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# Effects of Climate Change on Economic Growth: A Perspective of the Heterogeneous Climate Regions in Africa

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**Abstract:** Climate change is a negative global externality that threatens economic growth. In our study, we firstly reviewed the transmission mechanisms of climate change affecting economic growth based on existing literature. Secondly, we respectively used the fixed effect method and the panel vector autoregression method to test the short-run and long-run effects of climate change on the economic growth of 44 countries in six climatic zones in Africa, from 2000 to 2019. The results showed that temperature has inverted U-shaped effects on the economic growth of countries in tropical rainforest and tropical dry climate zones, but a U-shaped effect in warm temperate humid regions. The heterogeneity test was based on industrial and geographical perspectives. Climate change has a significant inverted U-shaped effect on agricultural and services output in tropical rainforest and tropical dry climate zones. Moreover, climate change positively impacts economic growth in coastal regions, but has no significant impact on inland countries. Lastly, the long-run results indicate that tropical rainforest and subtropical humid regions show a greater ability to adapt to climate change, while tropical desert regions show greater volatility resilience in response to climate change.

**Keywords:** climate change; economic growth; fixed effect; Africa; panel vector autoregression method

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## 1. Introduction

Climate change, as a natural phenomenon caused by human social production and activity, has been identified as one of the most daunting challenges facing the contemporary world. As countries around the world move towards a carbon-neutral era, the issue of shared governance on climate change is taking center stage in global politics. The international community has attached great importance to climate change, and signed a series of agreements to reduce greenhouse gas emissions and protect the ecological environment since the 20th century, such as the United Nations Framework Convention on Climate Change (UNFCC), the Kyoto Protocol, and the Paris Agreement. The worldwide conferences have played a great role in curbing climate change. Ironically, because of the unique exogenous characteristic of climate change, there exist free-rider, cost, and inefficiency problems [1,2]. There are a number of problems between countries around the world in the areas of climate geo-economies and climate geo-politics [3]. Climate change is a major obstacle to economic growth and social development [4]. According to research studies, climate change could be the main cause of reduced agricultural yields and increased food risks [5], worsening disease incidence [6], and the gap between the rich and poor [7]. It is increasingly apparent that the underlying issues of climate change need to be emphasized.

Climate change is a global issue in the post-industrial era of 'rethinking' the costs of development, although the African continent is barely responsible for its history [8]. When some African countries spend economic resources in mitigating and adapting to climate change, their economic growth will be limited. This is because these resources are necessary to upgrade infrastructure or enhance social welfare. Africa is the region most severely affected by climate change [9], yet it obviously contributes to a small proportion of global greenhouse emissions. However, Africa is an area that struggles the most to cope with climate change because of its heavy reliance on rain-fed agriculture, which is the main livelihood of the largest segment of the population. According to the latest data, the May global surface temperature in 2022 was 1.39 °F (0.77 °C) higher than the 20th-century average of 58.6 °F (14.8 °C) [10]. In Africa, the temperature rise has been slightly faster than the global average level. Africa's annual temperature has increased at an average rate of 0.13 °C (0.23 °F) per decade since 1910 [11]. Over the period of 2000–2018, temperature has had a particularly significant impact on the economic growth in sub-Saharan Africa. Figure 1 directly shows the impact of annual average temperature changes on the economic growth rate. It can be seen that despite a slight lag, the annual growth rate of GDP changed with the same trend from 2000 to 2015. Accordingly, Africa is expected to be hit hardest by the effects of global warming.

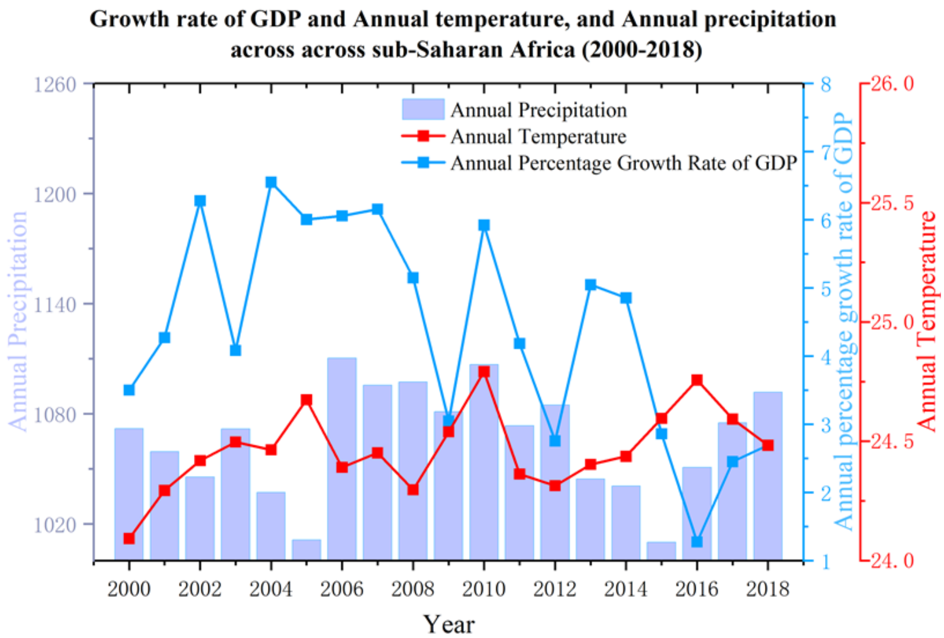


**Figure 1.** Annual percentage rates in GDP per capital and annual temperature across sub-Saharan Africa. Source: Authors' compilation based on World Bank data.

Resources and environment are not only endogenous variables for economic development, but are also rigid constraints on the scale and speed of economic development in the future of sustainable development on the African continent. The available research on the effects of climate change on economic growth in Africa fall into the following two main categories: (1) In terms of research perspectives, researchers have mainly selected individual African countries or sub-Saharan areas as samples for quantitative studies, while there are few studies on whole samples that take the entire African continent as a sample; (2) few scholars have analyzed the impacts of climate on economic growth in Africa in two comparative ways, different geographical locations and different climatic regions.

