Exploring the Impacts of Climate Change and Biocapacity on Agriculture Value Added: Novel Evidence from Africa

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Abstract

Economies in Africa are often characterized as natural-resource dependent and most susceptible to climate change; they also face drastic depletion of their biocapacity. Climate change and biocapacity depletion jointly affects the level of value added to agriculture, fishing and forestry. However, studies documenting the impact of climate change and biocapacity on agriculture value added are rare. In this study, we assessed the impact of climate change and biocapacity on agriculture fishing and forestry value-added in 38 African countries over 15-years span. We applied several estimation techniques including the pooled group mean and dynamic fixed effects panel autoregressive distributed lag (PARDL) simulations, with data from 2006 to 2020. Results show that precipitation, temperature, agricultural employment, and gross fixed capital formation significantly increase value added in the long and short term, whereas biocapacity exhibits a negative relationship, implying unsustainable use of natural capital. The result indicates stronger long-term impacts of rainfall and temperature since production could be well planned with better weather predictability in the long run. The findings highlight the intricate balance between economic growth and ecological limits in Africa's primary sectors. By integrating biocapacity into the climate–growth nexus, the study provides novel empirical evidence that strengthens the ecological economics discourse and offers practical guidance for promoting climate-resilient and environmentally sustainable agricultural development in Africa.
Keywords: climate change, biocapacity, value added, Africa, panel data

Introduction

Climate change poses a substantial threat to both environmental sustainability and economic development especially in Africa, where many sectors (particularly, agriculture, fishing, and forestry) rely heavily on natural resources (Iyiola et al., 2023). Climate change has been associated with erratic weather patterns, desertification, and the degradation of marine and forest ecosystems, all of which can disrupt livelihoods and diminish the value-added contributions from these primary sectors (Intergovernmental Panel on Climate Change, 2023). Available data from the Emergency Event Database (EM-DAT) suggests that climate related natural disasters are on the rise, globally, with far-reaching economic and social implications, particularly among vulnerable populations with little or no mitigation and/or adaptation capacity (Wollburg et al. 2024; FAO 2021). For example, estimates from EM-DAT show that the economic loss of climate related natural disasters was over $220 billion in 2022 alone, affecting around 185 million people and exceeding the average in the last two decades (CRED, 2023). The trends in climate related disasters indicates that their frequency and impact are likely to get worse in the future (Wollburg et al. 2024).

While climate change has emerged as a major source of concern, biocapacity (that is, the capacity of ecosystems to regenerate resources to sustain the ecological services for human survival) has seen a continuous decline, globally, with a faster rate of decline in Africa than in most other regions of the world. Based on data from Global Footprint Network[1], Africa's biocapacity declined from 4.25 global hectares per person in 1961 to 0.99 global hectares per person in 2022, compared to a decline from 3.18 global hectares per person to 1.51 global hectares per person within the same period, globally. Biocapacity, however, plays a crucial role in determining the sustainability of economic activities heavily reliant on natural resources like agriculture (Sarkodie, 2021).

An important research question is about whether both climate change and biocapacity significantly affect economic transformation through agricultural value-added especially in Africa. Our review of the existing literature shows that empirical research on the impact of climate change and biocapacity on agricultural value added is generally lacking. Although a substantial body of literature has examined the intricate relationship between environmental stressors and economic performance in developing regions, research on the impact of climate change in Africa has focused more on yield, economic growth and biophysical effects, with limited attention paid to the direct impact it may have on agricultural value added. For example, Lobell et al (2011) have demonstrated that rising temperatures and changing precipitation patterns have already had measurable negative effects on crop yields in Sub-Saharan Africa. Similarly, Barange et al (2014) have highlighted that warming oceans and acidification are

[1] The data is available online at https://data.footprintnetwork.org/?_ga=2.63917551.1568261390.1748540325-151850707.1748258379#/

altering fish stocks and marine biodiversity, with direct consequences for fisheries-dependent communities. In the forestry sector, research has indicated that climate-induced shifts in rainfall and temperature regimes threaten forest regeneration and increase susceptibility to pests and wildfires (Mwangi & Wardell, 2012). A few studies such as Barrios et al. (2008), Exenberger and Pondorfer (2011) and Coulibaly et al. (2020) have examined the effect of rainfall and temperature on agricultural production using data on African countries. However, these studies are limited either because the data they relied on are outdated or they failed to account for any measures of environmental sustainability such as biocapacity in modeling the effect of climate change on agriculture.

