively. The environmental sustainability estimates are generally negative across sectors, with the strongest and statistically significant effect observed in agriculture, where a one-unit increase in temperature reduces environmental sustainability by 0.214%.

The findings reveal substantial sectoral heterogeneity in the sustainability effects of climate change. While precipitation generally improves sustainability outcomes across several sectors, temperature tends to weaken economic and environmental sustainability. The effects of $CO_2$ emissions vary across sectors, indicating that climate-

related sustainability outcomes differ according to sectoral characteristics, productive structures, and levels of climate sensitivity within Sub-Saharan Africa.

**Table 7: Pool Mean Group Estimations [PMG]: Dependent Variable: Sustainability across Sectors within SSA.**

| | **PANEL A:** SOCIAL SUSTAINABILITY | | | | | **PANEL B**: ECONOMIC SUSTAINABILITY | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Model 1** | **Model 2** | **Model 3** | **Model 4** | **Model 5** | **Model 1** | **Model 2** | **Model 3** | **Model 4** | **Model 5** |
| Variable | Agriculture | Industry | Manufacturing | Services | Tourism | Agriculture | Industry | Manufacturing | Services | Tourism |
| ln_Precipitation | 4.6684*** | 2.5032 | 1.1923*** | 0.6711 | 0.6954*** | 0.0151** | 0.0260 | 0.0304** | 0.0314** | 0.0190** |
| | (0.8681) | (1.5925) | (0.5415) | (1.1284) | (0.1618) | (0.0057) | (0.0140) | (0.0145) | (0.0130) | (0.0063) |
| CO2 emissions | 0.040** | -0.034 | -0.020* | -0.020 | - 0.004 | -0.0049 | 0.0260 | -0.0038 | -0.0063 | -0.0071 |
| | (0.013) | (0.024) | (0.008) | (0.017) | (0.002) | (0.0058) | (0.0140) | (0.0060) | (0.0043) | (0.0056) |
| Temperature | -0.025 | 0.774* | -0.066 | -0.443 | -0.120** | -0.0026** | -0.002** | 0.0014 | -0.002*** | -0.0013 |
| | (0.184) | (0.329) | (0.112) | (0.238) | (0.033) | (0.0009) | (0.001) | (0.0013) | (0.0006) | (0.0022) |
| Foreign direct investment | -0.0173 | 0.0898* | -0.0186 | 0.0365 | -0.0075 | -0.0014** | -0.002** | -0.0013** | -0.0014** | -0.001** |
| | (0.0274) | (0.0503) | (0.0171) | (0.0356) | (0.0051) | (0.0005) | (0.0005) | (0.0005) | (0.0005) | (0.0001) |
| Total resource rent | 0.0692*** | 0.0285 | 0.1470*** | 0.1730*** | 0.0029 | 0.0017** | 0.0013** | 0.0011 | 0.0008 | 0.0012** |
| | (0.0179) | (0.0328) | (0.0111) | (0.0232) | (0.0033) | (0.0006) | (0.0006) | (0.0006) | (0.0006) | (0.0006) |
| Education | 0.2633*** | 0.1185* | 0.0585*** | 0.3837*** | 0.0603*** | 0.0055*** | 0.0063*** | 0.0063*** | 0.0056*** | 0.0053*** |
| | (0.0307) | (0.0564) | (0.0192) | (0.0399) | (0.0057) | (0.0011) | (0.0012) | (0.0012) | (0.0012) | (0.0010) |
| Gross capital formation | 0.0299 | 0.1545*** | 0.0116 | 0.1076*** | 0.0210*** | 0.0012** | 0.0013** | 0.0013** | 0.0016** | 0.0008 |
| | (0.0226) | (0.0415) | (0.0141) | (0.0294) | (0.0042) | (0.0006) | (0.0005) | (0.0005) | (0.0005) | (0.0005) |
| Political stability | 1.1745*** | 1.4615*** | 0.8517*** | 1.2886** | 0.1873** | 0.9273 | 0.4699 | 1.8057*** | 0.2472 | 0.1732 |
| | (0.3047) | (0.5590) | (0.1901) | (0.3961) | (0.0568) | (0.6135) | (1.1255) | (0.3827) | (0.7975) | (0.1144) |
| Observations | 896 | 896 | 896 | 896 | 896 | 896 | 896 | 896 | 896 | 896 |

***Note**: Estimates with robust SE are in parentheses. *** p<0.001, ** p<0.01, * p<0.05. DVs;* Social Sustainability, Economic Sustainability

**Table 8: Pool Mean Group Estimations [PMG]: Dependent Variable: Sustainability across sectors**

| | **PANEL C:** ENVIRONMENTAL SUSTAINABILITY | | | | |
|---|---|---|---|---|---|
| | **Model 1** | **Model 2** | **Model 3** | **Model 4** | **Model 4** |
| Variable | Agriculture | Industry | Manufacturing | Services | tourism |
| Temperature | -0.0301** | -0.1357 | -0.1598 | -0.1424 | -0.1433 |
| | (0.0096) | (0.1259) | (0.1298) | (0.1298) | (0.1228) |
| ln_Precipitation | 0.3289** | 0.3202 | 0.2538 | 0.4192 | 0.2814** |
| | (0.1644) | (0.7672) | (0.7651) | (0.7949) | (0.1381) |
| $CO_2$ Emissions | -0.2880 | -0.2965 | -0.3512 | -0.2869*** | -0.2946 |
| | (0.2869) | (0.2841) | (0.2340) | (0.0943) | (0.2871) |
| Trade | 0.0134 | 0.0138 | 0.0145 | 0.0126 | 0.0130 |
| | (0.0120) | (0.0116) | (0.0130) | (0.0118) | (0.0120) |
| Foreign direct | -0.0099 | -0.0067 | -0.0109 | -0.0108 | -0.0084 |
| investment | (0.0193) | (0.0195) | (0.0197) | (0.0194) | (0.0196) |
| Total resource rent | 0.0825*** | 0.0783*** | 0.0869*** | 0.0760*** | 0.0813*** |
| | (0.0220) | (0.0171) | (0.0254) | (0.0164) | (0.0185) |
| Education | 0.1069* | 0.1054** | 0.1079* | 0.0984 | 0.0997** |
| | (0.0479) | (0.0446) | (0.0454) | (0.0517) | (0.0498) |
| Gross capital | 0.0457** | 0.0413** | 0.0456** | 0.0421** | 0.0495** |
| formation | (0.0170) | (0.0161) | (0.0166) | (0.0166) | (0.0182) |
| Observations | 896 | 896 | 896 | 896 | 896 |

*Estimates are robust. Stars: *** p<0.001, ** p<0.01, * p<0.05*

***3.5 Threshold Effects of Climate Change on Sustainability***

Table 9 presents the threshold estimates for economic, environmental, and social sustainability using temperature, precipitation, and $CO_2$ emissions as threshold variables. The results indicate that the sustainability effects of climate change vary across different climatic regimes.

For economic sustainability, the estimated temperature threshold is 22.29°C. Below this threshold, temperature exerts a positive and statistically significant effect, increasing economic sustainability by 0.094%. Above the threshold, the coefficient becomes negative and statistically significant, reducing economic sustainability by 0.0090%. Precipitation also exhibits threshold behaviour, with an estimated threshold of 216.21 mm. Below the threshold, precipitation increases economic sustainability by 0.0639%, whereas the coefficient becomes negative and statistically significant above the threshold, reducing economic sustainability by 0.0231%. The estimated $CO_2$ threshold is 0.1434 metric tons per capita. Below this threshold, $CO_2$ emissions exert a positive but statistically insignificant effect, while the coefficient becomes negative and statistically insignificant above the threshold.

The threshold effects are more pronounced for environmental sustainability. The estimated temperature threshold is 23.15°C. Below this level, temperature increases environmental sustainability by 0.2839%, whereas the coefficient becomes negative and statistically significant above the threshold, reducing environmental sustainability by 0.7711%. Precipitation records a threshold of 362.11 mm, below which it exerts a positive effect on environmental sustainability. Above the threshold, the coefficient becomes negative and statistically significant. Similarly, $CO_2$ emissions record a threshold of 1.9000 metric tons per capita. Below the threshold, $CO_2$ emissions increase environmental sustainability by 0.3641%, whereas above the threshold, the coefficient becomes negative, reducing environmental sustainability by 0.0467%.

For social sustainability, the estimated temperature threshold is 27.40°C. Below this threshold, temperature increases social sustainability by 0.1822%, while the coefficient becomes negative and statistically insignificant above the threshold. Precipitation records a threshold level of 1135.89 mm. Below the threshold, precipitation increases social sustainability by 0.1907%, whereas the coefficient becomes negative and statistically significant above the threshold, reducing social sustainability by 0.3677%. The estimated $CO_2$ threshold is 3.2836 metric tons per capita.

Below the threshold, $CO_2$ emissions exert a positive but statistically insignificant effect. Above the threshold, the coefficient becomes negative and statistically significant, reducing social sustainability by 0.0115%.

The threshold estimates indicate that the sustainability effects of climate variables are not constant across climatic conditions. In several cases, the direction and magnitude of the effects change once climate indicators exceed critical threshold levels.

**Table 9: Hansen Panel Threshold Models Estimation: Dependent Variable: Sustainability**

| | ECONOMIC SUSTAINABILITY | | | ENVIRONMENTAL SUSTAINABILITY | | | SOCIAL SUSTAINABILITY | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Model 1** | **Model 2** | **Model 3** | **Model 1** | **Model 2** | **Model 3** | **Model 1** | **Model 2** | **Model 3** |
| **Variable** | *Temp* | *Prec* | *$CO_2$* | *Temp* | *Prec* | *$CO_2$* | *Temp* | *Prec* | *$CO_2$* |
| Optimal threshold | 22.29/℃ | 216.21/mm | 0.1434/pc | *23.15/℃* | *362.11/mm* | *1.9/pc* | *27.40/℃* | *1135.89/mm* | *3.2836/pc* |
| *Below threshold* | 0.0940** | | | 0.2839** | | | 0.1822** | | |
| | (0.0456) | | | (0.1014) | | | (0.0931) | | |
| *Above threshold* | -0.0090** | | | -0.7711*** | | | -0.0418 | | |
| | (0.0043) | | | (0.2206) | | | (0.0852) | | |
| *Below threshold* | | 0.0639*** | | | 0.2839** | | | 0.1907*** | |
| | | (0.0215) | | | (0.1014) | | | (0.0430) | |
| *Above threshold* | | -0.0231*** | | | -0.7711*** | | | -0.3677*** | |
| | | (0.0063) | | | (0.2206) | | | (0.0503) | |
| *Below threshold* | | | 0.0964 | | | 0.3641* | | | 0.0042 |
| | | | (0.0687) | | | (0.2202) | | | (0.0148) |
| *Above threshold* | | | -0.0965 | | | -0.0467 | | | -0.0115** |
| | | | (0.7380) | | | (0.0550) | | | (0.0068) |
| Total source rent | 0.0061 | 0.0661 | -0.0630 | 0.0478*** | 0.0669** | 0.043** | 0.1755*** | 0.0625* | -0.0021 |
| | (0.0072) | (0.0663) | (0.0617) | (0.0230) | (0.0229) | (0.0230) | (0.0205) | (0.0262) | (0.0036) |
| Gross capital formation | 0.0023 | 0.0196** | 0.0023 | 0.0339** | 0.0368* | 0.0241 | 0.1941*** | 0.3275*** | 0.0020 |
| | (0.0065) | (0.0083) | (0.0515) | (0.0209) | (0.0204) | (0.0184) | (0.0406) | (0.0365) | (0.0030) |
| Foreign direct investment | 0.0034 | -0.0112 | 0.0277 | 0.0422** | 0.0422** | 0.0117 | 0.0283 | 0.0018 | 0.0027 |
| | (0.0062) | (0.0969) | (0.0566) | (0.0207) | (0.0207) | (0.0208) | (0.0225) | (0.0212) | (0.0034) |
| Education | 0.0917** | 0.2320*** | 0.0681** | 0.0229 | 0.0215 | 0.0030 | 0.6443*** | 0.8125*** | 0.0616*** |
| | (0.0312) | (0.0238) | (0.0279) | (0.1097) | (0.0911) | (0.1019) | (0.0408) | (0.0274) | (0.0160) |
| Consumer price index | 0.0007 | -0.0395*** | 0.0030 | -0.0019 | -0.0028 | -0.0013 | -0.112*** | -0.1310*** | -0.0001 |
| | (0.0129) | (0.0096) | (0.1320) | (0.0049) | (0.0040) | (0.0049) | (0.0269) | (0.0262) | (0.0008) |
| Labor force | 0.0224 | 0.0306*** | 0.0123 | 0.0673* | -0.0131 | -0.0099 | -0.058* | 0.060 (0.040) | 0.009** |
| | (0.0194) | (0.0088) | (0.0150) | (0.0398) | (0.0596) | (0.0500) | (0.030) | | (0.004) |
| Observations | 896 | 896 | 896 | 896 | 896 | 896 | 896 | 896 | 896 |

*Notes: Significance levels *** p<0.01, ** p<0.05, * p<0.10. Standard errors in parentheses.*

### *3.6 Subregional Threshold Effects of Climate Change on Sustainability*

Tables 10–12 present the subregional threshold estimates for economic, social, and environmental sustainability across East Africa, Southern Africa, Central Africa, and West Africa. The results reveal considerable heterogeneity in the threshold effects of climate variables across the subregions.