In this research, we divided Africa into six climatic zones to analyze the impact of climate change on economic growth in Africa and its transmission mechanisms, using a panel regression with data during 2000–2019. To confirm our findings, we employed the fixed effect model to examine the relationship between climate change and economic growth. Furthermore, we identified the extent to which climate change affects economic growth according to the different climate zones. Moreover, our research further analyzed the impact of climate change on different production sectors, such as the agricultural sector, the industrial sector and the service sector. Climate change has a short-term shock impact on the economy, but there is also a long-term lag for this shock. Therefore, to identify the long-term effects of climate change on economic growth, we explored the long-term interaction between economic growth and climate change using a panel vector autoregression (PVAR) model.

Our findings provide new scientific results towards the underlying relationship between climate change and economic growth by concentrating on six climatic regions in Africa. Economic growth may be influenced not only by a country's climatic region, but also its geographical location. Specifically, climate change has a negative impact on the economic growth in countries that are close to the equator, but a positive impact on economic growth in countries far from the equator. Furthermore, our analysis found that agriculture is the sector that is most vulnerable to climate shocks. The analysis of PVAR results showed that the African continent is able to adapt to the impact of climate change shocks. Our research provides policy implications for sustainable development in the world.

The rest of the study is structured as follows: Section 2 covers the literature review; Section 3 outlines the empirical framework, methodology, and data; Section 4 presents the empirical results and discussion; extended research is presented in Section 5; Section 6 provides the discussion; Section 7 features the conclusion and policy implications.

## 2. Literature Review

Scholars have been exploring whether and how climatic conditions affect the nature of societies and the economic performance for many centuries. The multidisciplinary nature of quantitative research has elucidated key linkages in the coupling of complex natural environments and human systems, revealing significant impacts of climate on aspects concerning human and physical capital. Ancient research focused on the delineation of the climate system [12], and the causal effects of climate on different social structures and economic prosperity [13]. Recent research has turned to the environmental impacts or effects of population expansion and energy over-exploitation [14]. Contemporary research has focused on estimating the economic and social impacts of global climate change [15–17] and its exogenous governance [18,19].

Contemporary important research on the relationship between environment and economy involves the environmental Kuznets hypothesis (EKC). The EKC implies that environmental deterioration and economic growth have an inverted-U connection. When a country is in the early stages of economic development, economic growth comes at the expense of environmental degradation, but when the economy crosses a certain threshold, economic growth will contribute to environmental protection, showing a dynamic equilibrium between them [20]. The EKC has generated significant empirical research, with some confirming it [21–23] while others reject it [24–26]. Theoretically, the linkage between climate change and economic growth could be established through macroeconomic and microeconomic dimensions. From the macroeconomic side, the empirical literature can be organized around the thoughts of testing agricultural and industrial channel effects. Some researchers used a Ricardian model that considers farmers' adaptations to climate change, in order to analyze the impact of climate factors on agricultural yields [27–29]. Beyond the agricultural sector, some researchers studied the impact of interannual variations in temperature on industrial output and political stability in economies of different income levels [30]. In addition, other studies reported the impact of climate change on GDP growth [31,32] and the sustainability of globalized economies. Thus, climate change affects economic growth through the macro-output channel. From the microeconomic side, the empirical studies focused on the effect of climate change on labor productivity [33,34], population growth [35], and social and demographic factors. In the social field, evidence from multitudinous contexts repeatedly demonstrate that women are more vulnerable to the effects of climate change [36]. Similarly, climate change exacerbates group violence and aggression [37,38], and eventually leads to institutional breakdown and state failure [39,40].

Previous studies have analyzed the socio-economic impacts of climate change in different subject areas, and mainly focused on the perspectives of different geographical locations and countries around the world. Thus, there is a lack of research on the impact of climate change on economic growth in different climatic regions. The heterogeneous effects of climate change on growth rates are informed by both theoretical and empirical evidence. Some scholars explored the coupling between carbon emissions, economic growth, and temperature, based on climate heterogeneity in Africa. Carbon dioxide emissions in heterogeneous regions of Africa will raise per capita income, but the negative effect of temperature rise will reduce per capita income [41]. Abidoye et al. (2015) [42] analyzed the differential effects of temperature shocks on economic growth in 34 African countries, using annual fluctuations in temperature across Africa from 1961 to 2009, and indicated that a one-unit rise in temperature proxy reduces GDP growth by 0.667 percentage points; however, this impact is heterogeneous across countries. Moreover, Adom and Amoani (2021) [43] argue that temperature exerts significant negative effects on economic growth, while these effects are moderated by the level of adaptation readiness through output and institution channels. Their results revealed a negative effect of temperature on income within country and cross-country data. Baarsch et al. (2020) [44] used country-level data for Africa, and embedded an economic model with three risk dimensions to analyze the convergence of climate change damage; they found that climate change damage accounted for 10–15% of GDP per capita growth, and that East African countries are expected to have difficulty adapting to climate change. Molua et al. (2020) [45] explored the extent to which extreme weather events affected economic development and policies to address climate change in countries in the southeast of the continent, assessing the economic vulnerability and damage costs for countries in the region. Arndt et al. (2019) [46] developed a mathematical model to predict the impact of future climate change on economic growth. Their research also concluded that existing climate change mitigation policies will contribute to the economic development of six African countries by 2050. In addition to the direct impact of climate change on economic growth in Africa, some scholars have argued that climate change will affect economic growth through indirect mechanisms. For example, climate change can affect supply chain stability, and thus influence economic growth. Blekking et al. (2022) [47] suggested that food system transformations are driven by climate change and urbanization in sub-Saharan Africa, and proved that urbanization and food retailers' supply chains are also linked through political, economic, and social pathways. If the supply chain breaks down, economic growth will be greatly affected. Thus, numerous studies have shown that climate change can affect economic growth, based on different samples and time panels.