Although biocapacity has gained attention as a crucial ecological metric for assessing the pressure exerted on natural systems, we do not know much about its long run and short run relationship with agricultural value added in Africa. This research gap exists despite the prevailing belief that declining biocapacity, relative to ecological demand, indicates unsustainable exploitation, which consequently undermines the resilience of land- and sea-based economic sectors (see Wackernagel et al. 2002; Borucke et al. 2013). The existing research has mainly focused on measuring biocapacity together with ecological footprint and understanding their dynamics and driving factors across space and time (see Monfreda et al. 2004; Borucke et al. 2013; Gabbi et al. 2021; Niccolucci et al. 2021). In relation to this, Sampene et al. (2023) found a positive association between biocapacity and ecological footprint for South Asian economies while Ali et al. (2021) found that biocapacity negatively predict changes in CO_2 emissions in Nigeria, an agrarian-based economy. A recent study by Onyeneke et al. (2024a), however, examined the impact of biocapacity on the yield of different crops using a panel data of African countries, and found heterogenous results the direction (sign) of the impact across different crops. This study builds on the study by Onyeneke et al. (2024a) by exploring the impact of biocapacity on agriculture output by using an aggregate measure of agricultural output (that is, agriculture, fishing and forestry value added).

This study is based on the perspective of ecological economics, which suggests that the economy is embedded within and constrained by environmental systems (Costanza et al., 1997). This theory highlights the limitations to growth due to finite ecological capacities and stresses the feedback loop between environmental degradation and economic vulnerability. Additionally, the vulnerability-resilience framework (Turner et al., 2003) explains the varying abilities of countries to absorb shocks from environmental stressors, focusing on adaptive capacity, institutional readiness, and ecological health. These theoretical perspectives emphasize the importance of examining both climate-related and biophysical constraints when assessing the sustainability of sectoral value added in Africa.

This study seeks to empirically test the association between climate-related and biophysical constraints on agriculture growth by employing panel data analysis across African countries, incorporating both environmental and economic indicators. Thereby, by bridging the gap between ecological and economic analyses, the paper contributes to a more integrated understanding of the relationship between the environment and the economy in natural resource exploitation in Africa. The findings are expected to inform policy strategies aimed at enhancing adaptive capacity, promoting ecological restoration, and fostering resilient economic growth in the face of environmental change. The focus of this study and the findings thereof address a research problem that carries a multidisciplinary appeal and ignites interest across policy circles, academia and practice. Climate change and its impacts are multifaceted with both direct and indirect impact on economic and socio-physical phenomena as well as having an existential implication for people at all levels, locally and globally. It is in this regard that Sustainable Development Goals 13 (SDG 13) calls for climate action, which among other things, seeks to build knowledge, resilience and adaptive capacity as well as integrate climate measures into policies and planning. This paper contributes to the body of research evidence needed for supporting climate action and to ensure its successful execution especially in the context of Africa. Also, this study contributes to knowledge by providing Africa-wide panel evidence on how climate change and biocapacity jointly affect agriculture, fishing, and forestry value added over a 15-year period. Conceptually, it integrates biocapacity into the climate–growth nexus and distinguishes short-run shocks from long-run equilibrium effects using a Panel Autoregressive Distributed Lag (PARDL) framework. Empirically, it fills a gap by analyzing sector-specific value added, extending beyond agriculture to include fishing and forestry, and by testing biocapacity as a moderator of climate impacts. Methodologically, the use of PARDL addresses mixed integration orders, cointegration, and feedback dynamics often neglected in African climate–economy studies. The study also operationalizes biocapacity for macro-sector applications and applies robust, bias-resistant panel estimators with cross-sectional dependence controls, multiple climate hazards, and moderator pathways for readiness and adaptation. Policy-wise, the findings identify both immediate and structural risks, highlight ecological and climatic thresholds critical for resilience, and provide actionable insights for adaptation planning, ecosystem restoration, and green economy strategies.

The remaining sections of the paper present empirical methods including data sources and estimation models and quantitative techniques. Subsequently, the third section presents the results from the model estimations while, finally, in-depth discussion of the results and conclusions and policy implications are presented in the fourth and last section.

Methodology

Data source

Our study focused on Africa. Africa is often described as one of the most vulnerable regions to climate change risks and impacts with low adaptive capacity. Data spanning a period of fifteen (2006 to 2020) and spanning across thirty-eight (38) countries were used. Table 1 shows the countries studied. Data availability informed the choice of the period covered and countries studied.