For economic sustainability, the estimated temperature thresholds range from 21.38°C in Southern Africa to 29.45°C in East Africa. Below the threshold, temperature exerts positive and statistically significant effects in East Africa and Southern Africa, increasing economic sustainability by 0.380% and 0.702%, respectively. Above the threshold, the coefficients become negative, reducing economic sustainability by 0.227% in East Africa and 0.588% in Southern Africa. Precipitation also records threshold effects across all subregions. The estimated thresholds range from 507.9 mm in Southern Africa to 2222 mm in Central Africa. Below the threshold, precipitation improves economic sustainability across the subregions, with the strongest effect observed in Southern Africa, where economic sustainability increases by 6.658%. Above the threshold, the coefficients become negative across all subregions. $CO_2$ emissions display similar nonlinear effects. Below the threshold, $CO_2$ emissions increase economic sustainability in East Africa, Southern Africa, and West Africa, with the largest effect recorded in East Africa (6.629%). Above the threshold, the coefficients become negative across all subregions.

The threshold estimates for social sustainability also reveal nonlinear climate effects. Temperature thresholds range from 24.34°C in Southern Africa to 27.14°C in West Africa. Below the threshold, temperature increases social sustainability in Southern Africa and West Africa by 0.0114% and 0.0141%, respectively. Above the threshold, the coefficients become negative across all subregions. Precipitation improves social sustainability below the threshold in all subregions, with the strongest effect recorded in Central Africa (0.0504%). However, the coefficients become negative above the threshold. Similarly, $CO_2$ emissions increase social sustainability below the threshold in East Africa and West Africa but become negative once threshold levels are exceeded.

Table 12 presents the environmental sustainability threshold estimates. The estimated $CO_2$ thresholds range from 0.2873 metric tons per capita in Southern Africa to 7.9766 metric tons per capita in West Africa. Below the threshold, $CO_2$ emissions improve environmental sustainability across all subregions, whereas the coefficients become negative above the threshold. Temperature also records strong threshold effects. Below the threshold, temperature improves environmental sustainability across the four subregions, with the largest positive effect observed in Southern Africa (1.076%). Above the threshold, the coefficients become negative, particularly in East Africa and West Africa. Precipitation exhibits a similar pattern. Positive effects are observed below the threshold across all subregions, while the coefficients become negative once threshold levels are exceeded.

The threshold estimates indicate that the sustainability effects of temperature, precipitation, and $CO_2$ emissions vary considerably across subregions. In most cases, the coefficients change direction once climate indicators exceed their estimated threshold values, highlighting the presence of important nonlinearities in the climate–sustainability relationship across Sub-Saharan Africa.

**Table 10: Hansen Panel Threshold Models Estimation: Dependent Variable: Sustainability across subregions**

| | ***ECONOMIC SUSTAINABILITY*** | | | | ***SOCIAL SUSTAINABILITY*** | | | |
|---|---|---|---|---|---|---|---|---|
| Climate Variable | *Model 1* East Africa | *Model 2* Southern Africa | *Model 3* Central Africa | *Model 4* West Africa | *Model 1* East Africa | *Model 2* Southern Africa | *Model 3* Central Africa | *Model 4* West Africa |
| *Optimal threshold Temperature* | *29.43°C* | *21.38°C* | *23.01°C* | *29.74°C* | *26.3100*℃ | *24.3400*℃ | *24.8800*℃ | *27.1400*℃ |
| Below Threshold | 0.380** | 0.702** | 0.095 | 0.439 | 0.0029 | 0.0114*** | 0.0002 | 0.0141*** |
| | (0.180) | (0.293) | (0.345) | (0.139) | (0.0028) | (0.0028) | (0.0016) | (0.0039) |
| Above Threshold | –0.227 | –0.588** | –0.053 | –0.400 | -0.0008 | -0.0006 | -0.0028** | -0.0423*** |
| | (0.179) | (0.269) | (0.135) | (0.135) | (0.0027) | (0.0023) | (0.0014) | (0.0099) |
| *Optimal Threshold Precipitation* | *1583.71mm/yr* | *507.97 mm/yr* | *2122 mm/yr* | *1877 mm/yr* | *297.50mm/yr* | *291.26Mm/yr* | *130.22Mm/yr* | *292.24Mm/yr* |
| Below Threshold | 0.401 | 6.658 | 3.055** | 6.014*** | 0.0207** | 0.0210* | 0.0504*** | 0.0239 |
| | (0.866) | (5.762) | (1.142) | (1.394) | (0.0093) | (0.0123) | (0.0185) | (0.0216) |
| Above Threshold | –0.005 | –1.240 | –2.532** | –2.803** | -0.0124 | -0.0294*** | -0.0295* | -0.0116 |
| | (0.833) | (5.293) | (1.087) | (1.017) | (0.0087) | (0.0111) | (0.0174) | (0.0204) |
| *Optimal threshold* $CO_2$ | *0.04/pc* | *6.421/pc* | *6.0918/pc* | *5.9545/pc* | *1.0905/pc* | *1.1798/pc* | *3.2857/pc* | *0.0466/pc* |
| Below Threshold | 6.629*** | 0.360*** | 1.995*** | 0.061* | 0.0464*** | 0.0003 | 0.0248*** | 2.7377*** |
| | (1.199) | (0.044) | (0.511) | (0.035) | (0.0098) | (0.0005) | (0.0041) | (0.3770) |
| Above Threshold | –0.018** | –0.007 | –0.895** | –0.101*** | -0.0039*** | -0.0002 | -0.0008*** | -0.0010*** |
| | (0.009) | (0.022) | (0.408) | (0.026) | (0.0032) | (0.0004) | (0.0001) | (0.0002) |
| Foreign direct investment | 0.079** | 0.101*** | 0.067** | 0.086*** | -0.0010*** | 0.0024*** | -0.0009* | -0.0004 |
| | (0.027) | (0.027) | (0.027) | (0.027) | (0.0002) | (0.0005) | (0.0005) | (0.0006) |
| Trade | 0.049** | -0.047** | -0.002 | -0.045** | 0.0003* | 0.0007*** | 0.0003** | 0.0006*** |
| | (0.020) | (0.020) | (0.012) | (0.021) | (0.0002) | (0.0002) | (0.0001) | (0.0002) |
| Gross capital formation | 0.020 | 0.010 | 0.001 | 0.011 | 0.0006* | 0.0004 | 0.0002 | 0.0034*** |
| | (0.022) | (0.033) | (0.021) | (0.033) | (0.0003) | (0.0003) | (0.0004) | (0.0003) |
| Consumer Price Index | -0.007*** | -0.003 | -0.004** | -0.001 | 0.0002*** | 0.0001*** | 0.0005*** | 0.0002*** |
| | (0.001) | (0.002) | (0.002) | (0.002) | (0.00001) | (0.00001) | (0.0001) | (0.00001) |
| Total resource rent | 0.129*** | 0.126*** | 0.088*** | 0.106*** | 0.0014*** | 0.0006 | 0.0011** | 0.0001 |
| | (0.028) | (0.027) | (0.026) | (0.027) | (0.0002) | (0.0004) | (0.0005) | (0.0003) |
| Education | 0.019 | 0.226*** | 0.065 | 0.201*** | 0.0099*** | 0.0031*** | 0.0017*** | 0.0038*** |
| | (0.035) | (0.054) | (0.040) | (0.055) | (0.0007) | (0.0006) | (0.0004) | (0.0004) |
| Observation | 896 | 896 | 896 | 896 | 896 | 896 | 896 | 896 |

*Notes: Significance levels *** p<0.01, ** p<0.05, * p<0.10. Standard errors in parentheses.*

**Table 11: Environmental Sustainability threshold Panel Regression Estimation**

| | ENVIRONMENTAL SUSTAINABILITY | | | |
|---|---|---|---|---|
| Variable | Model 1<br>Central Africa | Model 2<br>East Africa | Model 3<br>Southern Africa | Model 4<br>West Africa |
| *Optimal threshold: CO2 emissions* | *3.1764/pc* | *2.8027/pc* | *0.2873/pc* | *7.9766/pc* |
| Below threshold | 1.566*** | 1.636*** | 10.290** | 0.070* |
| | (0.359) | (0.313) | (3.903) | (0.036) |
| Above threshold | -0.741** | -0.021** | -0.032** | -0.043*** |
| | (0.229) | (0.009) | (0.013) | (0.012) |
| *Optimal threshold: Temperature* | *20.43*℃ | *18.03*℃ | *22.48*℃ | *20.57*℃ |
| Below threshold | 0.202 | 0.064 | 1.076*** | 0.119** |
| | (0.245) | (0.181) | (0.364) | (0.058) |
| Above threshold | -0.085 | -0.221 | -0.925*** | -0.176*** |
| | (0.223) | (0.171) | (0.336) | (0.080) |
| Optimal threshold: Precipitation | 299.85/mm | 215.05/mm | 275.11/mm | *990.3/mm* |
| Below threshold | 0.590 | 0.576 | 0.322 | 3.515*** |
| | (0.577) | (1.089) | (2.744) | (1.150) |
| Above threshold | -0.044 | -0.579 | -1.020 | -0.947*** |
| | (0.544) | (0.910) | (2.537) | (0.356) |
| Foreign direct investment | -0.022 | 0.014 | -0.284*** | 0.040*** |
| | (0.014) | (0.028) | (0.088) | (0.013) |
| Trade | 0.023** | -0.005 | 0.029 * | 0.018*** |
| | (0.011) | (0.008) | (0.017) | (0.005) |
| Gross capital formation | 0.032* | 0.055*** | 0.031 | 0.033*** |
| | (0.020) | (0.017) | (0.061) | (0.010) |
| Consumer price index | -0.008*** | -0.007*** | -0.010 | -0.003*** |
| | (0.003) | (0.001) | (0.012) | (0.001) |
| Total resource rent | 0.055*** | 0.016 | 0.070 | 0.023* |
| | (0.015) | (0.015) | (0.082) | (0.012) |
| Education | 0.183*** | 0.091*** | 0.218*** | 0.041** |
| | (0.045) | (0.023) | (0.060) | (0.018) |
| Observation | 896 | 896 | 896 | 896 |

*Notes: Significance levels *** p<0.01, ** p<0.05, * p<0.10. Standard errors in parentheses.*

***3.7 Effects of Urbanisation on Sustainability***

Table 12 presents the comparative estimates from the Common Correlated Effects Mean Group (CCEMG), Driscoll–Kraay fixed effects, and pooled Common Correlated Effects (CCEP) estimators for the relationship between urbanisation and sustainability in Sub-Saharan Africa. The estimates account for cross-sectional dependence, slope heterogeneity, and unobserved common factors across countries. The findings remain broadly consistent across the three estimators, although the magnitude and statistical significance of the coefficients differ across sustainability dimensions.

Urbanisation exerts a positive and statistically significant effect on economic sustainability across all estimation techniques. A one-unit increase in urbanisation improves economic sustainability by 0.464% under the CCEMG estimator, 0.360% under the Driscoll–Kraay estimator, and 0.890% under the pooled CCEP estimator.