Throughout the literature, most of the studies about the impact of climate change on economic development have only focused on individual countries or parts of Africa. There is a lack of research that explores the relationship between climate change and economic growth in Africa from the perspective of climate heterogeneity. This research attempted to construct a multi-perspective analysis framework of regional differences and heterogeneous climate systems. We selected representative climatic regional economies in the African continent as a research sample, and carried out a study based on the comparative evaluation of heterogeneous climate zones and differential geographical locations. Thus, we can summarize the basic model of the relationship between climate change and spatial economic systems and economic growth, and provide a common response to climate change in the African continent.

## 3. Empirical Framework, Methodology, and Data

### 3.1. Empirical Framework

Studies have shown that there is a significant inverted U-shaped or U-shaped relationship between temperature and labor productivity. A smaller rise in temperature facilitates increased production in the agricultural sector, while providing more climate resources for productive life during climate change. Furthermore, the country has a stronger short-term adaptive capacity to adapt to climate change. Thus, countries can more fully utilize climate resources to promote economic growth. However, Zhang et al. (2018) [48] and Graff Zivin et al. (2018) [49] argued that short-term changes in temperature could affect total factor productivity in agricultural and industrial enterprises, and alter the allocation of labor time, as well as reduce cognitive capacity. Furthermore, temperature fluctuations can affect economic growth by increasing crime and disease rates, the risk of regime breakdown, and even leading to frequent regime changes [50]. On the one hand, rising temperature increases the probability of social unrest brought on by famine; on the other hand, it largely reduces the opportunity cost of engaging in violence and confronting the government [51]. High-temperature waves can trigger population movements and lead to significant migration waves, increasing the incidence of conflict in refugee influxes and affecting social stability [37]. Moreover, high-temperature waves can directly lead to reduced agricultural yields and lower rural household incomes. Farmers may migrate their families to more climate-friendly areas or directly across borders in search of new livelihoods, leading to changes in the regional labor force [52]. Similarly, extreme temperatures can put pressure on rapidly aging countries, increasing mortality among older populations and children [53]. Therefore, when the temperature exceeds a certain level, either too high or too low, it will lead to a decrease in labor productivity and labor supply capacity, resulting in a decrease in output.

Agriculture is one of the sectors most sensitive to climate change, and short-term fluctuations in temperature will lead to large changes in agricultural yields, which in turn will affect agricultural output levels [54,55]. Research shows that rising global temperatures will affect agricultural yields in low-latitude countries, but high-latitude countries will benefit from exploitable arable land and earlier-maturing crops from rising temperatures [56]. Temperature fluctuations not only cause a significant negative effect on the agricultural sector, but can also impact non-farm sector output through direct or indirect transmission mechanisms. The impact of temperature shocks on agriculture may be transmitted further downstream to industrial manufacturing production [57]. In addition, rising temperatures may affect the functioning of other industrial sectors, reducing the effectiveness of air conditioning and leading to possible absenteeism of workers [58]. Thus, when the temperature fluctuates, it will directly affect agricultural output and indirectly affect industrial and services output. Temperature shocks can affect the spatial balance of the global economic structure, interrupt supply chains, or redistribute labor affecting international trade, ultimately impacting economic growth. Temperature shocks can lead countries to adopt import strategies to offset the effects of temperature on indigenous industries and agriculture, and also reduce the export of areas subject to temperature shocks.

There is significant variability in the impact of temperature changes on economic growth in different geographical locations and different climatic regions. High-income countries can cope with the impacts of temperature changes on domestic industries by increasing demand for electricity and importing alternative products. However, low-income countries are more vulnerable to temperature shocks, as a result of lower productivity levels and poorly constructed infrastructure. High-income countries can recover from the effects of temperature shocks on social production through measures such as peer-to-peer financial subsidies and assistance from social welfare agencies; meanwhile, low-income countries have fewer measures available. The temperature has a heterogeneous effect on the economic shocks in different climatic regions, with colder climatic regions at higher latitudes being likely beneficiaries from increasing agricultural yields, available land area, and lower energy costs associated with rising temperatures; meanwhile, regions in lower and middle latitudes may suffer from higher energy prices, labor supply shortages, and lower labor productivity.

Figure 2 illustrates the climate and economic transmission mechanisms. We assumed that the climate system is initially in an equilibrium state. When there is an increase in endogenous greenhouse gas emissions caused by economic growth and exogenous greenhouse gas emissions, the total atmospheric greenhouse gas emissions will increase. Thus, the equilibrium of the atmospheric circulation system becomes disrupted by the limited absorption rates of oceans and the biosphere. Furthermore, increased greenhouse gas emissions and other exogenous climate factors lead to increases in atmospheric and surface temperatures, creating climate risks such as sea level rise, droughts, and higher frequencies of extreme weather. When the factors of production in a region are affected by climate change, this region's output and economic growth will also be influenced. Thus, based on the research mechanism, this study put forward the following hypotheses to be tested.