Table 1. Sampled countries

Code	Country
1	Algeria
2	Angola
3	Benin
4	Burkina Faso
5	Burundi
6	Cameroon
7	Chad
8	Congo Democratic Republic
9	Congo Republic
10	Côte d'Ivoire
11	Equatorial Guinea
12	Eswatini
13	Ethiopia
14	Gabon
15	Gambia
16	Ghana
17	Guinea
18	Guinea-Bissau
19	Kenya
20	Madagascar
21	Malawi
22	Mali
23	Mauritania
24	Mauritius
25	Morocco
26	Mozambique
27	Namibia
28	Niger
29	Nigeria
30	Rwanda

31	Senegal
32	South Africa
33	Tanzania
34	Togo
35	Tunisia
36	Uganda
37	Zambia
38	Zimbabwe

The variables considered in this study include gross fixed capital formation in agriculture, fishing and forestry; biocapacity; temperature; rainfall; employment in agriculture; and agriculture, forestry, and fishing, value added. Gross fixed capital formation data was obtained from the FAOSTAT database while biocapacity data was obtained from the Global Footprint Network database. Temperature and precipitation were obtained from the World Bank Climate Change Knowledge Portal database while agriculture, forestry, and fishing, value added and employment in agriculture were obtained from the World Development Indicators database. The description of the variables and their respective data sources were presented in Table 2.

Table 2. Description of the variables

Variables	Source
Gross Fixed Capital Formation (Agriculture, Forestry and Fishing) (million USD)	FAOSTAT
Precipitation (mm)	World Bank Climate Change Knowledge Portal
Temperature (^{0}C)	World Bank Climate Change Knowledge Portal
Biocapacity (global hectares)	Global Footprint Network
Employment in agriculture (% of total employment) (modeled ILO estimate)	World Development Indicator
Agriculture, forestry, and fishing, value added (% of GDP)	World Development Indicators

Econometric strategy

The paper employed the pooled mean group and dynamic fixed models of the panel autoregressive distributed lag framework to model the impact of climate change on value addition in agriculture. Our dependent variable, value addition in agriculture is proxied by agriculture, forestry, and fishing value added. The independent variables include temperature, rainfall, and biocapacity while employment in agriculture and gross fixed capital formation served as the control variables. One of the advantages of the panel autoregressive distributed lag framework lies in its ability to determine first and second orders cointegration among all the variables (Kumar et al., 2021). The framework is also free from endogeneity problem (Onyeneke et al., 2024a; Chidiebere-Mark et al., 2022).

We employed two different unit root tests to determine the stationarity or otherwise of the dataset used in this paper. These include Im–Pesaran–Shin (IPS) unit-root test and Cross-sectionally Augmented Im-Pesaran-Shin (CIPS) unit root test. To determine whether the datasets have long-run and short-run relationships, we subjected the model variables to three different cointegration tests. These include Kao, Pedroni and Westerlund tests for cointegration. The implicit model of our panel autoregressive distributed lag framework is stated as follows:

$$\mathrm{VAD} = \mathrm{f(GFCF, RAIN, TEMP, BIOC, EMP)} \qquad (1)$$

Where;

VAD = Agriculture, forestry, and fishing, value added (% of GDP)

GFCF = Gross Fixed Capital Formation (Agriculture, Forestry and Fishing) (million USD)

RAIN = Precipitation (mm)

TEMP = Temperature (^{0}C)

BIOC = Biocapacity (global hectares)

EMP = Employment in agriculture (% of total employment) (modeled ILO estimate)

The observed values of the variables were converted to natural logarithm. This was done to control potential heteroskedasticity in our dataset (Onyeneke et al., 2025a; Onyeneke et al., 2025b). The explicit model of the panel autoregressive distributed lag model is written thus:

$$\mathrm{lnVAD_{it}} = \beta_0 + \beta_1\mathrm{lnGFCF_{it}} + \beta_2\mathrm{lnRAIN_{it}} + \beta_3\mathrm{lnTEMP_{it}} + \beta_4\mathrm{lnBIOC_{it}} + \beta_5\mathrm{lnEMP_{it}} + \varepsilon_{it} \qquad (2)$$

Where; i:1, 2, 3, …, 38 countries; t:2006, 2007, 2008, …, 2020 year; ln is natural logarithm; ε is the error term. Furthermore, β_1, β_2, β_3, β_4, and β_5 define the estimated percentage change in agriculture, forestry, and fishing, value added explained by a unit percent change in gross fixed capital formation, precipitation, temperature, biocapacity, and employment in agriculture, respectively.

Standard panel regressions as expressed model in equation 2 can be used to estimate efficient and consistent if all the variables are stationary at levels. In a situation where some variables are stationary at levels and others stationary at first difference, a dynamic model for panel data with cointegration is required and such model should be an autoregressive distributed lag model (ARDL). The pooled mean group (PMG) and dynamic fixed effect (DFE) models are popular in the literature for computing dynamic heterogeneous panel datasets. To understand the long-run impacts and the long run adjustment rate, it is necessary to identify the short run dynamics.