The relationship between urbanisation and social sustainability is generally positive but less consistent across estimators. Under the Driscoll–Kraay estimator, a one-unit increase in urbanisation increases social sustainability by 0.0011%, while the positive coefficients obtained from the CCEMG and pooled CCEP estimators remain statistically insignificant.

Urbanisation records negative and statistically significant effects on environmental sustainability across all estimation approaches. A one-unit increase in urbanisation reduces environmental sustainability by 0.0738% under the CCEMG estimator, 0.7488% under the Driscoll–Kraay estimator, and 5.0272% under the pooled CCEP estimator.

The results indicate that urbanisation is associated with stronger economic sustainability outcomes, provides limited support for social sustainability, and contributes negatively to environmental sustainability across Sub-Saharan Africa.

**Table 12: CCEMG, Driscoll-Kraay, and Pooled CCEP Estimations: Dependent Variable: Sustainability**.

| | ***Social Sustainability*** | | | ***Economic Sustainability*** | | | ***Environmental Sustainability*** | | |
|---|---|---|---|---|---|---|---|---|---|
| Variable | Model 1 CCEMG | Model 2 Driscoll-Kraay FE | Model 3 CCEP | Model 1 CCEMG | Model 2 Driscoll-Kraay FE | Model 3 CCEP | Model 1 CCEMG | Model 2 Driscoll-Kraay FE | Model 3 CCEP |
| Urbanisation | 0.0008 | 0.0011** | 0.0020 | 0.464** | 0.360** | 0.890*** | -0.0738** | -0.7488* | -5.0272** |
| | (0.0007) | (0.0006) | (0.0019) | (0.182) | (0.174) | (0.126) | (0.0354) | (0.4403) | (2.4627) |
| Total resource rent | 0.0007 | 0.0005* | 0.0005 | 0.024 | 0.030*** | 0.070*** | 0.1783 | -0.0476*** | 0.0143 |
| | (0.0005) | (0.0003) | (0.0005) | (0.017) | (0.011) | (0.008) | (0.2138) | (0.0156) | (0.0184) |
| Foreign direct investment | 0.001*** | 0.0006* | 0.0007** | 0.066** | 0.068** | -0.040 | 0.0613 | 0.0322 | 0.0075 |
| | (0.0002) | (0.0003) | (0.0002) | (0.023) | (0.028) | (0.025) | (0.0511) | (0.0196) | (0.0223) |
| Consumer price index | -0.0001 | -0.0001*** | -0.0001 | -0.002 | -0.001 | -0.002 | -0.2422 | 0.0010 | 0.0003 |
| | (0.0002) | (0.0001) | (0.0001) | (0.002) | (0.001) | (0.002) | (0.1676) | (0.0017) | (0.0024) |
| Gross capital formation | 0.0001 | 0.0008*** | 0.00001 | 0.028 | 0.019 | 0.0005 | 0.0848 | 0.0356*** | 0.0177 |
| | (0.0001) | (0.0003) | (0.0008) | (0.020) | (0.018) | (0.018) | (0.0634) | (0.0078) | (0.0493) |
| Education | 0.005** | 0.0058*** | 0.0069*** | 0.091** | 0.054*** | 0.027 | 0.0514 | 0.0708** | 0.1611** |
| | (0.002) | (0.0007) | (0.0019) | (0.034) | (0.014) | (0.028) | (0.3069) | (0.0361) | (0.0856) |
| Trade | 0.0001 | 0.0004*** | 0.0011*** | -0.015 | -0.014 | 0.018*** | 0.0283 | 0.0149** | 0.0260 |
| | (0.0001) | (0.0001) | (0.0003) | (0.010) | (0.012) | (0.005) | (0.0335) | (0.0070) | (0.0216) |
| Government Effectiveness | 0.012** | 0.0133 | 0.0528** | 0.119*** | 0.108*** | 0.005 | 0.5121 | 0.0298 | 0.1639* |
| | (0.005) | (0.0091) | (0.0205) | (0.040) | (0.021) | (0.029) | (0.4374) | (0.0182) | (0.0922) |
| Observations | 896 | 896 | 896 | 896 | 896 | 896 | 896 | 896 | 896 |
| R-squared | 0.4322 | 0.1112 | 0.2866 | 0.095 | 0.063, | 0.227 | 0.000 | 0.001 | 0.003 |

*NOTE: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$. Standard errors are shown in parentheses directly under the coefficients: DVs: Social Sustainability, Economic Sustainability, and Environmental Sustainability*

### *3.8 Effects of Urbanisation on Sustainability across Subregions*

The Driscoll–Kraay estimates reveal considerable variation in the relationship between urbanisation and sustainability across Central Africa, East Africa, Southern Africa, and West Africa. Tables 13 and 14 present the subregional estimates for social, environmental, and economic sustainability.

Urbanisation records positive and statistically significant effects on social sustainability in East Africa and Southern Africa. A one-unit increase in urbanisation improves social sustainability by 0.0005% in East Africa and 0.0022% in Southern Africa. In contrast, the coefficients remain statistically insignificant in Central Africa and West Africa.

The effects of urbanisation on environmental sustainability differ across the subregions. Urbanisation exerts a positive and statistically significant effect in East Africa, where a one-unit increase in urbanisation improves environmental sustainability by 0.3045%. By contrast, urbanisation reduces environmental sustainability by 0.3558% in Southern Africa. The coefficients for Central Africa and West Africa remain statistically insignificant.

The estimates for economic sustainability also vary across the subregions. As reported in Table 14, urbanisation records a positive and statistically significant effect in Central Africa. A one-unit increase in urbanisation improves economic sustainability by 0.909%. The coefficients remain statistically insignificant in West Africa and Southern Africa, while the coefficient for East Africa is negative but statistically insignificant.

The findings indicate that the sustainability effects of urbanisation differ across Sub-Saharan African subregions. Positive effects are observed in some regions and sustainability dimensions, whereas the coefficients remain weak or statistically insignificant in others.

**Table 13: Driscoll–Kraay Estimation: Dependent Variable: Sustainability across subregions**

| | Social Sustainability | | | | Environmental Sustainability | | | |
|---|---|---|---|---|---|---|---|---|
| Variable | Model 1 Central Africa | Model 2 East Africa | Model 3 Southern Africa | Model 4 West Africa | Model 1 Central Africa | Model 2 East Africa | Model 3 Southern Africa | Model 4 West Africa |
| Urbanisation | 0.0001 | 0.0005** | 0.0022** | 0.0003 | -0.0585 (0.0879) | 0.3045*** | -0.3558** | 0.0077 |
| | (0.0005) | (0.0002) | (0.0009) | (0.0006) | | (0.0741) | (0.1463) | (0.0359) |
| Total resource rent | 0.0003* | 0.0009*** | 0.0008* | 0.0002 | 0.0580** | 0.0404 | 0.3348*** | 0.0272 |
| | (0.0002) | (0.0002) | (0.0005) | (0.0003) | (0.0256) | (0.0283) | (0.1125) | (0.0236) |
| Foreign direct investment | 0.0001 | -0.0003 | 0.0001 | 0.0001 | 0.0153 (0.0215) | 0.0450 | -0.2032*** | 0.0461* |
| | (0.0002) | (0.0002) | (0.0002) | (0.0002) | | (0.0431) | (0.0508) | (0.0277) |
| Consumer price index | -0.0008*** | -0.0001 | -0.0002*** | -0.0001 | 0.0058 (0.0123) | 0.0093*** | -0.0290** | -0.0032*** |
| | (0.0002) | (0.0001) | (0.0001) | (0.0002) | | (0.0033) | (0.0147) | (0.0010) |
| Gross capital formation | 0.0001 | 0.0002* | 0.0009*** | 0.0002* | -0.0804*** | -0.0484 | 0.1643*** | -0.0302** |
| | (0.0003) | (0.0001) | (0.0001) | (0.0001) | (0.0162) | (0.0335) | (0.0531) | (0.0153) |
| Education | 0.0041*** | 0.0003 | 0.0005 | 0.0004 | 0.0124 (0.0747) | -0.0358 | 0.1909** (0.0820) | 0.0179 |
| | (0.0009) | (0.0003) | (0.0004) | (0.0003) | | (0.0718) | | (0.0462) |
| Trade | 0.0001 | -0.0002 | 0.0003*** | -0.0001 | 0.0324*** | 0.0149 | 0.0105 | 0.0207** |
| | (0.0001) | (0.0001) | (0.0001) | (0.0001) | (0.0106) | (0.0157) | (0.0140) | (0.0101) |
| Government effectiveness | 0.0086* | 0.0723*** | 0.0094** | 0.0140* | -0.3075 (0.5284) | 1.6883*** | 2.2592** (1.1033) | -0.0992 |
| | (0.0047) | (0.0092) | (0.0044) | (0.0076) | | (0.3915) | | (0.4717) |
| N (Observations) | 118.0000 | 180.0000 | 91.0000 | 242.0000 | 216 | 216 | 216 | 216 |
| $R^2$ (Within) | 0.7635 | 0.7353 | 0.7387 | 0.6111 | 0.6583 | 0.3882 | 0.5482 | 0.2021 |

*Note: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$.; Standard errors are shown in parentheses directly under coefficients*

**Table 14: Driscoll–Kraay estimation: Sustainability across subregions**

| | *Economic Sustainability* | | | |
|---|---|---|---|---|
| | Model 1 | Model 2 | Model 3 | Model 4 |
| Variables | Central Africa | West Africa | Southern Africa | East Africa |
| Urbanisation | 0.909** | 1.026 | 1.297 | -0.084 |
| | (0.445) | (0.783) | (1.208) | (0.112) |
| Total resource rent | 0.076 ** | 0.178*** | 0.337 | 0.0140 |
| | (0.036) | (0.061) | (0.226) | (0.011) |
| Foreign direct investment | 0.041 | 0.128 | -0.008 | -0.0280 |
| | (0.034) | (0.102) | (0.227) | (0.024) |
| Consumer price index | -0.043 | -0.038 | -0.041 | 0.0120 |
| | (0.023) | (0.026) | (0.051) | (0.008) |
| Gross capital formation | 0.002 | 0.002 | -0.062 ** | 0.0001 |
| | (0.006) | (0.004) | (0.027) | (0.001) |
| Trade | 0.027 | 0.019 | -0.017 | 0.035*** |
| | (0.031) | (0.033) | (0.050) | (0.013) |
| Government effectiveness | 1.415 *** | 1.671 ** | 0.502 ** | 0.0200 |
| | (0.501) | (0.782) | (0.232) | (0.036) |
| Education | 0.077 | 0.304 *** | 0.013 | 0.033 ** |
| | (0.106) | (0.099) | (0.140) | (0.017) |
| Observation | 216 | 216 | 216 | 216 |

*Note: *** p < 0.01; ** p < 0.05; * p < 0.10.; Standard errors are shown in parentheses directly under the coefficient.*

### *3.9 Effects of Urbanisation on Sustainability across Sectors*

The pooled Common Correlated Effects (CCEP) estimates reveal considerable variation in the sustainability effects of urbanisation across the agriculture, industry, manufacturing, services, and tourism sectors. Tables 15 and 16 present the sectoral estimates for economic, social, and environmental sustainability.

Urbanisation records mixed effects on economic sustainability across the sectors. A one-unit increase in urbanisation reduces economic sustainability by 0.285% in agriculture, although the coefficient remains statistically insignificant. In contrast, urbanisation improves economic sustainability by 0.577% in industry, 0.264% in manufacturing, 1.161% in services, and 0.092% in tourism. The largest positive coefficient is observed in the services sector.

The effects of urbanisation on social sustainability are positive and statistically significant across all sectors. A one-unit increase in urbanisation increases social sustainability by between 0.0022% and 0.0025%, with the largest effect recorded in industry. The coefficients remain positive across agriculture, manufacturing, services, and tourism.

Table 16 reports the estimates for environmental sustainability. Urbanisation exerts negative and statistically significant effects across all sectoral models. A one-unit increase in urbanisation reduces environmental sustainability by between 0.3968% and 0.4534%. The largest negative effect is observed in manufacturing, followed by services, tourism, agriculture, and industry.

The findings indicate that the sustainability effects of urbanisation differ across sectors. Urbanisation is associated with stronger economic sustainability in industry, manufacturing, services, and tourism, contributes positively to social sustainability across all sectors, and reduces environmental sustainability throughout the sectoral models.