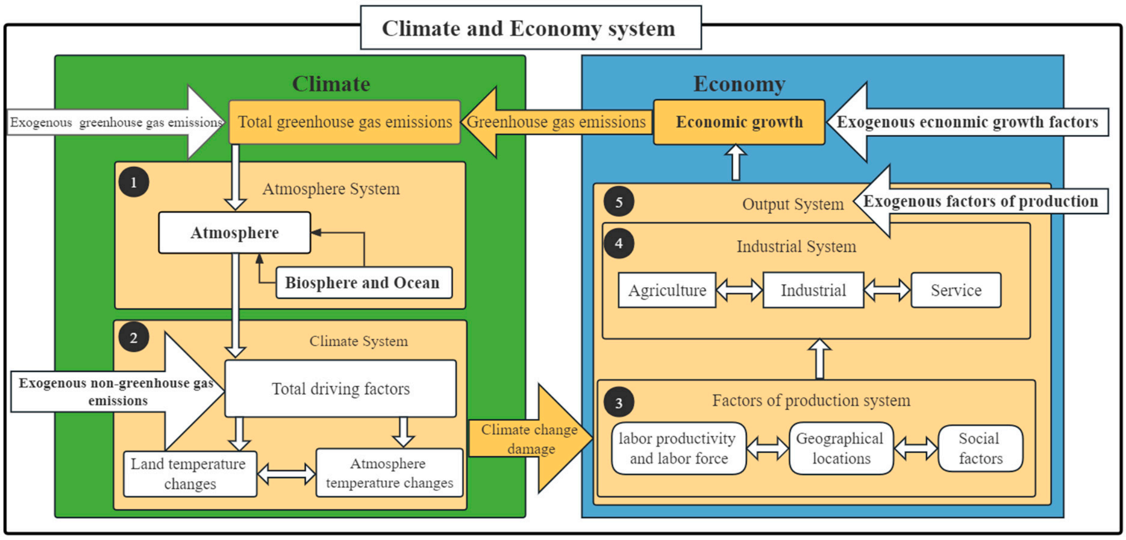


**Figure 2.** Climate economic transmission mechanism. Note: A stylized schematic of the empirical framework explains how climate change affects economic growth. (1) Greenhouse gas emission cycle; (2) driving factors of temperature changes; (3) a range of literature views on how climate change affects factors of production; (4) three industrial systems; (5) total output system.

**Hypothesis 1.** *Climate change has a non-linear impact on economic growth in heterogenous climatic regions.*

**Hypothesis 2.** *Agriculture, industry, and services are more vulnerable to temperature shocks in climate zones that are closer to the equator, while in other climatic regions, industries located away from the equator are less affected.*

### *3.2. Econometric Methodology*

Panel data contain many informative quantities of individual differences, and fixed-effects models can identify potential variability among individuals or groups of panel samples. Moreover, fixed effects can eliminate unobservable individual heterogeneity effects that do not vary over time, reducing endogeneity problems and achieving more robust results. In our study, we divided the African climate zone into six climate zones, each with its own climatic conditions; thus, the fixed effects model helped us to identify the extent to which economic growth in different climate zones was affected by climate change. Furthermore, climate has a significant non-linear and lagging effect on economic growth [59]. We used temperature as a proxy variable for climate change, based on our empirical framework. Thus, our baseline econometric model was a quadratic specification of temperature and economic growth to estimate the relationship between economic growth and its key determinants in Equation (1):

$$LnGDP_{it} = \beta_0 + \beta_1 Tem_{it} + \beta_2 {Tem_{it}}^2 + \sum_{j=3}^{n} \beta_{jt} X_{jt} + \gamma_{it} + \varepsilon_{it} \quad (1)$$

In Equation (1), $LnGDP_{it}$ is the explanatory variable, which represents the level of economic development of country $i$ in year $t$. To eliminate statistical errors caused by inflation, the economic development of country $i$ was measured by GDP in constant

2010 US dollars. $Tem_{it}$ and $Tem_{it}{}^2$ are the explanatory variable of the model, representing the average temperature in country $i$ in year $t$, which measures the extent of climate change impacts. $\sum_{j=3}^{n} \beta_{jt} X_{jt}$ represents the control variable. $\gamma_{it}$ is the individual fixed effects and $\varepsilon_{it}$ being the residual error.

$X_{it}$ represents control variables that influence economic growth. Carbon dioxide emissions ($CO_2$) and precipitation are considered to be climate control variables that broadly influence the economic growth of a country. This is because increased carbon emissions damage the natural environment and cause economic development to deviate from a sustainable development path. However, scholars have different views on the impact of carbon emissions on economic growth; some scholars believe that carbon emissions negatively affect economic growth [41], while others believe that there is a U-shaped relationship between carbon emissions and economic growth [20,60], such as the Kuznets curve of the environment. Rainfall was also our control variable. Barrios et al. (2010) [61] argued that increased rainfall worsens the conditions for economic growth; however, EI Khanji and Hudson (2016) [62] and Damania et al. (2020) [63] suggested that rainfall had an inverted U-shaped effect on economic growth, and this may be because for dry areas, the marginal economic returns are greater than those for wetter areas. The level of urbanization is measured by the number of urban populations in a country as a proportion of the total population, with a higher proportion indicating a higher level of urbanization. Urbanization is one of the core control variables to promote economic growth [64]. The higher the level of urbanization, the stronger the economic growth capacity of a country, because cities can promote the circulation and exchange of resources and gather capital to create greater production capacity. The degree of trade openness is measured by the proportion of a country's total foreign trade to its GDP in $t$ year, with a higher proportion indicating a country's close economic interaction with the rest of the world. Many studies have proven that international trade improves the level of economic development through such mechanisms as productivity improvement, technology spillover and participation in global value division of labor chains [65,66]. The proportion of renewable energy is measured by the proportion of renewable energy to total energy. The proportion of renewable energy use reflects a country's energy structure. Scholars believe that renewable energy is closely related to economic growth. The higher the proportion of renewable energy used, the faster the economic growth [67]. The proportion of labor force participation is measured by a country's labor force divided by its total population, with a high percentage indicating that a country has an adequate labor force to promote economic growth [68].

### *3.3. Climatic Regions and Data*

#### 3.3.1. Climatic Regions

It was necessary to identify the different climate zones in Africa before we analyzed the impact of temperature change on economic growth. The climate classification of African countries used was based on the Köppen–Geiger Climate classification, from the UN Climate Change Knowledge Portal (See the online Climate Change Knowledge Portal: https://climateknowledgeportal.worldbank.org/ (accessed on 15 September 2022)). Since some countries crossed climatic zones, we considered the region of a country with the largest share of a climate to be its climatic zone. In this study, Africa was divided into six main regions, namely the subtropical humid (STD), subtropical dry (STM), tropical dry (TDR), tropical desert (TDS), tropical rainforest (TM), and warm temperate humid (WTM) regions. Table 1 reports the characteristics of the different climatic zones.