The long- and short-run impacts of climate variation and biocapacity on value addition in agriculture over time and across different countries in Africa using the panel ARDL can be estimated thus:

$$\Delta \mathrm{lnVAD}_{it} = \beta_i + \beta_{1i}\mathrm{lnVAD}_{i,t-1} + \beta_{2i}\mathrm{lnGFCF}_{i,t-1} + \beta_{3i}\mathrm{lnRAIN}_{i,t-1} + \beta_{4i}\mathrm{lnTEMP}_{i,t-1} + \beta_{5i}\mathrm{lnBIOC}_{i,t-1} + \beta_{6i}\mathrm{lnEMP}_{i,t-1} + \sum_{j=1}^{p_1} \gamma_{1ij}\,\Delta\mathrm{lnVAD}_{i,t-j} + \sum_{j=1}^{p_2} \gamma_{2ij}\,\Delta\mathrm{lnGFCF}_{i,t-j} + \sum_{j=1}^{p_3} \gamma_{3ij}\,\Delta\mathrm{lnRAIN}_{i,t-j} + \sum_{j=1}^{p_4} \gamma_{4ij}\,\Delta\mathrm{lnTEMP}_{i,t-j} + \sum_{j=1}^{p_5} \gamma_{5ij}\,\Delta\mathrm{lnBIOC}_{i,t-j} + \sum_{j=1}^{p_6} \gamma_{6ij}\,\Delta\mathrm{lnEMP}_{i,t-j} + \epsilon_{it} \quad (3)$$

Where; Δ denotes first differences, β_i is a constant, $\gamma_{nij(n=1,\ldots,6)}$ denote short-run coefficients, $\beta_{mi(m=1,\ldots,6)}$ are long-run coefficients and ϵ_{it} is an error term. Equation (3) could be re-stated with an error correction term as follows:

$$\Delta \mathrm{lnVAD}_{it} = \vartheta_i + \sum_{j=1}^{p_1} \gamma_{1ij}\,\Delta\mathrm{lnVAD}_{i,t-j} + \sum_{j=1}^{p_2} \gamma_{2ij}\,\Delta\mathrm{lnGFCF}_{i,t-j} + \sum_{j=1}^{p_3} \gamma_{3ij}\,\Delta\mathrm{lnRAIN}_{i,t-j} + \sum_{j=1}^{p_4} \gamma_{4ij}\,\Delta\mathrm{lnTEMP}_{i,t-j} + \sum_{j=1}^{p_5} \gamma_{5ij}\,\Delta\mathrm{lnBIOC}_{i,t-j} + \sum_{j=1}^{p_6} \gamma_{6ij}\,\Delta\mathrm{lnEMP}_{i,t-j} + \lambda_i \mathrm{ECT}_{i,t-1} + \epsilon_{it} \quad (4)$$

Where; $ECT_{i,t-1}$ is the error correction term.

Results

Summary statistics

In Table 3, we present the summary statistics of variables used for the analysis. The country-time combinations yield 570 observations from 38 African countries over a 15-year time span (2006 -2020). The standard deviation of gross fixed capital formation in agriculture including forestry and fishing shows a wide disparity among sample countries showing extreme minimum and maximum. The average precipitation and temperature are around 1037mm and 24.6^{0}C with drier regions experiencing very low precipitation (62.6mm) or hotter temperature (29.8^{0}C). Also, country heterogeneity exists in biocapacity as this capacity varies widely among the sample countries. Lastly, agriculture employs close to half (approximately 49%) of total employment in studied countries. Due to the presence of wide disparities in the selected environmental and economic variables, the natural logarithmic transformation is applied to smooth out all extreme values.

Table 3. Descriptive Statistics

Variable	N	Minimum	Maximum	Mean	Std. Deviation
Gross Fixed Capital Formation (Agriculture, Forestry and Fishing) (million USD)	570	8.8	18914.4	818.16	2439.07
Precipitation (mm)	570	62.6	3406.58	1036.69	574.52
Temperature (^{0}C)	570	17.77	29.76	24.59	3.21

Biocapacity (global hectares)	570	870000	3.20e+08	3.72e+07	5.41e+07
Employment in agriculture (% of total employment) (modeled ILO estimate)	570	5.32	90.07	48.64	20.87
Agriculture, forestry, and fishing, value added (% of GDP)	570	0.89	45.88	18.78	10.52

Multicollinearity

We examined whether there is a problem of multicollinearity with the independent variables in this study (see Table 4). The test result for the variance inflation factor (VIF) and tolerance of the variables suggest that there is absence of multicollinearity among our independent variables. All the variables have VIF below the acceptable threshold of 5. Previous studies have used this threshold to establish the absence of multicollinearity (see Onyeneke et al., 2023a; Onyeneke et al., 2023b; Elom et al. 2024a; Onyeneke et al., 2024b). Moreover, the tolerance levels are all above 0.25, which is an acceptable threshold below which multicollinearity becomes a concerning issue.