**Table 15: Pooled CCEP regression results: Sustainability across Sectors**

| | *ECONOMIC SUSTAINABILITY* | | | | | *SOCIAL SUSTAINABILITY* | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Model 1** | **Model 2** | **Model 3** | **Model 4** | **Model 5** | **Model 1** | **Model 2** | **Model 3** | **Model 4** | **Model 5** |
| *Variable* | *Agriculture* | *Industry* | *Manufacturing* | *Services* | *Tourism* | *Agriculture* | *Industry* | *Manufacture* | *Services* | *Tourism* |
| Urbanisation | -0.285 | 0.577*** | 0.264** (0.121) | 1.161*** | 0.092** | 0.0022* | 0.0025* | 0.0023** | 0.0023* | 0.0022* |
| | (0.212) | (0.212) | | (0.211) | (0.037) | (0.0013) | (0.0013) | (0.0010) | (0.0013) | (0.0012) |
| Total resource rent | 0.168*** | 0.019 | 0.022** | 0.001 | 0.009*** | 0.0005*** | 0.0001 | 0.0002** | 0.0001 | 0.0003 |
| | (0.014) | (0.014) | (0.008) | (0.014) | (0.002) | (0.0002) | (0.0005) | (0.0001) | (0.0003) | (0.0004) |
| Foreign direct investment | 0.043 | 0.091*** | 0.130*** | 0.243*** | 0.011** | -0.0007*** | -0.0008** | -0.0005*** | -0.0004*** | -0.0006** |
| | (0.031) | (0.030) | (0.017) | (0.030) | (0.005) | (0.0002) | (0.0003) | (0.0001) | (0.0001) | (0.0003) |
| Trade | -0.167*** | -0.041*** | 0.022*** | 0.011 | -0.017*** | -0.0006 | -0.0005 | -0.0008 | -0.0002 | -0.0001 |
| | (0.008) | (0.008) | (0.005) | (0.008) | (0.001) | (0.0051) | (0.0081) | (0.0091) | (0.0341) | (0.0061) |
| Gross capital formation | 0.012 | -0.123*** | 0.106*** | 0.164*** | -0.038*** | 0.0368*** | 0.0369*** | 0.0376*** | 0.0356*** | 0.0370*** |
| | (0.030) | (0.030) | (0.017) | (0.030) | (0.005) | (0.0036) | (0.0035) | (0.0035) | (0.0033) | (0.0039) |
| Government effectiveness | 0.861 | 2.266** | 1.603*** | 3.310*** | 0.865*** | 0.519*** | 0.119*** | 0.015 | 0.104** | 0.053*** |
| | (0.935) | (0.931) | (0.531) | (0.930) | (0.163) | (0.045) | (0.045) | (0.026) | (0.045) | (0.008) |
| Observation | 896 | 896 | 896 | 896 | 896 | 896 | 896 | 896 | 896 | 896 |

*Note: *** p < 0.01; ** p < 0.05; * p < 0.10. Standard errors are shown in parentheses directly under the coefficient.*

**Table 16: Pooled CCEP regression results: Sustainability across subregions**

| | ENVIRONMENTAL SUSTAINABILITY | | | | |
|---|---|---|---|---|---|
| Variable | Agriculture | Industry | Manufacturing | Services | Tourism |
| Urbanisation | -0.4349*** | -0.3968*** | -0.4534*** | -0.4257*** | -0.4441*** |
| | (0.1322) | (0.1327) | (0.1372) | (0.1421) | (0.1418) |
| Total resource rent | 0.0337*** | 0.0382*** | 0.0460*** | 0.0346*** | 0.0364*** |
| | (0.0115) | (0.0115) | (0.0143) | (0.0116) | (0.0118) |
| Foreign direct investment | -0.0022 | 0.0023 | -0.0018 | -0.0010 | -0.0012 |
| | (0.0115) | (0.0112) | (0.0114) | (0.0110) | (0.0115) |
| Trade | -0.0066 | -0.0050 | -0.0059 | -0.0057 | -0.0060 |
| | (0.0055) | (0.0051) | (0.0056) | (0.0052) | (0.0055) |
| Government effectiveness | 1.3736*** | 1.3450*** | 1.5186*** | 1.4907*** | 1.4169*** |
| | (0.1702) | (0.1704) | (0.1858) | (0.1667) | (0.1719) |
| Observation | 896 | 896 | 896 | 896 | 896 |
| $R^2$ (within) | 0.1191 | 0.1236 | 0.1173 | 0.1120 | 0.1089 |

**** p < 0.01; ** p < 0.05; * p < 0.10. Standard errors are shown in parentheses directly under the coefficient.*

**3.10 Panel Threshold Effects of Urbanisation on Sustainability**

Table 17 presents the panel threshold estimates for the relationship between urbanisation and sustainability in Sub-Saharan Africa. The results indicate that the effects of urbanisation vary across different levels of urban development. The estimated threshold values are 33.0869% for economic sustainability, 34.9860% for social sustainability, and 38.97% for environmental sustainability.

Urbanisation records a positive and statistically significant effect on economic sustainability below the threshold level. A one-unit increase in urbanisation improves economic sustainability by 0.628% when urbanisation remains below 33.0869%. Above the threshold, the coefficient becomes negative and statistically significant, reducing economic sustainability by 0.588%.

A similar pattern is observed for social sustainability. Below the threshold level of 34.9860%, a one-unit increase in urbanisation increases social sustainability by 0.0044%. However, the coefficient becomes negative and statistically significant above the threshold, reducing social sustainability by 0.004%.

The results for environmental sustainability indicate weaker threshold effects. Below the threshold level of 38.97%, urbanisation exerts a positive but statistically insignificant effect on environmental sustainability. Above the threshold, the coefficient becomes negative, although it remains statistically insignificant.

The threshold estimates suggest that the sustainability effects of urbanisation are not constant across different stages of urban development. Positive effects are generally observed below the estimated threshold levels, whereas the coefficients become weaker or negative once urbanisation exceeds the identified thresholds.

**Table 17: Panel Threshold Regression Estimation**

| Variable | Economic Sustainability | Social Sustainability | Environmental Sustainability |
|---|---|---|---|
| **Optimal Threshold (%)** | **33.0869** | **34.9860** | **38.97** |
| Urbanisation (below threshold) | 0.628*** | 0.0044*** | 0.0516 |
| | (0.200) | (0.0010) | (0.0328) |
| Urbanisation (above threshold) | -0.588*** | -0.004*** | -0.0310 |
| | (0.194) | (0.0009) | (0.0305) |
| Total resource rent | 0.034** | 0.0005** | 0.0486*** |
| | (0.017) | (0.0002) | (0.0103) |
| Foreign direct investment | 0.069*** | 0.0007*** | 0.0325** |
| | (0.022) | (0.0003) | (0.0132) |
| Consumer price index | -0.001 | -0.0001*** | -0.0012 |
| | (0.002) | (0.00001) | (0.0009) |
| Gross capital formation | 0.016 | 0.0007*** | 0.0365*** |
| | (0.018) | (0.0002) | (0.0104) |
| Education | 0.059** | 0.0057*** | 0.0693*** |
| | (0.026) | (0.0003) | (0.0163) |
| Trade | -0.017* | 0.0004*** | 0.0156*** |
| | (0.010) | (0.0001) | (0.00507) |
| Government effectiveness | 0.026*** | 0.0167*** | 1.3326*** |
| | (0.009) | (0.0055) | (0.2850) |
| Observations | 896 | 896 | 896 |
| R-squared | 0.4966 | 0.4775 | 0.4195 |

**** p < 0.01; ** p < 0.05; * p < 0.10. Standard errors are shown in parentheses directly under the coefficient.*

***3.11 Subregional Panel Threshold Effects of Urbanisation on Sustainability***

The threshold estimates reveal substantial variation in the sustainability effects of urbanisation across Central Africa, East Africa, Southern Africa, and West Africa. Tables 18 and 19 present the subregional threshold estimates for economic, social, and environmental sustainability.

For economic sustainability, the estimated urbanisation thresholds range from 24% in Southern Africa to 30% in West Africa. Below the threshold, urbanisation exerts positive effects across all subregions. The strongest positive effect is observed in East Africa, where a one-unit increase in urbanisation improves economic sustainability by 1.179%. Above the threshold, the coefficients become negative across all subregions, particularly in Central Africa and East Africa, where economic sustainability declines by 1.137% and 0.242%, respectively.

Urbanisation also records threshold effects on social sustainability across the subregions. The estimated threshold values range from 29.21% in Southern Africa to 39.25% in Central Africa. Below the threshold, urbanisation improves social sustainability in East Africa by 0.0073%, while the coefficients remain relatively small in the other subregions. Above the threshold, the coefficients become negative and statistically significant in Central Africa, East Africa, and Southern Africa. The largest negative effect is recorded in East Africa, where social sustainability declines by 0.0059% once urbanisation exceeds the threshold level.

Table 19 reports the threshold estimates for environmental sustainability. The estimated urbanisation thresholds range from 29.97% in East Africa to 39.40% in Central Africa. Below the threshold, urbanisation improves environmental sustainability in Southern Africa and West Africa by 0.8233% and 0.0843%, respectively. Above the threshold, the coefficients become negative across all subregions. The largest negative effect is observed in Southern Africa, where environmental sustainability declines by 0.6940%.

The threshold estimates indicate that the sustainability effects of urbanisation differ across Sub-Saharan African subregions. In most cases, urbanisation contributes positively to sustainability below the estimated threshold levels, while the coefficients become weaker or negative once urbanisation exceeds the identified thresholds.

**Table 18: Panel threshold regression: Dependent variable: Sustainability**

| | Economic Sustainability | | | | Social Sustainability | | | |
|---|---|---|---|---|---|---|---|---|
| | **Model 1** | **Model 2** | **Model 3** | **Model 4** | **Model 1** | **Model 2** | **Model 3** | **Model 4** |
| *Variable* | *Central Africa* | *East Africa* | *Southern Africa* | *West Africa* | *Central Africa* | *East Africa* | *Southern Africa* | *West Africa* |
| Urban _low | 0.469* | 1.179* | 0.737 | 0.230** | 0.0038*** | 0.0073*** | 0.0058*** | 0.0009 |
| | (0.254) | (0.667) | (0.679) | (0.110) | (0.0009) | (0.0020) | (0.0010) | (0.0013) |
| Urban_high | -1.137** | -0.242*** | -0.004 | -0.001 | -0.0030*** | -0.0059*** | -0.0047*** | -0.0006 |
| | (0.561) | (0.051) | (0.120) | (0.029) | (0.0008) | (0.0017) | (0.0009) | (0.0011) |
| Total resource rent | 0.440*** | 0.047 | 0.143 | 0.074 | 0.0003 | 0.0019*** | 0.0001 | 0.0014*** |
| | (0.061) | (0.080) | (0.086) | (0.065) | (0.0003) | (0.0002) | (0.0006) | (0.0004) |
| Foreign direct investment | 0.233*** | -0.120 | -0.105 | 0.074 | 0.0005* | 0.0003 | 0.0008** | 0.0020*** |
| | (0.057) | (0.145) | (0.073) | (0.088) | (0.0003) | (0.0005) | (0.0004) | (0.0004) |
| Consumer price index | -0.080** | -0.001 | -0.008 | -0.006** | -0.0005*** | -0.0002 | -0.0004*** | -0.0001 |
| | (0.034) | (0.003) | (0.010) | (0.003) | (0.0001) | (0.0001) | (0.0001) | (0.0001) |
| Gross capital formation | 0.058 | 0.084 | 0.130 | 0.062 | 0.0001 | 0.0012*** | 0.0005* | 0.0001 |
| | (0.060) | (0.058) | (0.089) | (0.039) | (0.0003) | (0.0004) | (0.0003) | (0.0003) |
| Trade | 0.140** | 0.472*** | 0.086 ** | 0.203*** | -0.0001 | 0.0006*** | 0.0006*** | 0.0007*** |
| | (0.060) | (0.063) | (0.033) | (0.022) | (0.0001) | (0.0002) | (0.0001) | (0.0002) |
| Education | 0.198 | 0.084 | 0.053 | 0.029 | 0.0083*** | 0.0030*** | 0.0023*** | 0.0064*** |
| | (0.277) | (0.181) | (0.079) | (0.085) | (0.0005) | (0.0004) | (0.0003) | (0.0006) |
| Government effectiveness | 0.294* | 0.275** | 0.236 | 0.081 | 0.0131* | 0.0805*** | 0.0037 | 0.0115 |
| | (0.177) | (0.138) | (0.201) | (0.132) | (0.0078) | (0.0083) | (0.0091) | (0.0099) |
| *Observation* | 202 | 230 | 174 | 258 | 216 | 216 | 216 | 216 |
| ***Optimal Thresholds*** | ***29%*** | ***27%*** | ***24%*** | ***30%*** | ***39.2453*** | ***33.5648*** | ***29.2077*** | ***31.0536*** |
| *R-Square* | 0.675 | 0.460, | 0.316 | 0.446 | 0.8984 | 0.7795 | 0.9366 | 0.5575 |