**Table 1.** Basic information of the six African climate zones. Source: authors' self-painting using the UN Climate Change Knowledge Portal.

| Climatic Regions | Location | Countries | Major Climatic Features |
|---|---|---|---|
| Subtropical humid (STD) | Central Africa | Cameroon<br>Central African Republic<br>Gabon<br>Republic of Congo<br>Congo<br>Uganda<br>Burundi | (i) Temperatures are high (annual average 24–25 °C)<br>(ii) Rains fall throughout the year, averaging between 1600 mm and 2000 mm annually.<br>(iii) Humidity is high<br>(iv) Distinct dry and rainy seasons |
| Subtropical Dry (STM) | East and South West Africa | Tunisia; Angola<br>Namibia; Zambia<br>Botswana; Zimbabwe<br>Tanzania; Malawi<br>Mozambique; Madagascar<br>Kenya; Rwanda | (i) Temperatures are warm (annual average 21–23 °C<br>(ii) Rainfall is unevenly distributed, with low precipitation from April to October and high precipitation from October to next year's April |
| Tropical Dry (TDR) | Part of central Africa and west Africa | Chad<br>Nigeria<br>Benin<br>Burkina Faso<br>Senegal<br>Gambia | (i) Temperatures are high (annual average 26–29 °C)<br>(ii) Strong rainfall events are regular during the rainy season, mostly from March to October<br>(iii) The climate has a clear division of wet and dry seasons |
| Tropical Desert (TDS) | North Africa | Egypt<br>Libya<br>Algeria<br>Mali<br>Mauritania<br>Niger | (i) Temperatures are high (annual average 22–25 °C), with scorching temperatures of daily thermal variations<br>(ii) Rain is rare and irregular<br>(iii) Climate is dry, hot, and dominated by desert |
| Tropical Rainforest (TM) | West Africa | Togo; Ghana; Comoros<br>Côte d'Ivoire; Sierra Leone<br>Guinea-Bissau<br>Equatorial Guinea<br>Cape Verde; Mauritius | (i) Temperatures are high (annual average 25–27 °C)<br>(ii) Strong rainfall events are regular all year<br>(iii) Humidity is very high |
| Warm Temperate Humid (WTM) | North and South Africa | South Africa<br>Lesotho<br>Eswatini<br>Morocco | (i) Temperatures are warm (annual average 17–19 °C)<br>(ii) High temperatures but little rain in summer; on the contrary, low temperatures and much rain in winter |

Note: According to the existing climate information, we analyzed the climate characteristics of the six climatic regions that were classified. In the process of analysis, we followed the principle of subjectivity, and tried to make an overview of the overall characteristics of the sample.

### 3.3.2. Data

The data employed for this study was a dataset of 44 African countries from 2000 to 2019, and Table 1 also provides information specific to the countries we selected. However, considering the data accessibility for some countries' economic data in Africa, some countries were removed. For example, in Somalia, the data of international trade were uncounted since 2000, and most of the data only updated or started in 2012. In Eritrea, there were more missing data. Thus, we had a total of 44 sample countries for panel data, and they are introduced into the third column of Table 1. Data on the level of economic development, $CO_2$ emissions per capita, the level of urbanization, openness to trade, labor force participation rate, and the share of renewable energy use came from the World Bank; temperature and precipitation data came from the UN Climate Change Knowledge Portal. Table 2 provides descriptive statistics for the variables. We performed multicollinearity and unit root tests on the selected variables. The results found no multicollinearity and unit roots in any of them.

**Table 2.** Descriptive statistics of variables.

| Variables | Observations | Mean | Sd | Min | Max |
|---|---|---|---|---|---|
| GDP | 836 | 23.14 | 1.53 | 20.29 | 26.92 |
| $CO_2$ | 836 | 1.21 | 1.95 | 0.02 | 11.68 |
| Temperature | 836 | 24.26 | 3.42 | 11.86 | 29.38 |
| Precipitation | 836 | 1003.46 | 608.22 | 22.50 | 3145.62 |
| Urbanization | 836 | 41.20 | 16.83 | 8.25 | 89.37 |
| Openness | 836 | 69.78 | 36.00 | 0.05 | 225.02 |
| Renewable energy | 836 | 58.08 | 31.21 | 0.06 | 98.34 |
| labor | 836 | 66.49 | 0.42 | 42.39 | 90.34 |

After collecting the required data, we managed to construct a scatter plot of the variables and fitted curves, in order to directly visualize the non-linear characteristics of climate change affecting economic growth. Figure 3 presents scatter plots and fitted quadratic curve lines of temperature (Celsius) and precipitation (millimeter) versus economic growth in the sample from 2000 to 2019, with a clear non-linear relationship between temperature and economic growth.