Table 4 Variance inflation factor and tolerance of the variables

Variable	Tolerance	VIF
lnGFCF	0.464	2.154
lnRAIN	0.846	1.182
lnTEMP	0.923	1.083
lnBIOC	0.458	2.183
lnEMP	0.784	1.275

Cross-sectional dependence

We carried out a cross-sectional dependence test to check cross-sectional independence properties of the variables in our model. This is the first step in the econometric strategy adopted in this paper. The cross-sectional dependence test is important to validate our chosen econometric framework since the presence of cross-sectional independence can bias the result from the estimated model. To reject the null hypothesis of cross-sectional independence, the CD-statistic should be significant at 1% level of probability implying that the p-values should be lower than 1%. The probability values of the CD-test were lower than 1%, hence the null hypothesis was rejected (see Table 5). The result indicates that the variables, lnVAD, lnGFCF, lnRAIN, lnTEMP, lnBIOC and lnEMP had their computed CDs lower than 1%. The cross-section dependence tests suggest that the countries chosen for this study have similar characteristics and shocks (Pesaran, 2015).

Table 5 Cross-sectional dependence test

Variable	CD-test	p-value
lnVAD	4.28	0.000
lnGFCF	44.79	0.000
lnRAIN	11.03	0.000
lnTEMP	43.58	0.000
lnBIOC	19.13	0.000
lnEMP	65.38	0.000

Stationarity test

We applied both a first-generation panel unit root test (Im et al., 2003) and a second-generation panel unit root test (Pesaran, 2007) to check the stationarity and order of integration of the dependent and independent variables. The results are presented in Table 6. The variables were tested at level [I(0)] and first difference [I(1)]. We found that precipitation, temperature and biocapacity were stationary at level in both the first-generation and second-generation panel unit root tests, while all the variables were stationary at first difference in both the first-generation and second-generation panel unit root tests. Based on the results, the study rejected the null hypotheses that all panels contain unit roots, and the series have a unit root. The test findings indicate that the variables are I(1) and the maximum integration level is specified as 1. The variables in our model showed mixed nature of stationarity properties, being stationary at level and first difference. This suggests the presence of cointegrating relationship among the variables and the need to conduct several cointegration tests to confirm this.

Table 6 Stationarity test

Cross-sectionally Augmented Im-Pesaran-Shin (CIPS)			
Variable	**At level**		
	At level	**At first difference**	**Decision**
lnVAD	−1.612	−3.622***	I(1)
lnGFCF	−1.997	−3.389***	I(1)
lnRAIN	−3.875***	−5.268`***	I(0)
lnTEMP	−3.290***	−5.283***	I(0)
lnBIOC	−2.895***	−4.281***	I(0)
lnEMP	−1.427	−2.512***	I(1)
Im–Pesaran–Shin (IPS)			
Variable			
	At level	**At first difference**	**Decision**
lnVAD	−0.185	−13.291***	I(1)
lnGFCF	1.817	−13.216***	I(1)
lnRAIN	−12.462***	−26.996***	I(0)
lnTEMP	−7.999***	−14.946***	I(0)
lnBIOC	−6.312***	−7.810***	I(0)

lnEMP	4.670	−4.550***	I(1)

***p < 0.01 indicates significance at 1%

Cointegration test

If unit root tests contain I(1) variables, this shows the presence of cointegration. It is appropriate to test the cointegration in such models. As a result, we employed three panel cointegration tests – the Kao, Pedroni and Westerlund tests. The results of the cointegration test are presented in Table 7. The results indicate a long-run relationship exists among the variables in our model. Given the significance of the statistics, the null hypothesis of no cointegration is rejected (Elom et al., 2024b; Munonye et al., 2025). Therefore, there are both long-run and short-run relationships between the dependent variable (agriculture, forestry and fishing value added) and the explanatory variables (gross fixed capital formation, precipitation, temperature, biocapacity, and employment in agriculture). This further justifies our choice of panel autoregressive distributed lag framework in this study to model the short-run and long-run impacts of climate variation and biocapacity on value addition in agriculture, forestry and fishing sectors in Africa.

Table 7. Cointegration test

Kao test for cointegration	
Statistic	
Modified Dickey–Fuller t	1.642*
Dickey–Fuller t	1.665**
Augmented Dickey–Fuller t	2.641***
Unadjusted modified Dickey–Fuller t	0.184
Unadjusted Dickey–Fuller t	0.389
Pedroni test for cointegration	
Statistic	
Modified Phillips–Perron t	7.454***
Phillips–Perron t	−2.983***
Augmented Dickey–Fuller t	−2.527***
Westerlund test for cointegration	
Statistic	
Variance ratio	1.327*

***p < 0.01, **p < 0.05, *p < 0.1 indicate significance at 1%, 5% and 10% respectively

Panel ARDL estimates of the impacts of climate change and biocapacity on value addition in agriculture