**Note***: Standard errors are in parentheses. $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Estimates account for regional thresholds in urbanisation across SSA.*

**Table 19: Panel threshold Estimation: Dependent variable: Sustainability**

| | Environmental Sustainability | | | |
|---|---|---|---|---|
| | **Model 1** | **Model 2** | **Model 3** | **Model 4** |
| Variable | Central Africa | East Africa | Southern Africa | West Africa |
| Urban-low | 0.1097* | 0.0750 | 0.8233*** | 0.0843** |
| | (0.0600) | (0.0500) | (0.2633) | (0.0450) |
| Urban-high | -0.0385 | -0.0110 | -0.6940*** | -0.0592 |
| | (0.0500) | (0.0400) | (0.2334) | (0.0380) |
| Total resource rent | 0.0027 | 0.0368*** | 0.1484 | 0.0314 |
| | (0.0210) | (0.0180) | (0.1280) | (0.0200) |
| Foreign direct investment | 0.0375 | 0.0255 | 0.3177*** | 0.0412 |
| | (0.0260) | (0.0220) | (0.0990) | (0.0300) |
| Consumer price index | -0.0013 | -0.0059 | -0.0130 | -0.0026 |
| | (0.0060) | (0.0050) | (0.0120) | (0.0060) |
| Gross capital formation | 0.0086 | 0.0746*** | 0.1132** | 0.0287 |
| | (0.0200) | (0.0150) | (0.0620) | (0.0190) |
| Education | 0.3252*** | 0.1331*** | 0.2535*** | 0.0021 |
| | (0.0400) | (0.0380) | (0.0620) | (0.0370) |
| Trade | -0.0269*** | 0.0126 | 0.0680*** | 0.0154 |
| | (0.0100) | (0.0090) | (0.0207) | (0.0100) |
| Government effectiveness | 2.0663*** | 2.1192*** | 2.7802** | 0.1468 |
| | (0.6200) | (0.5400) | (1.6230) | (0.5800) |
| ***Optimal Threshold*** | ***39.3954*** | ***29.9665*** | ***30.0736*** | ***35.7357*** |
| $R^2$ | 0.6827 | 0.2508 | 0.4563 | 0.2003 |
| Observation | 216 | 216 | 216 | 216 |

**** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$. Threshold variable: Urbanisation; Dependent variable: EPI. Standard errors are shown in parentheses*

***3.12 Effects of Persistent Drought Conditions on Sustainability***

The quantile regression estimates reveal considerable variation in the effects of persistent drought conditions across the sustainability distribution in Sub-Saharan Africa. Tables 20 and 21 present the quantile estimates for economic, social, and environmental sustainability using the Palmer Drought Severity Index (PDSI) as the measure of drought conditions.

For economic sustainability, PDSI records negative coefficients across all quantiles. The coefficients remain statistically insignificant at the lower and middle quantiles but become negative and statistically significant at the upper quantile (Q0.90). A one-unit increase in drought severity reduces economic sustainability by 0.156% at Q0.90.

The effects of drought conditions on social sustainability are negative and statistically significant across the entire distribution. A one-unit increase in drought severity reduces social sustainability by 0.014% at Q0.25, 0.012% at Q0.50, 0.010% at Q0.75, and 0.009% at Q0.90. The magnitude of the coefficients declines across the higher quantiles, although the negative effect remains statistically significant throughout.

Table 21 presents the quantile estimates for environmental sustainability. The coefficient is negative but statistically insignificant at the lower quantile (Q0.10). At the median quantile (Q0.50), the coefficient becomes positive and statistically significant, indicating that a one-unit improvement in PDSI increases environmental sustainability by 0.321%. The coefficients remain positive at the upper quantiles, although they are statistically insignificant.

The quantile estimates indicate that the sustainability effects of persistent drought conditions vary across the conditional distribution of sustainability outcomes. The negative effects are most pronounced for social sustainability, while the effects on economic and environmental sustainability differ across quantiles.

**Table 20: Quantile Regression Estimation: Dependent Variable: Sustainability**

| | Economic Sustainability | | | | | Social Sustainability | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | ***Model 1*** | ***Model 2*** | ***Model 3*** | ***Model 4*** | ***Model 5*** | ***Model 1*** | ***Model 2*** | ***Model 3*** | ***Model 4*** | ***Model 5*** |
| **Quantiles** | **Q0.10** | **Q0.25** | **Q0.50** | **Q0.75** | **Q0.90** | **Q0.10** | **Q0.25** | **Q0.50** | **Q0.75** | **Q0.90** |
| Palmer drought severity index | -0.183<br>(0.323) | -0.255*<br>(0.138) | -0.074<br>(0.057) | -0.039<br>(0.058) | -0.156**<br>(0.074) | -0.012***<br>(0.003) | -0.014***<br>(0.003) | -0.013**<br>(0.005) | -0.010***<br>(0.003) | -0.009*<br>(0.005) |
| Foreign direct investment | -0.0640<br>(0.110) | 0.005<br>(0.036) | -0.013<br>(0.013) | -0.012*<br>(0.007) | -0.029**<br>(0.013) | -0.002<br>(0.002) | -0.002<br>(0.002) | -0.001<br>(0.002) | -0.003<br>(0.002) | -0.003*<br>(0.002) |
| Total resource rent | 0.070**<br>(0.021) | 0.008<br>(0.038) | 0.016**<br>(0.006) | 0.011**<br>(0.005) | 0.020**<br>(0.006) | 0.002***<br>(0.001) | 0.001**<br>(0.001) | -0.001<br>(0.001) | -0.004***<br>(0.001) | -0.004***<br>(0.001) |
| Consumer price index | -0.003<br>(0.004) | -0.001<br>(0.004) | -0.000<br>(0.002) | -0.0001<br>(0.001) | -0.001**<br>(0.0001) | -6.46E-05**<br>(9.09E-n 05) | 0.0002<br>(0.0001) | -5.43E-05<br>(0.0001) | 3.02E-05<br>(0.001) | -1.06E-06<br>(9.04E-05) |
| Gross capital formation | 0.014<br>(0.060) | 0.025<br>(0.025) | 0.015*<br>(0.008) | 0.011<br>(0.007) | 0.005<br>(0.006) | 0.002***<br>(0.0002) | 0.004***<br>(0.0003) | 0.003***<br>(0.001) | 0.003***<br>(0.0003) | 0.002<br>(0.001) |
| Agriculture | 0.066*<br>(0.037) | 0.027<br>(0.025) | 0.019**<br>(0.008) | 0.009<br>(0.009) | 0.002<br>(0.010) | -0.0003<br>(0.0005) | -0.0001<br>(0.0002) | -0.0001<br>(0.001) | -0.004<br>(0.006) | -0.0002<br>(0.004) |
| Education | 0.076**<br>(0.033) | 0.065**<br>(0.034) | 0.016**<br>(0.007) | 0.012**<br>(0.005) | 0.015**<br>(0.006) | 0.008***<br>(0.002) | 0.009***<br>(0.001) | 0.009***<br>(0.001) | 0.008***<br>(0.001) | 0.009***<br>(0.001) |

*Note: Standard errors are reported in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. The estimates report the effects of persistent drought conditions on sustainability.*

**Table 21: Quantile Regression**

| | Environmental Sustainability | | | | |
|---|---|---|---|---|---|
| | ***Model 1*** | ***Model 2*** | ***Model 3*** | ***Model 4*** | ***Model 5*** |
| Variables | **Q0.10** | **Q0.25** | **Q0.50** | **Q0.75** | **Q0.90** |
| Palmer severity index | -0.025 | 0.379** | 0.321** | 0.149 | 0.249 |
| | (0.214) | (0.205) | (0.179) | (0.194) | (0.157) |
| Foreign direct | -0.198 | -0.217** | -0.234*** | -0.247*** | -0.274*** |
| investment | (0.125) | (0.103) | (0.085) | (0.090) | (0.079) |
| Total resource rent | 0.174** | 0.264*** | 0.211*** | 0.201*** | 0.132*** |
| | (0.087) | (0.047) | (0.030) | (0.039) | (0.046) |
| Consumer price index | -0.015*** | -0.031*** | -0.030*** | -0.023*** | -0.027*** |
| | (0.006) | (0.007) | (0.006) | (0.006) | (0.004) |
| Gross capital formation | 0.215*** | 0.128** | 0.047 | 0.013 | 0.101** |
| | (0.060) | (0.061) | (0.047) | (0.057) | (0.049) |
| Agriculture | 0.075*** | 0.053*** | 0.017 | 0.013 | 0.019 |
| | (0.025) | (0.019) | (0.019) | (0.019) | (0.032) |
| Education | 0.219*** | 0.345*** | 0.378*** | 0.334*** | 0.339*** |
| | (0.064) | (0.055) | (0.042) | (0.044) | (0.051) |

*NOTE: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$. Coefficients are reported with bootstrapped standard errors in parentheses. Each column corresponds to a conditional quantile ($\tau$) of EPI estimated using quantile regression.*

***3.13 Effects of Persistent Drought Conditions on Sustainability across Subregions***

The quantile regression estimates reveal considerable variation in the sustainability effects of persistent drought conditions across the Sub-Saharan African subregions. Tables 22 and 23 present the quantile estimates for social, environmental, and economic sustainability across Central Africa, East Africa, Southern Africa, and West Africa.

For social sustainability, the estimates are predominantly negative across the subregions. In Central Africa, a one-unit increase in drought severity reduces social sustainability by 0.023% at Q0.10. Similarly, West Africa records negative and statistically significant coefficients across most quantiles, with the largest effect observed at Q0.10, where social sustainability declines by 0.017%. East Africa records negative and statistically significant coefficients at Q0.25 and Q0.50, while the coefficients for Southern Africa remain largely statistically insignificant across the distribution.

The effects of drought conditions on environmental sustainability differ across the subregions. In Central Africa and Southern Africa, the coefficients are negative and statistically significant at Q0.10, reducing environmental sustainability by 0.484% and 0.582%, respectively. By contrast, positive and statistically significant coefficients are observed at Q0.90 in Central Africa and East Africa, where environmental sustainability increases by 1.745% and 0.813%, respectively.

Table 23 presents the quantile estimates for economic sustainability. East Africa records negative coefficients across the distribution, with statistically significant effects at Q0.50 and Q0.90. A one-unit increase in drought severity reduces economic sustainability by 0.175% at Q0.50 and 0.198% at Q0.90. The coefficients for Central Africa, Southern Africa, and West Africa remain largely statistically insignificant across most quantiles.

The findings indicate that the sustainability effects of persistent drought conditions vary across Sub-Saharan African subregions and across different points of the sustainability distribution. The negative effects are more evident for social sustainability, while the effects on environmental and economic sustainability differ across regions and quantiles.