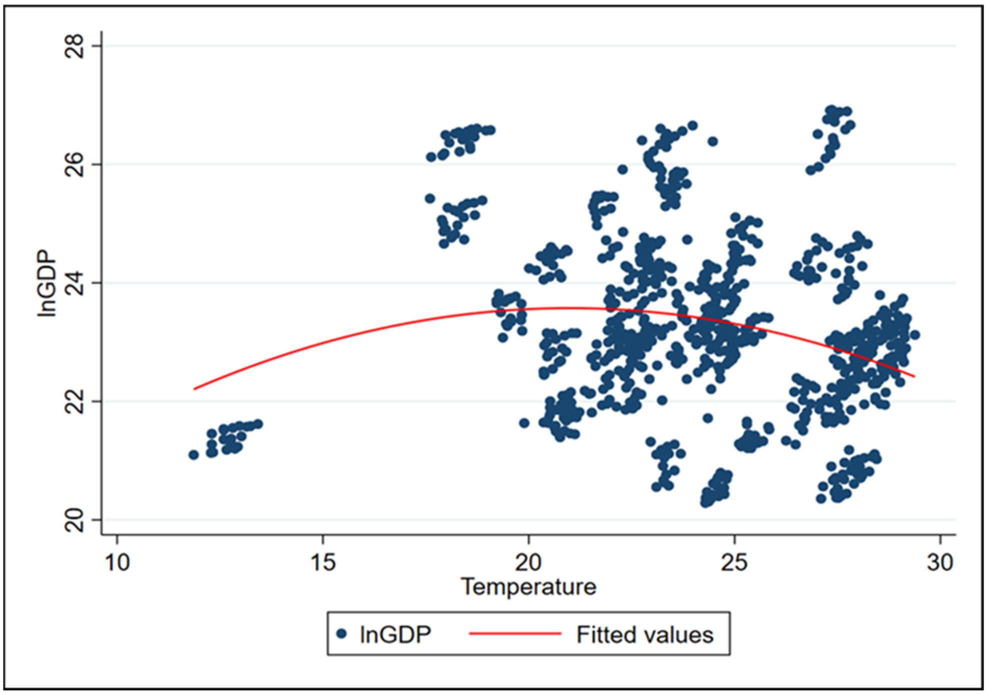


**Figure 3.** Temperature and lnGDP scatter chart.

## 4. Empirical Results and Discussion

### *4.1. Baseline Regression Results*

Equation (1) was used to test the relation between the temperature and the economic growth ability in the six climatic regions: STD, STM, TDS, TDR, TM, and WTM. Furthermore, we drew the distribution of the six climatic regions in Africa in Figure 4, and the regression results are shown in Table 3.

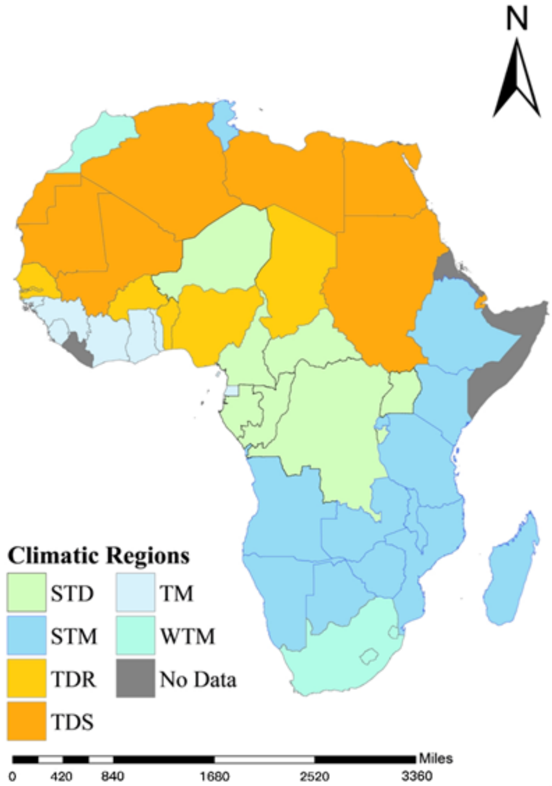


**Figure 4.** Climatic regions and regression results in Africa. Note: Somalia, Eritrea, and Liberia lacked important data, so we did not report their climate patterns nor select them in the regression sample.

**Table 3.** Climate regions test.

| Variables | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| | **STD** | **TDS** | **TM** | **WTM** | **TDR** | **STM** |
| $Temperature^2$ | 0.014 | −0.006 | −0.027 ** | 0.012 ** | −0.190 *** | 0.006 |
| | (1.22) | (−0.76) | (−2.12) | (2.60) | (−3.54) | (0.33) |
| Temperature | −0.730 | 0.462 | 1.593 ** | −0.333 ** | 10.766 *** | −0.271 |
| | (−1.29) | (1.11) | (2.49) | (−2.08) | (3.58) | (−0.33) |
| Lnpre2 | 0.056 | 0.054 | 0.094 ** | 0.034 | 0.119 * | −0.093 * |
| | (0.92) | (1.41) | (2.29) | (1.21) | (1.85) | (−1.67) |
| $CO_2$ | 0.191 *** | 0.229 *** | 0.108 *** | 0.035 | 0.047 | 0.100 |
| | (2.90) | (5.35) | (8.39) | (0.94) | (0.15) | (1.06) |
| Urbanization | 0.081 *** | 0.020 *** | 0.061 *** | 0.064 *** | 0.041 *** | 0.052 *** |
| | (19.53) | (3.72) | (15.25) | (11.89) | (6.66) | (9.04) |
| Openness | −0.004 *** | −0.001 | 0.002 * | −0.001 ** | −0.000 | 0.001 |
| | (−4.44) | (−1.39) | (1.93) | (−2.58) | (−0.29) | (0.78) |
| Renew | −0.006 | −0.024 *** | −0.002 | 0.001 | −0.007 | −0.015 *** |
| | (−1.62) | (−4.20) | (−0.92) | (0.20) | (−1.39) | (−3.84) |
| Labor | −0.013 ** | −0.034 *** | −0.020 *** | −0.018 * | −0.042 *** | −0.014 * |
| | (−2.32) | (−4.05) | (−3.54) | (−1.83) | (−4.96) | (−1.83) |
| Constant | 29.260 *** | 17.248 *** | −4.107 | 23.820 *** | −129.084 *** | 27.801 *** |
| | (4.31) | (3.26) | (−0.50) | (13.25) | (−3.06) | (3.01) |
| Observations | 140 | 120 | 180 | 80 | 120 | 240 |
| R-squared | 0.864 | 0.744 | 0.824 | 0.855 | 0.771 | 0.598 |
| Number of countries | 7 | 6 | 9 | 4 | 6 | 12 |
| Country FE | YES | YES | YES | YES | YES | YES |

Note: $CO_2$ represents carbon dioxide emissions per capita. Renew represents the proportion of renewable energy. *** Statistical significance at $p$-value < 0.01; ** statistical significance at $p$-value < 0.05; * statistical significance at $p$-value < 0.1.