We used the pooled mean group (PMG) and the dynamic fixed effect (DFE) model to assess the long-run and short-run relationship between the dependent variable (agriculture, forestry and fishing value added) and independent variables (gross fixed capital formation, precipitation, temperature, biocapacity, and employment in agriculture) in the presence of cross-section dependence and presented the results in Table 8. The PMG and DFE are second-generation estimation models, which provide reliable, consistent and efficient results under cross section dependence. The Hausman test was used to determine the method that best fits our dataset. From our result, the PMG is favoured, and it also had the highest number of significant variables in both the short-run and long-run. The PMG estimation of the impacts climate variation, biocapacity, gross fixed capital formation and employment in agriculture on agriculture, forestry and fishing value added showed varied results in the short run and in the long run (Table 8).

There is a positive and significant relationship between gross fixed capital formation in agriculture, fishing and forestry and agriculture, forestry and fishing value added in both the short run and long run. This implies that gross fixed capital formation significantly increased agriculture, forestry and fishing value added both in the short run and long run. A 1% increase in gross fixed capital formation in agriculture, fishing and forestry increased agriculture, forestry and fishing value added both by 0.03% in the long run and by 0.19% in the short run.

There is a positive and significant relationship between precipitation and agriculture, forestry and fishing value added in both the short run and long run. This implies that precipitation significantly increased agriculture, forestry and fishing value added both in the short run and long run. A 1% increase in precipitation increased agriculture, forestry and fishing value added both by 1.53% in the long run and by 0.14% in the short run. Precipitation significantly increased value addition in agriculture, fishing and forestry both in the short run and long run, showing the importance of rainfall in agriculture, fishing and forestry on the continent. Agriculture in Africa is largely rainfed. In Africa, only about 4% of arable land is currently irrigated, this is significantly lower than the proportion in Asia (37%) and Latin America (14%) (Wanyama et al., 2024; Kadigi et al., 2019). While irrigation holds significant potential for increasing agricultural productivity, most of the African food production relies on rainfed farming.

There is a positive and significant relationship between temperature and agriculture, forestry and fishing value added in both the short run and long run. This implies that temperature significantly increased agriculture, forestry and fishing value added both in the short run and long run. A 1% increase in temperature increased agriculture, forestry and fishing value added both by 6.93% in the long run and by 0.76% in the short run.

There is a negative and significant relationship between biocapacity, and agriculture, forestry and fishing value added in both the short run and long run. This implies that biocapacity significantly decreased agriculture, forestry and fishing value added both in the short run and long run. A 1% increase in biocapacity decreased agriculture, forestry and fishing value added both by 0.98% in the long run and by 0.57% in the short run. This poses a challenge in the achievement of sustainable food value chain management and shows the use of unsustainable use of earth's capital in agricultural, fisheries and forestry value addition activities. The need to increase food security has driven unsustainable use of earth's natural capital on the continent. This in turn reduces the quality of value added in agricultural products and food produced. Sustainable food value chain management is also hampered by unsustainable use of earth's capital. Onyeneke et al. (2024a) found a negative impact between biocapacity and rice yield in Africa. They attributed this impact to unsustainable use of earth's biologically productive lands and water resources.

There is a positive and significant relationship between employment in agriculture and agriculture, forestry and fishing value added in the long run. This implies that employment in agriculture significantly increased agriculture, forestry and fishing value added in the long run. A 1% increase in employment in agriculture increased agriculture, forestry and fishing value added both by 1.11% in the long run.

Table 8. Panel ARDL results from pooled mean group and dynamic fixed effect estimators

Variables	**Agriculture, forestry and fishing value added**	
	PMG	**DFE**
Long-run impacts		
lnGFCF	0.04	0.23
	(1.75)*	(3.54)***
lnRAIN	1.53	0.42
	(10.57)***	(1.60)
lnTEMP	6.93	2.50
	(6.60)***	(1.08)
lnBIOC	−0.98	−0.92
	(−6.43)***	(−2.74)***
lnEMP	1.11	0.75
	(9.62)***	(3.46)***
Short-run impacts		

ECT	−0.19	−0.23
	(−4.40)***	(−9.11)***
ΔlnGFCF	0.19	0.14
	(2.95)***	(6.89)***
lnRAIN	0.14	0.08
	(2.10)**	(2.05)**
lnTEMP	0.76	0.47
	(2.10)**	(1.13)
lnBIOC	−0.57	0.17
	(−1.91)*	(1.85)*
lnEMP	0.59	0.30
	(1.06)	(2.63)***
Constant	3.23	-0.76
	(4.45)***	(-0.35)

Hausman test of poolability (H_o: difference in coefficients not systematic)

	PMG and DFE
$\chi^2(5)$	0.04
p-value	1.000
Decision	The PMG is preferred over the DFE

Note: z-values are presented in parentheses. *** denotes statistical significance at 1%, ** denotes statistical significance at 5%, and * denotes statistical significance at 10%. ECT is the error correction term/speed of adjustment towards the long run equilibrium.