**Table 22: Quantile regression estimation: Dependent Variable: Sustainability across Subregions**

| | Social Sustainability | | | | Environmental Sustainability | | | |
|---|---|---|---|---|---|---|---|---|
| | ***Model 1*** | ***Model 2*** | ***Model 3*** | ***Model 4*** | ***Model 1*** | ***Model 2*** | ***Model 3*** | ***Model 4*** |
| Quantile | Central Africa | East Africa | Southern Africa | West Africa | Central Africa | East Africa | Southern Africa | West Africa |
| Q0.10 | -0.023*** | -0.011 | -0.001 | -0.017*** | -0.484*** | -0.154 | -0.582** | -0.218 |
| | (0.009) | (0.010) | (0.002) | (0.004) | (1.00) | (0.32) | (0.27) | (0.17) |
| Q0.25 | -0.005 | -0.023*** | -0.003 | -0.014*** | -0.200 | -0.146 | -0.342 | -0.066 |
| | (0.010) | (0.008) | (0.004) | (0.003) | (0.71) | (0.24) | (0.28) | (0.23) |
| Q0.50 | -0.022 | -0.023*** | -0.006 | -0.012*** | 0.051 | -0.139 | -0.281 | -0.031 |
| | (0.021) | (0.005) | (0.007) | (0.006) | (0.37) | (0.23) | (0.34) | (0.15) |
| Q0.75 | -0.024 | 0.023*** | 0.008 | -0.011** | -0.203 | 0.309 | -0.271 | 0.078 |
| | (0.023) | (0.006) | (0.007) | (0.006) | (0.55) | (0.38) | (0.47) | (0.18) |
| Q0.90 | -0.013 | 0.012 | -0.004 | 0.011 | 1.745** | 0.813** | -0.063 | 0.083 |
| | (0.018) | (0.010) | (0.014) | (0.008) | (0.93) | (0.48) | (0.74) | (0.20) |

***Notes:*** *Entries are coefficients with standard errors in parentheses. Significance: *** p<0.01, ** p<0.05, * p<0.10.*

**Table 23: Quantile Regression Estimation**

| | Economic Sustainability | | | | |
|---|---|---|---|---|---|
| | ***Model 1*** | ***Model 2*** | ***Model 3*** | ***Model 4*** | ***Model 5*** |
| **Subregion** | **Q0.1** | **Q0.25** | **Q0.5** | **Q0.75** | **Q0.9** |
| Central Africa | 0.310 | 0.336 (0.448) | 0.234 (0.213) | -0.059 (0.160) | 0.029 |
| | (0.331) | | | | (0.186) |
| East Africa | -0.174 | -0.048 (0.284) | -0.175** | -0.101 (0.067) | -0.198** |
| | (0.231) | | (0.087) | | (0.090) |
| Southern Africa | 0.326 | -0.329 (0.594) | 0.121 (0.201) | -0.038 (0.052) | -0.045 |
| | (0.390) | | | | (0.066) |
| West Africa | 0.002 | -0.117 (0.253) | -0.014 (0.061) | 0.042 (0.032) | -0.015 |
| | (0.240) | | | | (0.070) |

***Notes:*** *Each cell reports the coefficient followed by its robust bootstrapped standard error in parentheses. *, **, and *** denote significance at the 10 %, 5 %, and 1 % levels respectively.*

### *3.14 Effects of Persistent Drought Conditions on Sustainability across Sectors*

The quantile regression estimates reveal considerable variation in the sustainability effects of persistent drought conditions across the agriculture, industry, manufacturing, and services sectors in Sub-Saharan Africa. Tables 24 and 25 present the sectoral quantile estimates for economic, social, and environmental sustainability using the Palmer Drought Severity Index (PDSI) as the measure of drought conditions.

For economic sustainability, most coefficients remain statistically insignificant across the sectors and quantiles. However, a positive and statistically significant coefficient is observed in the services sector at Q0.10, where a one-unit improvement in PDSI increases economic sustainability by 0.022%. By contrast, industry records a negative and statistically significant coefficient at Q0.90, where a one-unit increase in drought severity reduces economic sustainability by 0.131%.

The effects of drought conditions on social sustainability differ across sectors and quantiles. At Q0.10, drought severity reduces social sustainability by 0.360% in agriculture, 0.160% in industry, 0.060% in manufacturing, and 0.310% in services. Positive and statistically significant coefficients emerge at the middle quantiles in several sectors. At Q0.50, social sustainability increases by 0.058% in agriculture, 0.188% in industry, and 0.177% in services.

Environmental sustainability also exhibits heterogeneous responses across the sectors. At Q0.10, drought severity reduces environmental sustainability by 0.0125% in agriculture, 0.013% in industry, and 0.017% in services. Positive and statistically significant coefficients are observed at the middle and upper quantiles. In agriculture, environmental sustainability increases by 0.025% at Q0.50 and 0.023% at Q0.75, while industry records positive effects of 0.023% and 0.021% at the corresponding quantiles. Positive and statistically significant coefficients are also observed in the services sector at Q0.75 and Q0.90.

The results indicate that the sustainability effects of persistent drought conditions differ across sectors and across the conditional distribution of sustainability outcomes. The effects are particularly pronounced for social and environmental sustainability, while the economic sustainability effects remain relatively limited and concentrated within specific sectors and quantiles.

**Table 24*:* Quantile regression estimation: Dependent Variable: Sustainability across Sectors**

| | *ECONOMIC SUSTAINABILITY* | | | | *SOCIAL SUSTAINABILITY* | | | |
|---|---|---|---|---|---|---|---|---|
| **Quantile** | **Model 1 Agriculture** | **Model 2 Industry** | **Model 3 Manufacturing** | **Model 4 Services** | **Model 1 Agriculture** | **Model 2 Industry** | **Model 3 Manufacturing** | **Model 4 Services** |
| Q0.1 | -0.015 | 0.014 | -0.026 | 0.022** | -0.360** | -0.160** | -0.060** | -0.310** |
| | (0.057) | (0.095) | (0.024) | (0.012) | (0.167) | (0.087) | (0.027) | (0.195) |
| Q0.25 | -0.002 | -0.188 | -0.022 | 0.009 | -0.057 | -0.059 | -0.051 | -0.016 |
| | (0.029) | (0.169) | (0.024) | (0.011) | (0.210) | (0.214) | (0.186) | (0.192) |
| Q0.5 | -0.035 | -0.059 | 0.006 | -0.000 | 0.058** | 0.188* | 0.118 | 0.177** |
| | (0.029) | (0.059) | (0.018) | (0.007) | (0.011) | (0.111) | (0.127) | (0.088) |
| Q0.75 | -0.018 | -0.042 | 0.007 | 0.003 | 0.250 | 0.203 | 0.232 | 0.213 |
| | (0.018) | (0.042) | (0.027) | (0.006) | (0.220) | (0.230) | (0.226) | (0.219) |
| Q0.9 | -0.028 | -0.131*** | -0.029 | -0.002 | 0.286 | 0.256 | 0.286 | 0.226 |
| | (0.022) | (0.051) | (0.020) | (0.010) | (0.192) | (0.213) | (0.193) | (0.201) |

**Table 25: Quantile regression estimation**

| | *ENVIRONMENTAL SUSTAINABILITY* | | | |
|---|---|---|---|---|
| ***Quantile*** | **Model 1** ***Agriculture*** | **Model 2** ***Industry*** | **Model 3** ***Manufacturing*** | **Model 4** ***Services*** |
| Q0.10 | -0.0125*** | -0.013*** | -0.003 | -0.017*** |
| | (0.004) | (0.004) | (0.011) | (0.004) |
| Q0.25 | -0.021*** | 0.020*** | 0.0001 | -0.019*** |
| | (0.005) | (0.005) | (0.010) | (0.005) |
| Q0.50 | 0.025*** | 0.023*** | -0.009 | -0.020*** |
| | (0.005) | (0.005) | (0.008) | (0.005) |
| Q0.75 | 0.023*** | 0.021*** | 0.010 | 0.011*** |
| | (0.007) | (0.007) | (0.010) | (0.006) |
| Q0.90 | 0.005 | 0.007 | 0.009 | 0.004*** |
| | (0.008) | (0.008) | (0.009) | (0.005) |

***Notes:*** *Entries are coefficients with standard errors in parentheses.*
*Significance: *** p<0.01, ** p<0.05, * p<0.10.*

### 4.1 Climate Change and Sustainability Outcomes

The findings indicate that climate change remains a significant factor shaping sustainability outcomes in Sub-Saharan Africa. The negative effects of temperature on economic, social, and environmental sustainability suggest that rising temperatures continue to constrain development across the region. Higher temperatures reduce agricultural productivity, increase water stress, lower labour efficiency, and place additional pressure on natural ecosystems. These effects are particularly important in Sub-Saharan Africa, where many economies remain dependent on climate-sensitive sectors and possess limited adaptive capacity. The stronger adverse effect observed for environmental sustainability further demonstrates the vulnerability of ecological systems to increasing temperature conditions. Similar evidence has been reported by the IPCC (2023), Romanello et al. (2023), and Adebayo et al. (2024), who found that rising temperatures weaken environmental quality and broader development outcomes in climate-vulnerable economies.

Precipitation contributes positively to sustainability outcomes, indicating the importance of stable rainfall conditions for development in the region. Rainfall supports agricultural production, food security, water availability, and hydropower generation, all of which contribute to economic performance, social welfare, and environmental stability. The stronger economic effect reflects the continued dependence of many Sub-Saharan African economies on rain-fed agricultural systems. This finding supports the conclusions of Abidoye et al. (2022) and Nhamo et al. (2023), who identified favourable rainfall conditions as an important source of resilience and sustainable development in African economies. At the same time, the result highlights the potential risks associated with increasing rainfall variability under changing climatic conditions.

The contrasting effects of carbon emissions reveal an important sustainability trade-off. While carbon emissions contribute positively to economic sustainability, they reduce environmental sustainability. This outcome suggests that economic activities in many countries within the region continue to rely on carbon-intensive production processes, fossil fuel consumption, and extractive activities. Such activities may support income generation and economic expansion in the short run but generate environmental costs that undermine long-term sustainability. Similar conclusions were reached by Pata and Isik (2021), Khan et al. (2023), and Nathaniel et al. (2024), who found that carbon-intensive growth often improves economic performance while weakening environmental quality.

The subregional findings demonstrate that climate effects are not uniform across Sub-Saharan Africa. The stronger adverse effects observed in West and East Africa indicate higher levels of climate vulnerability compared with Central and Southern Africa. These differences may reflect variations in economic structure, climate exposure, infrastructure development, and institutional capacity. West and East Africa remain highly dependent on climate-sensitive activities and frequently experience droughts, rainfall variability, and food insecurity. Consequently, climatic changes are more likely to translate into economic, social, and environmental pressures within these subregions. The relatively weaker effects observed in Southern Africa may reflect stronger adaptive capacity and better infrastructure systems. Similar regional differences have been documented by Serdeczny et al. (2017), Abidoye et al. (2022), and Romanello et al. (2023).

The sectoral results further indicate that climate change affects sustainability through multiple transmission channels. Agriculture emerges as the most climate-sensitive sector, reflecting its dependence on temperature and rainfall conditions. Climatic disturbances therefore influence sustainability not only through production losses but also through their effects on livelihoods, food systems, and environmental quality. The results also show that manufacturing, services, and tourism remain exposed to climate-related risks, although the magnitude of the effects differs across sectors. These differences reflect variations in resource dependence, energy requirements, and production structures.

The threshold estimates provide additional evidence that climate–sustainability relationships are nonlinear. Temperature, precipitation, and carbon emissions exhibit critical levels beyond which their effects become less favourable or detrimental. This finding indicates that the sustainability consequences of climate change intensify once climatic conditions exceed the adaptive capacity of economic, social, and environmental systems. Similar nonlinear responses have been identified by Burke et al. (2015) and the IPCC (2023), who noted that climate impacts often become more severe beyond critical thresholds.

### *4.2 Urbanisation and Sustainability Outcomes*

The findings reveal that urbanisation plays a complex role in shaping sustainability outcomes in Sub-Saharan Africa. While urban expansion contributes positively to economic sustainability, its effects on social sustainability are relatively modest, and its effects on environmental sustainability are largely adverse. These results indicate that the sustainability consequences of urbanisation depend on the dimension of sustainability being considered and the capacity of countries to manage the challenges associated with rapid urban growth.

The positive relationship between urbanisation and economic sustainability reflects the role of cities as centres of production, investment, innovation, and market integration. Urban areas facilitate labour mobility, improve access to infrastructure, promote business development, and create opportunities for economies of scale. These advantages contribute to productivity growth and economic diversification, which are essential components of long-term economic sustainability. The findings support the urban development literature, which argues that urbanisation can catalyze structural transformation by shifting economic activity from low-productivity sectors towards more productive industrial and service-based activities (Henderson et al., 2017; Cobbinah et al., 2023). The positive economic effects observed in the study therefore suggest that urbanisation continues to play an important role in supporting development across many Sub-Saharan African economies.