The regression results showed that, when the temperature changes, the coefficient of economic growth in the TM and TDR regions showed a clear inverted U-shape. This result indicates that when the temperature of main climatic regions changes, the positive effect of the temperature on economic growth strengthened. However, when the temperature reached a certain threshold, this could damage economic growth. This situation may be because the western part of the African continent is a typical tropical desert and tropical dry climate. It is often exposed to heat waves and irregular rainfall. The local population has adapted to the hot wave conditions over a long period of time, and the high level of adaptation contributed to the growth of the local economy. However, the ability of the residents to adapt and mitigate climate change is limited. Unpredictable heat shocks damage economic activity; therefore, when the temperature changes in TM and TDR, the growth effect of temperature has an inverted U-shaped effect on economic growth ability.

From the perspective of the WTM region, the regression results indicated that temperature change showed a U-shaped relationship with economic growth. This may have been because when the temperature rose, the new environment was unsuitable for residents to adapt, thus leading to a decline in output. However, when people adapt to the temperature, the temperature will be good for economic growth. In the STD, TDS, and STM zones, the coefficient of temperature term was not significant. This result indicates that temperature changes had no obvious effect on the economic growth. This may have been because when faced with high temperature shocks, these countries had a high adaptation and mitigation capacity for climate change. Meanwhile, some countries in these climatic regions have a high output elasticity that allows for a rapid return to previous production levels.

Table 3 also reports spatially explicit results which we used to compare differences between the six climatic regions from a geographical perspective. It highlights how the inclusion of the six climatic regions led to very different results for the indicators. The results illustrate that there was an inverted U-shaped relationship between economic growth and climate change in the TDR and TM regions. However, the relationship in the WTM climatic zone was reversed. The results also showed that climate zones close to the equator, such as the TDR and TM regions, were more vulnerable to climate change, while regions far from the equator were more likely to reap the benefits of climate change.

In conclusion, we found that climate change had a negative impact on economic growth in countries that are close to the equator, and a positive impact on economic growth in countries far from the equator, in northern and southern Africa. The TDR and TM climate zones near the equator were negatively affected by climate change, while the WTM climate zone far from the equator was positively affected by climate change. These results strongly support Hypothesis 1.

### *4.2. Robustness Check*

Firstly, considering the significant dynamics of the production ability of countries because of climate change (i.e., the production of an industry in the last period will affect the production level of this industry in the current period because every industry will adjust the production structure based on last climatic condition), we added the lagging term of precipitation into the regression for the robustness test. Meanwhile, numerous research studies have shown that precipitation has a significant lagging impact on economic growth. Secondly, the presence of extremes affected the model fit curve and caused biased estimates. Therefore, it is crucial to exclude the impact of extreme weather on model regressions to analyze the impact of temperature on economic growth from a horizontal perspective. In this study, a 1% tail-shrink was applied to the dependent and core explanatory variables to investigate the effect of temperature on the economy. Table 4 reports the robustness check results. The results show that our regression results are robust. Temperature had a significant inverted U-shaped impact on economic growth in both the TDR and TM zones, but a U-shaped impact on economic growth in the WTM zone. In addition, temperature had no statistically significant impact on the STD, TDS, and STM regions.

**Table 4.** Robustness check.

| Variables | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| | **STD** | **TDS** | **TM** | **WTM** | **TDR** | **STM** |
| Temperature$^2$ | 0.027 | −0.008 | −0.023 * | 0.014 ** | −0.120 * | 0.003 |
| | (2.05) | (−0.91) | (−1.77) | (2.48) | (−1.97) | (0.17) |
| Temperature | −1.309 ** | 0.536 | 1.383 ** | −0.468 ** | 6.806 ** | −0.215 |
| | (−2.13) | (1.17) | (2.08) | (−2.15) | (1.99) | (−0.27) |
| Lnpre2 | −0.009 | 0.048 | 0.056 | 0.033 | 0.112 * | −0.083 |
| | (−0.14) | (1.14) | (1.22) | (1.15) | (1.74) | (−1.49) |
| Lnpre2_1 | 0.027 | 0.066 | 0.013 | 0.004 | 0.150 ** | −0.050 |
| | (0.38) | (1.43) | (0.28) | (0.16) | (2.28) | (−0.94) |
| $CO_2$ | 0.010 | 0.232 *** | 0.138 *** | 0.088 * | 0.112 | 0.090 |
| | (0.14) | (5.49) | (8.57) | (1.97) | (0.35) | (0.97) |
| Urbanization | 0.078 *** | 0.018 *** | 0.062 *** | 0.063 *** | 0.036 *** | 0.049 *** |
| | (15.79) | (3.28) | (15.06) | (12.24) | (5.51) | (8.50) |
| Openness | −0.004 *** | −0.002 | 0.001 | −0.001 ** | −0.001 | 0.000 |
| | (−4.33) | (−1.35) | (1.21) | (−2.28) | (−0.47) | (0.47) |
| Renew | −0.010 *** | −0.024 *** | −0.001 | −0.001 | −0.008 | −0.019 *** |
| | (−2.74) | (−4.18) | (−0.44) | (−0.35) | (−1.57) | (−4.62) |
| Labor | −0.011 * | −0.034 *** | −0.025 *** | −0.008 | −0.035 *** | −0.012 |
| | (−1.72) | (−4.01) | (−4.33) | (−0.79) | (−4.00) | (−1.48) |
| Constant | 37.193 *** | 16.251 *** | −0.442 | 24.603 *** | −75.018 | 28.752 *** |
| | (5.09) | (2.77) | (−0.05) | (10.55) | (−1.56) | (3.19) |
| Observations | 133 | 114 | 171 | 76 | 114 | 228 |
| R-squared | 0.831 | 0.737 | 0.803 | 0.860 | 0.727 | 0.607 |
| Number of countries | 7 | 6 | 9 | 4 | 6 | 12 |
| Country FE | YES | YES | YES | YES | YES | YES |

Note: *** Statistical significance at $p$-value < 0.01; ** statistical significance at $p$-value < 0.05; * statistical significance at $p$-value < 0.1.