Discussion

The results, as presented in the preceding section, fit well into the established knowledge of climate change impacts on agriculture in developing economies, more so from a wide panel of agrarian-based African countries. Specifically, the results highlight the positive effects of increases in rainfall (i.e., precipitation) on agricultural GDP, especially in the long term since a large percentage of Africa's agriculture is solely dependent on rainfall. Thus, the predominance of rain-fed agriculture in Africa makes the continent extremely susceptible to drought spells and the far-reaching effects on the environment, societies and the economy (Ayugi et al., 2022; Lottering et al., 2021). As also found by Paglialunga et al (2022), precipitation shortfalls could have significant adverse effects on agriculture production, poverty and inequality in rural agricultural households.

As predictability of the weather requires a longer timeframe where production could be well-suited to the observed rainfall patterns, the impact of rainfall is also stronger in the long run than in the near-term. This finding is also corroborated by (Damania et al., 2020; Gilmont et al., 2018; Pickson & Boateng, 2022). Thus, in shorter time intervals, the effect of increased rainfall on agriculture GDP could result in relatively less significant increases in agricultural performance and/or growth as found in this study and elsewhere (Kotz et al., 2022). However, extreme or prolonged daily rainfall could inundate farmlands and cause a decline in agriculture growth (Kotz et al., 2022; Meyghani et al., 2023). Other scholars like (Ciccone & Ismailov, 2022) found an inverted U-shape relationship between rainfall and agriculture output, as agriculture is harmed by both droughts and very wet conditions. Xu et al (2021) found that precipitation responses were highly heterogeneous with inverted-U effect on agriculture outputs. The findings from these other studies together with our results imply that for most of the African countries in our study, the average levels of rainfall over the period considered may be lower than the optimal levels such that increases in rainfall are positively associated with increases in agricultural value added.

Regarding atmospheric temperature, our results deviate from the popular narrative of a negative relationship between temperature and agriculture productivity. We find that increases (moderate) in temperature positively affect agricultural productivity in Africa. This suggests that most African countries operate within or near their optimal temperature ranges without leading to heat stresses (Stone, 2023). Though not very popular, this finding is also not uncommon. For example, Ye et al (2021) found that in China elevated temperatures contribute to significant yield increases. Similarly, a study in South Africa by Benhin (2008) revealed that a percentage increase in temperature led to $80 increase in crop net revenue and concluded that climate change could be beneficial if countries could take advantage of the relative benefits across seasons, farming systems and spatially. Our result is also consistent with that of Onyeneke et al. 2024b and Emenekwe et al. (2022), which show positive association between temperature maize production and rice production in Nigeria, respectively.

It is also possible that the otherwise adverse impact of temperature rise on agriculture value added could have been mitigated by observed increases in national employment and investment (GFCF) over the same period. For instance, investment in transportation and storage infrastructure has been found to reduce transaction costs, enhance market access, and minimize post-harvest losses and improve overall agriculture growth (Kaiser & Barstow, 2022; Zhou et al., 2021). Irrigation infrastructure also plays a particularly significant role in mitigating climate variability and extending growing seasons. In this regard increasing agriculture production and incomes. A study by Burney et al (2024) finds that investments in small-scale irrigation schemes significantly enhance yields and household incomes in rain-fed farming systems across Africa and Asia.

Also, the transformation of agricultural employment from subsistence-oriented to market-oriented activities is seen as a key pathway to productivity growth. Further, labour-intensive agricultural systems, when combined with access to technology and markets, can boost rural agriculture incomes and support structural transformation (Deininger et al., 2022). The interaction between employment and infrastructure is mutually reinforcing on productivity. Improved infrastructure can enhance the productivity of labour in agriculture, while a well-trained and adequately compensated workforce can better utilize infrastructure to generate growth and mitigate impact of climate change (Jayne et al., 2023).

Our results show an inverse relationship between agricultural value added and biologically productive capacity. This result suggests that activities leading to increases in agricultural value added are associated with an unsustainable depletion of the capacity of the natural environment to continuously provide ecological services in Africa. Other studies like Onyeneke et al. (2024a) and Rockström et al. (2024) also documented the effects of continuous expansion or intensification exceeding local biocapacity leads to soil degradation, biodiversity loss, deforestation, and water scarcity. Thus, overexploitation of indigenous natural resources and eco-services for development rather leads to long-term productivity declines in natural resources or eco-services, particularly when prioritizing wealth and prosperity at the expense of the natural environment (Aslan & Altinoz, 2021). This means that adaptation strategies that enhance biocapacity, such as restoring degraded lands and protecting ecosystem services, are therefore central to climate-resilient agriculture, as argued by Srivastav et al. (2021). Practices like crop diversification, organic soil amendments, and regenerative grazing have been shown to improve yields and restore ecosystem functions (Rockström et al., 2024).