The social sustainability results are positive but comparatively weaker. This outcome suggests that although urbanisation creates opportunities for improved access to education, healthcare, communication networks, and public services, these benefits are not distributed evenly across countries and populations. Rapid urban growth in many African cities has often outpaced the expansion of social infrastructure, resulting in overcrowding, informal settlements, housing deficits, and unequal access to basic services. Consequently, the potential social gains associated with urbanisation may be partially offset by increasing pressure on urban facilities and public services. Similar observations have been reported by Fox and Goodfellow (2021) and UN-Habitat (2022), who noted that rapid urban expansion frequently creates disparities in access to social amenities and urban opportunities.

The negative relationship between urbanisation and environmental sustainability indicates that current patterns of urban growth continue to generate significant environmental pressure across the region. Expanding urban populations increase demand for energy, transportation, housing, water resources, and waste management services. In many countries, these demands are met through infrastructure systems that rely heavily on fossil fuels and environmentally intensive production processes. The resulting increase in pollution, waste generation, land conversion, and resource consumption contribute to environmental degradation and weakens ecological sustainability. This finding is consistent with studies by Pata and Isik (2021), Khan et al. (2023), and Nathaniel et al. (2024), which found that rapid urban expansion often creates environmental challenges in developing economies where environmental management systems struggle to keep pace with urban growth.

The subregional results further demonstrate that the sustainability effects of urbanisation differ across Sub-Saharan Africa. Positive effects on social sustainability are more evident in East and Southern Africa, while economic sustainability gains are particularly pronounced in Central Africa. These differences likely reflect variations in infrastructure quality, urban planning systems, institutional capacity, and the stage of urban development across the subregions. The findings indicate that urbanisation does not produce uniform sustainability outcomes and that local conditions play an important role in determining whether urban growth contributes positively or negatively to development objectives.

The sectoral evidence also provides important insight into the channels through which urbanisation affects sustainability. Economic benefits are strongest in services, industry, manufacturing, and tourism, highlighting the close relationship between urban expansion and modern economic activities. Urban centres provide markets, infrastructure, and networks that support the growth of these sectors. By contrast, the weaker economic effects observed in agriculture may reflect the reallocation of labour and land away from traditional agricultural activities as urban areas expand. The environmental results indicate that urbanisation generates pressure across all sectors, suggesting that environmental challenges associated with urban growth are not confined to a single part of the economy.

The findings therefore indicate that urbanisation represents both an opportunity and a challenge for sustainable development in Sub-Saharan Africa. Urban growth can strengthen economic performance and improve

aspects of social well-being, but these gains may be accompanied by rising environmental costs if expansion occurs without adequate planning, infrastructure investment, and environmental regulation. Achieving sustainable urban development will therefore require policies that promote productive urban growth while simultaneously addressing environmental pressures and infrastructure constraints associated with rapid urban expansion.

### *4.3 Nonlinear and Threshold Effects*

A key contribution of this study is the identification of threshold effects in the relationships between climate change, urbanisation, and sustainability. The threshold estimates indicate that the effects of temperature, precipitation, carbon emissions, and urbanisation are not constant across different levels of development and environmental conditions. Instead, the direction and magnitude of these effects change once critical threshold values are exceeded. This finding suggests that linear approaches may underestimate the complexity of sustainability dynamics in Sub-Saharan Africa.

The climate-related threshold results show that moderate climatic conditions may initially support sustainability outcomes, whereas conditions beyond certain critical levels become detrimental. Temperature provides a clear example of this pattern. At relatively lower levels, temperature may support agricultural production and economic activities in some countries. However, once temperature rises beyond the identified thresholds, the adverse effects become more pronounced. Higher temperatures increase water stress, reduce labour productivity, lower agricultural yields, and accelerate environmental degradation. This transition from favourable to adverse effects demonstrates that climatic conditions can move from being supportive of development to becoming a significant constraint on sustainability. Similar nonlinear responses have been identified by Burke et al. (2015), who found that economic performance deteriorates as temperatures move beyond optimal levels.

The threshold effects associated with precipitation also reveal important sustainability implications. Moderate rainfall contributes positively to economic activity, social welfare, and environmental stability through its influence on agriculture, water resources, and ecosystem functioning. However, the results indicate that these benefits diminish once precipitation exceeds critical levels. Excessive rainfall may increase the frequency of floods, damage infrastructure, disrupt production activities, and create environmental stress. This finding demonstrates that both insufficient and excessive rainfall can generate sustainability challenges, highlighting the importance of climatic balance rather than simply higher rainfall levels.

Carbon emissions also exhibit nonlinear effects across sustainability dimensions. Lower levels of emissions appear compatible with economic activities that support development objectives. Beyond the identified thresholds, however, the adverse environmental consequences become increasingly apparent. Rising emissions intensify pollution, ecosystem degradation, and environmental pressure, thereby weakening long-term sustainability. The results therefore indicate that economic activities driven by carbon-intensive production systems become progressively less sustainable as emission levels increase. Similar conclusions have been reported by Pata and Isik (2021) and Khan et al. (2023), who found that environmental costs rise substantially once carbon emissions exceed critical levels.

The urbanisation threshold results provide additional evidence that the sustainability effects of urban growth depend on the stage of urban development. Below the estimated threshold levels, urbanisation generally contributes positively to economic and social sustainability. At these stages, urban expansion promotes infrastructure development, labour mobility, market integration, and access to public services. Beyond the threshold levels, however, the coefficients become weaker or negative. This pattern indicates that excessive urban concentration generates congestion pressures, infrastructure deficits, environmental stress, and increasing demands on public services. The findings therefore suggest that the benefits of urbanisation are not unlimited and may decline when urban growth exceeds the capacity of cities to provide adequate infrastructure and services. Similar evidence has been reported by Acheampong et al. (2021) and Nathaniel et al. (2024), who found that the sustainability gains associated with urbanisation diminish once urban growth outpaces institutional and infrastructural development.

The subregional threshold estimates further demonstrate that critical threshold levels differ across Sub-Saharan Africa. Some subregions experience sustainability pressures at relatively low levels of urbanisation and climate exposure, while others maintain positive sustainability outcomes until much higher threshold levels are

reached. These differences reflect variations in adaptive capacity, infrastructure quality, institutional effectiveness, and economic structure across the region. Consequently, a uniform policy approach is unlikely to be effective in addressing climate and urbanisation challenges across all subregions.

The threshold findings indicate that sustainability outcomes are strongly influenced by the capacity of economic, environmental, and social systems to absorb climatic and urban pressures. Once these pressures exceed critical limits, sustainability performance deteriorates more rapidly. This evidence points to the importance of early intervention strategies that prevent countries and cities from reaching levels at which climate and urbanisation pressures become increasingly difficult to manage. Strengthening adaptive capacity, improving urban planning, and investing in resilient infrastructure may therefore help delay or reduce the adverse consequences associated with crossing these critical thresholds.

### *4.4 Persistent Drought Conditions and Sustainability*

The findings demonstrate that persistent drought conditions constitute an important challenge to sustainable development in Sub-Saharan Africa. Unlike short-term climatic fluctuations, prolonged droughts generate cumulative effects that weaken productive capacity, disrupt livelihoods, increase environmental stress, and reduce resilience across economic and social systems. The quantile results indicate that these effects are not evenly distributed across countries, subregions, or sectors, suggesting that vulnerability to drought depends on existing sustainability conditions and adaptive capacity.

The adverse effects of drought on social sustainability are particularly pronounced. The consistently negative coefficients across most quantiles indicate that worsening drought conditions weaken welfare outcomes throughout the region. Drought reduces water availability, threatens food production, increases livelihood insecurity, and places additional pressure on public services. These challenges are especially important in countries where large segments of the population depend directly on climate-sensitive activities for income and subsistence. The stronger effects observed among countries with lower levels of social sustainability suggest that existing vulnerabilities amplify the social consequences of prolonged climate stress. This finding supports evidence presented by the IPCC (2023) and Nhamo et al. (2023), who identified drought as a major driver of food insecurity, migration pressures, and social vulnerability across African economies.

The effects of drought on economic sustainability are also evident, although they vary across the sustainability distribution. The stronger adverse effects observed at higher quantiles suggest that prolonged drought conditions can undermine productive systems even in countries with relatively stronger economic performance. This outcome reflects the dependence of many economies on agriculture, water resources, and climate-sensitive infrastructure. Persistent drought reduces agricultural output, weakens energy generation, discourages investment, and increases production costs. These effects can slow economic progress and weaken long-term sustainability. Similar conclusions have been reached by Abidoye et al. (2022) and the IPCC (2023), who reported that repeated climate shocks reduce economic resilience and constrain development prospects in vulnerable regions.

The environmental sustainability results reveal a more complex relationship. While drought conditions generally exert negative effects at lower levels of environmental sustainability, positive effects emerge at some middle and upper quantiles. This pattern may reflect differences in environmental management capacity and ecological resilience across countries. Economies with stronger environmental institutions and conservation systems may be better positioned to mitigate the ecological consequences of prolonged droughts, whereas countries with weaker environmental conditions remain more vulnerable to land degradation, vegetation loss, and ecosystem deterioration. The findings therefore indicate that environmental responses to drought depend not only on climatic conditions but also on the ability of countries to manage environmental risks effectively.

The subregional analysis further demonstrates that drought vulnerability differs considerably across Sub-Saharan Africa. The stronger negative effects observed in West Africa and East Africa reflect the high exposure of these subregions to recurrent droughts, rainfall variability, and food insecurity. In contrast, the weaker or less consistent effects observed in some parts of Southern and Central Africa suggest differences in economic structure, resource availability, and adaptive capacity. These regional differences indicate that drought-related sustainability challenges are shaped by both climatic conditions and local development characteristics.

The sectoral results provide additional evidence that drought effects are transmitted through multiple channels. Agriculture remains the most vulnerable sector because of its direct dependence on rainfall and water availability. However, the findings also reveal important effects within industry and services, demonstrating that drought conditions extend beyond agricultural production. Reduced water availability, disruptions to energy supply, and declining economic activity can affect a broad range of sectors throughout the economy. This evidence indicates that the consequences of persistent drought are economy-wide rather than sector-specific.

The drought-related findings underscore the importance of strengthening resilience to long-term climate stress. Investments in water resource management, drought-resistant technologies, climate-smart agriculture, and environmental conservation can reduce vulnerability to prolonged drought conditions. Expanding early warning systems and improving institutional preparedness may also enhance the capacity of countries and sectors to cope with increasing climate uncertainty. Such measures are likely to become increasingly important as drought episodes become more frequent and severe under changing climatic conditions.

### 4.5 Regional and Sectoral Heterogeneity

The findings demonstrate that the sustainability effects of climate change, urbanisation, and persistent drought conditions differ substantially across Sub-Saharan Africa. The stronger adverse climate effects observed in West and East Africa indicate higher levels of vulnerability within these subregions. This outcome may reflect greater dependence on climate-sensitive activities, recurrent drought episodes, rainfall variability, and relatively limited adaptive capacity. As a result, changes in climatic conditions are more likely to translate into economic, social, and environmental pressures within these subregions.

By contrast, the weaker and less consistent effects observed in parts of Central and Southern Africa suggest differences in economic structure, infrastructure development, and institutional capacity. Countries within these subregions may possess stronger adaptation mechanisms and more diversified economic systems that reduce direct exposure to climate-related shocks. These differences demonstrate that climate vulnerability is not uniform across Sub-Saharan Africa and that regional characteristics play an important role in shaping sustainability outcomes.

The sectoral analysis further reveals important differences in climate sensitivity. Agriculture emerges as the most vulnerable sector, reflecting its dependence on rainfall patterns, water availability, and temperature conditions. Consequently, climatic disturbances directly affect production, livelihoods, and food security. Manufacturing, industry, services, and tourism also experience climate-related effects, although the magnitude and direction of the impacts differ according to sectoral characteristics and resource requirements.

The urbanisation results show that modern sectors such as services, manufacturing, and industry benefit more from urban expansion than agriculture. Urban growth supports market integration, infrastructure development, and economic diversification within these sectors. However, environmental sustainability declines across most sectors as urbanisation increases, indicating that the environmental costs of urban growth remain widespread throughout the economy.

These findings indicate that sustainability challenges and opportunities differ across regions and sectors. Policies designed to improve sustainability outcomes should therefore recognise differences in climate exposure, economic structure, and adaptive capacity rather than relying on uniform approaches across countries and sectors.

## 5. Conclusion and Policy Implications

This study examined the effects of climate change and urbanisation on economic, environmental, and social sustainability in Sub-Saharan Africa using panel data for 32 countries over the period 1996–2023. The analysis incorporated temperature, precipitation, carbon emissions, and persistent drought conditions while accounting for threshold effects, subregional differences, sectoral heterogeneity, and distributional dynamics. By combining multiple estimation techniques, the study provides a comprehensive assessment of how climate change and urbanisation influence sustainability outcomes across the region.

The findings indicate that climate change remains a significant constraint to sustainable development in Sub-Saharan Africa. Rising temperatures reduce economic, environmental, and social sustainability, while precipitation generally contributes positively to sustainability outcomes. Carbon emissions reveal an important trade-off, supporting economic sustainability while weakening environmental sustainability. The results therefore indicate that many

economies within the region continue to depend on carbon-intensive development pathways that generate economic gains at the expense of environmental quality.

The analysis further demonstrates that the effects of climate change are neither uniform nor linear. The threshold estimates show that temperature, precipitation, carbon emissions, and urbanisation exhibit critical levels beyond which sustainability outcomes deteriorate. These findings indicate that climate and urban pressures become increasingly difficult to manage once economic, environmental, and social systems exceed their adaptive capacity. The subregional and sectoral analyses also reveal considerable heterogeneity. West and East Africa appear more vulnerable to climate-related pressures, while agriculture emerges as the most climate-sensitive sector. Persistent drought conditions exert particularly adverse effects on social sustainability and weaken economic performance in several parts of the region.

The urbanisation results indicate that urban growth contributes positively to economic sustainability and, to a lesser extent, social sustainability. However, urbanisation consistently weakens environmental sustainability. While expanding cities create opportunities for investment, employment, infrastructure development, and economic diversification, they also increase pressure on natural resources, energy systems, land use, and environmental quality. The threshold estimates further indicate that the benefits of urbanisation diminish once urban growth exceeds critical levels, highlighting the importance of effective urban planning and infrastructure provision.

Several policy implications emerge from these findings. First, governments should strengthen climate adaptation strategies by investing in irrigation systems, water resource management, drought monitoring, and climate-resilient agricultural technologies. Such measures are essential for reducing vulnerability to rising temperatures, rainfall variability, and persistent drought conditions. Second, urban development policies should prioritise sustainable and planned urban expansion. Investments in housing, public transport, waste management, drainage systems, and green infrastructure can help reduce the environmental costs associated with rapid urban growth while preserving its economic benefits.

Third, the transition towards cleaner energy systems should be accelerated across the region. Expanding renewable energy generation, promoting energy efficiency, and encouraging low-carbon production technologies can reduce environmental pressure without undermining economic development. Fourth, policy interventions should recognise regional and sectoral differences in climate vulnerability. Climate adaptation priorities in drought-prone agricultural economies may differ substantially from those required in more urbanised and industrialised settings. Consequently, sustainability policies should be tailored to local conditions rather than relying on uniform approaches across countries and sectors.

The findings also underscore the importance of strengthening institutional capacity. Improvements in governance, environmental management, disaster preparedness, and policy coordination can enhance resilience and support more effective responses to climate-related challenges. Continued investment in education and human capital development remains equally important because stronger skills and knowledge systems improve adaptive capacity and support long-term sustainability objectives.

Despite these contributions, several limitations should be acknowledged. The analysis relies on national-level indicators and may not fully capture local variations in climate vulnerability and sustainability outcomes. In addition, the study focuses on temperature, precipitation, carbon emissions, and persistent drought conditions, while other climate-related risks such as floods, heatwaves, and extreme weather events are not explicitly examined. Future research may therefore employ more disaggregated data and incorporate additional climate indicators to provide a deeper understanding of sustainability dynamics across the region. Further studies may also explore the role of governance, technological innovation, and renewable energy transition as mechanisms through which climate change and urbanisation influence sustainability outcomes.

The evidence presented in this study demonstrates that climate change and urbanisation remain central determinants of sustainability in Sub-Saharan Africa. Achieving long-term sustainability will require coordinated efforts that combine climate adaptation, sustainable urban development, environmental protection, institutional strengthening, and human capital investment. Progress in these areas will be critical for improving resilience and supporting sustainable development across the region.

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## Appendices

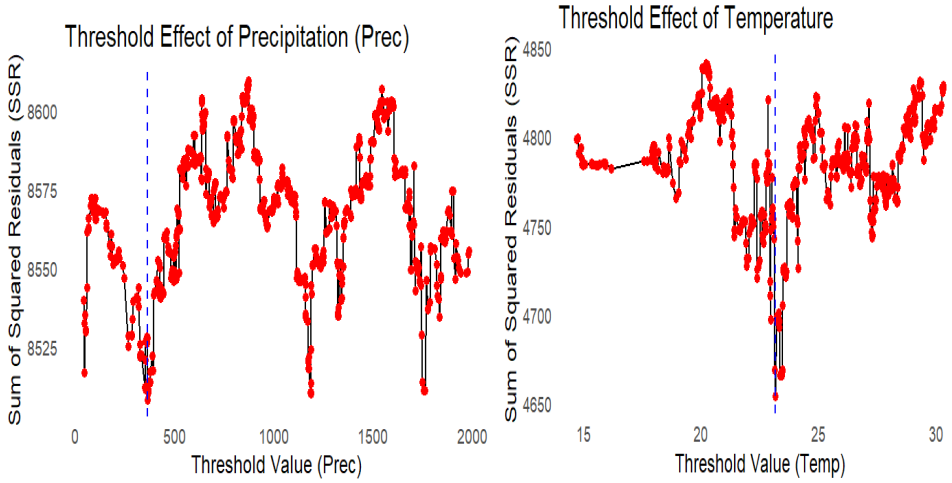
*Table A1: Fisher-ADF Unit Tests Root*

| Variables | FISHER-ADF Statistics (Level) | Lag (Level) | FISHER-ADF Statistics (1st Diff) | Lag (1st Diff) | Integration Order (I(0)/I(1)) |
|---|---|---|---|---|---|
| ES | 0.0000*** | 1 | 0.0000*** | 1 | I(0) |
| SOS | 0.0000*** | 1 | 0.0000*** | 1 | I(0) |
| EVS | 0.0000*** | 1 | 0.0000*** | 1 | I(0) |
| FDI | 0.0000*** | 1 | 0.0000*** | 1 | I(0) |
| CPI | 0.4650 | 1 | 0.0000*** | 1 | I(1) |
| TSR | 0.0000*** | 1 | 0.0000*** | 1 | I(0) |
| Trade | 0.0000*** | 1 | 0.0000*** | 1 | I(1) |
| Edu | 0.0011*** | 1 | 0.0000*** | 1 | I(1) |
| GFCF | 0.0001*** | 1 | 0.0000*** | 1 | I(0) |
| Agric | 0.0000*** | 1 | 0.0000*** | 1 | I(0) |
| Manuf | 0.0000*** | 1 | 0.0000*** | 1 | I(1) |
| LF | 0.0268** | 1 | 0.0000*** | 1 | I(0) |
| Temp | 0.0000*** | 1 | 0.0000*** | 1 | I(0) |
| Prec | 0.0000*** | 1 | 0.0000*** | 1 | I(0) |
| PDSI | 0.0000*** | 1 | 0.0000*** | 1 | I(0) |

**Table 2A: Pairwise Correlations**

| Variables | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) Economic sustainability | 1.000 | | | | | | | | | | | |
| (2) Social sustainability | 0.506 | 1.000 | | | | | | | | | | |
| (3) Environmental sustainability | 0.437 | 0.621 | 1.000 | | | | | | | | | |
| (4) Urbanisation | -0.087 | -0.117 | 0.082 | 1.000 | | | | | | | | |
| (5) Precipitation | 0.182 | 0.085 | 0.148 | -0.192 | 1.000 | | | | | | | |
| (6) Temperature | -0.131 | -0.032 | -0.106 | 0.127 | -0.106 | 1.000 | | | | | | |
| (7) $CO_2$ emissions | -0.262 | -0.112 | -0.277 | 0.048 | -0.372 | 0.120 | 1.000 | | | | | |
| (8) Government effectiveness | 0.068 | 0.562 | 0.699 | -0.147 | -0.240 | -0.042 | 0.105 | 1.000 | | | | |
| (9) Foreign direct investment | 0.005 | -0.012 | -0.126 | 0.010 | 0.034 | 0.084 | 0.118 | -0.082 | 1.000 | | | |
| (10) Total resource rent | 0.279 | 0.011 | -0.244 | 0.087 | -0.097 | -0.067 | 0.733 | -0.174 | 0.162 | 1.000 | | |
| (11) Gross capital formation | 0.127 | 0.172 | 0.166 | 0.042 | 0.155 | -0.147 | -0.413 | 0.125 | 0.010 | -0.166 | 1.000 | |
| (12) Consumer price index | 0.037 | 0.132 | 0.166 | 0.079 | 0.148 | 0.000 | -0.277 | -0.083 | -0.126 | -0.244 | 0.166 | 1.000 |

***Figure 1A:*** Threshold for climate change variables



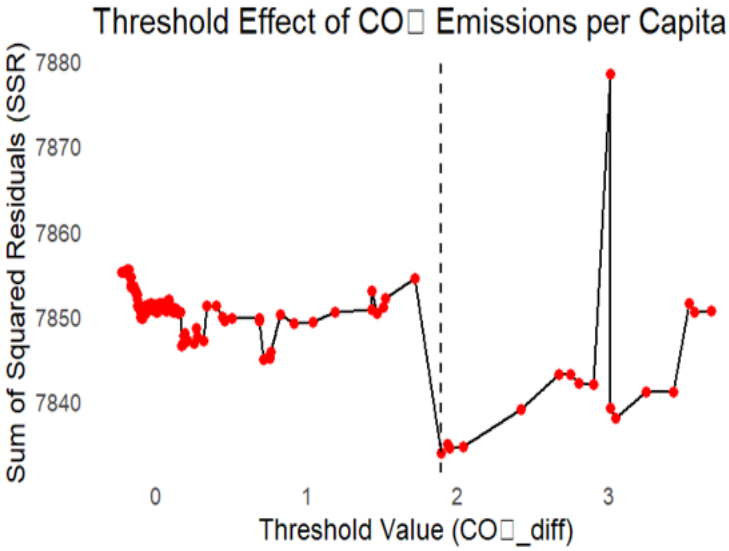



*Table 3A: List of countries included in the study*

| No. | Country |
|---|---|
| 1 | Angola |
| 2 | Benin |
| 3 | Botswana |
| 4 | Burkina Faso |
| 5 | Burundi |
| 6 | Cameroon |
| 7 | Central African Republic |
| 8 | Chad |
| 9 | Comoros |
| 10 | Congo, Republic of |
| 11 | Congo, Democratic Republic of the |
| 12 | Côte d'Ivoire |
| 13 | Equatorial Guinea |
| 14 | Ethiopia |
| 15 | Gabon |
| 16 | Gambia |
| 17 | Ghana |
| 18 | Guinea |
| 19 | Guinea-Bissau |
| 20 | Kenya |
| 21 | Lesotho |
| 22 | Madagascar |
| 23 | Mali |
| 24 | Mauritania |
| 25 | Mauritius |
| 26 | Namibia |
| 27 | Niger |
| 28 | Rwanda |
| 29 | Senegal |
| 30 | Sudan |
| 31 | Tanzania |
| 32 | Uganda |

*Table 4A: Regional classification of sample countries*

| Region | Countries |
|---|---|
| **West Africa** | Benin, Burkina Faso, Côte d'Ivoire, Gambia, Ghana, Guinea, Guinea-Bissau, Mali, Mauritania, Niger, Senegal |
| **Central Africa** | Angola, Cameroon, Central African Republic, Chad, Congo, Democratic Republic of the Congo, Equatorial Guinea, Gabon |
| **East Africa** | Burundi, Comoros, Ethiopia, Kenya, Rwanda, Tanzania, Uganda |
| **Southern Africa** | Botswana, Lesotho, Mauritius, Namibia |