Conclusions, Policy Implications and Limitations

This study examined the impacts of climate change and biocapacity on agriculture, forestry, and fishing value added across 38 African countries between 2006 and 2020 using a panel autoregressive distributed lag (PARDL) framework. The results provide novel insights into how climatic and ecological factors jointly influence Africa's primary production sectors.

The findings reveal that precipitation, temperature, employment in agriculture, and gross fixed capital formation significantly and positively influence agricultural value added in both the short and long run, underscoring the importance of favourable climatic conditions, labour engagement, and capital investments in sustaining productivity. Conversely, biocapacity exerts a significant negative effect on agricultural value added, implying that current growth trajectories in these sectors are achieved at the expense of ecological integrity and long-term sustainability.

The positive impacts of rainfall and temperature indicate that most African countries remain within ecological and climatic thresholds that are still conducive to agricultural productivity. However, the depletion of biocapacity highlights the growing environmental cost of production expansion, driven largely by unsustainable resource use and land degradation. This suggests that while short-term productivity gains are attainable, they may be undermined in the long run if ecological regeneration is not prioritized.

Overall, the study underscores that Africa's agricultural transformation cannot be sustained without simultaneously addressing ecological resilience and climate adaptation. Strengthening environmental governance, investing in climate-smart and resource-efficient technologies, and restoring natural ecosystems are critical to reversing current trends and ensuring the long-term viability of Africa's agri-food systems.

By integrating biocapacity into the climate–economy nexus, this research contributes new empirical evidence to ecological economics and offers actionable insights for policymakers seeking to harmonize agricultural growth with environmental sustainability. The results reaffirm that economic resilience and environmental health are interdependent and must be pursued together for inclusive, climate-resilient development across the continent.

The findings of this study have several important implications for policymakers, researchers, and development practitioners seeking to promote sustainable and climate-resilient growth in Africa's agricultural, forestry, and fisheries sectors. African governments should prioritize the transition toward climate-smart agricultural systems that combine productivity enhancement with ecological preservation. This involves scaling up investments in irrigation infrastructure, drought- and heat-tolerant crop varieties, soil moisture conservation, and renewable energy for agricultural production. Integrating these technologies will reduce overreliance on rainfall and enhance resilience against temperature variability.

Given the observed negative relationship between biocapacity and agricultural value added, urgent efforts are needed to restore degraded lands and ecosystems. Governments and regional bodies should promote reforestation, sustainable land use planning, watershed management, and marine ecosystem protection. Such initiatives will rebuild biocapacity and secure the natural resource base upon which agricultural productivity depends.

National and regional development frameworks should institutionalize biocapacity and ecological footprint accounting within agricultural and economic policy planning. This will enable policymakers to evaluate ecological limits, monitor environmental sustainability, and guide decisions toward regenerative growth rather than extractive expansion.

The study highlights that while increased rainfall, temperature, and capital investments can boost agricultural productivity, these gains are often accompanied by unsustainable exploitation of ecological resources. Policymakers must therefore strike a balance between short-term productivity and long-term ecological integrity. Integrating biocapacity metrics into agricultural and economic planning will enable countries to track environmental limits and adjust growth strategies, accordingly, preventing ecological overshoot. The results also suggest that climate adaptation policies should move beyond reactive responses toward proactive, ecosystem-based approaches that reinforce both productivity and sustainability.

Finally, the study reinforces the relevance of Sustainable Development Goals (SDGs) 2 (Zero Hunger), 13 (Climate Action), and 15 (Life on Land) by demonstrating that agricultural growth, climate resilience, and environmental sustainability must be pursued simultaneously. Aligning national climate policies, agricultural investments, and ecological restoration initiatives will be central to achieving these goals and ensuring resilient food systems across Africa.

Although this study provides novel empirical evidence on the relationships among climate change, biocapacity, and value added in Africa's agriculture, forestry, and fisheries sectors, several limitations should be acknowledged. First, data limitations constrained the analysis to 38 African countries over the period 2006–2020, primarily based on data availability. This restriction may have excluded some smaller or data-deficient countries, potentially limiting the generalizability of the findings. Future studies should extend the temporal and spatial coverage as more consistent and high-frequency data become available. Second, the study employed aggregate indicators of agriculture, forestry, and fishing value added due data availability. While useful for cross-country comparison, this aggregation may mask heterogeneity within sub-sectors. Subsequent research could disaggregate these sectors when data become available to examine how climate and biocapacity dynamics uniquely affect crops, livestock, forestry, and fisheries.

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