### *4.3. Heterogeneity Analysis*

#### 4.3.1. Industrial Heterogeneity Analysis

In this section, we divided the three main sectors in Africa into the agriculture sector, the industrial sector, and the services sector, in order to further analyze the extent to which climate change affected the economy. To ensure the accuracy of the study data, countries with large amounts of missing data were removed (We removed Angola, Kenya, Central African Republic, Cote d 'Ivoire, Ghana, Equatorial Guinea, Gambia, Chad, and Libya due to missing data). For countries with few missing data in some years, we used interpolation methods to fill in the blanks. We estimated the impact of climate change on the agricultural sector using Euqation (2), with $Lnagriculture_{it}$ representing the log of value added in agriculture. $Lnsector_{it}$ represents the log of value added in industry and services in Equation (3). We also excluded unit root problems, and did not change the control variables selected.

$$Lnagriculture_{it} = \beta_0 + \beta_1 Tem_{it} + \beta_2 {Tem_{it}}^2 + \sum_{j=3}^{n} \beta_{jt} X_{jt} + \gamma_{it} + \varepsilon_{it} \quad (2)$$

$$Lnsector_{it} = \beta_0 + \beta_1 Tem_{it} + \beta_2 {Tem_{it}}^2 + \sum_{j=3}^{n} \beta_{jt} X_{jt} + \gamma_{it} + \varepsilon_{it} \quad (3)$$

Our research reported the impact of climate change on the agricultural, industrial and service sectors. Table 5 reports the impact of temperature changes on agricultural output; Table 6 presents the impact of temperature changes on industrial output; Table 7 explains the impact of temperature changes on service output. Our analysis was based on the three regression results.

**Table 5.** Temperature effects on the agricultural sector.

| **Variables** | **(1)** | **(2)** | **(3)** | **(4)** | **(5)** | **(6)** |
|---|---|---|---|---|---|---|
| | **STD** | **TDS** | **TM** | **WTM** | **TDR** | **STM** |
| Temperature$^2$ | −0.006 | 0.015 | −0.064 *** | 0.012 * | −0.123 *** | 0.059 *** |
| | (−0.57) | (1.65) | (−4.64) | (1.82) | (−2.95) | (3.15) |
| Temperature | 0.359 | −0.688 | 3.428 *** | −0.397 * | 6.979 *** | −2.602 *** |
| | (0.68) | (−1.51) | (4.90) | (−1.75) | (2.96) | (−3.14) |
| Lnpre2 | −0.050 | 0.079 * | 0.029 | 0.070 * | 0.056 | 0.077 |
| | (−0.96) | (1.86) | (0.65) | (1.74) | (1.16) | (1.49) |
| $CO_2$ | −0.048 | 0.538 *** | 0.161 * | 0.051 | 0.446 ** | −0.143 |
| | (−0.85) | (6.70) | (1.80) | (0.97) | (2.36) | (−1.61) |
| Urbanization | 0.050 *** | 0.021 *** | 0.062 *** | 0.072 *** | 0.073 *** | 0.014 ** |
| | (13.93) | (3.38) | (11.81) | (9.52) | (12.36) | (2.51) |
| Openness | −0.002 *** | −0.006 *** | −0.001 | −0.001 *** | −0.001 | 0.001 |
| | (−2.90) | (−3.57) | (−0.68) | (−2.70) | (−0.81) | (0.97) |
| Renew | 0.004 | −0.016 *** | 0.010 *** | 0.015 *** | 0.002 | −0.024 *** |
| | (1.15) | (−2.69) | (2.80) | (2.99) | (0.64) | (−5.26) |
| Labor | −0.004 | −0.033 *** | −0.049 *** | 0.001 | 0.013 * | 0.006 |
| | (−0.75) | (−3.50) | (−5.22) | (0.07) | (1.89) | (0.75) |
| Constant | 15.133 ** | 30.777 *** | −26.301 *** | 19.729 *** | −81.030 ** | 49.474 *** |
| | (2.44) | (5.20) | (−2.90) | (7.75) | (−2.44) | (5.45) |
| Observations | 120 | 100 | 120 | 80 | 80 | 200 |
| R-squared | 0.807 | 0.786 | 0.677 | 0.692 | 0.917 | 0.407 |
| Number of countries | 6 | 5 | 6 | 4 | 4 | 10 |
| Country FE | YES | YES | YES | YES | YES | YES |

Note: *** Statistical significance at $p$-value < 0.01; ** statistical significance at $p$-value < 0.05; * statistical significance at $p$-value < 0.1.

**Table 6.** Temperature effects on the industrial sector.

| **Variables** | **(1)** | **(2)** | **(3)** | **(4)** | **(5)** | **(6)** |
|---|---|---|---|---|---|---|
| | **STD** | **TDS** | **TM** | **WTM** | **TDR** | **STM** |
| Temperature$^2$ | −0.048 ** | −0.006 | 0.005 | 0.012 ** | −0.018 | 0.063 ** |
| | (−2.01) | (−0.51) | (0.21) | (2.34) | (−0.49) | (2.39) |
| Temperature | 1.991 * | 0.481 | −0.066 | −0.336 * | 1.087 | −2.867 ** |
| | (1.76) | (0.78) | (−0.05) | (−1.89) | (0.52) | (−2.47) |
| Lnpre2 | 0.111 | 0.064 | 0.097 | 0.044 | 0.010 | −0.089 |
| | (0.99) | (1.11) | (1.11) | (1.39) | (0.23) | (−1.23) |
| $CO_2$ | 0.364 *** | −0.020 | 0.443 ** | 0.050 | −0.033 | 0.098 |
| | (2.99) | (−0.19) | (2.58) | (1.20) | (−0.20) | (0.79) |
| Urbanization | 0.078 *** | 0.005 | 0.076 *** | 0.043 *** | 0.006 | 0.065 *** |
| | (10.07) | (0.57) | (7.56) | (7.17) | (1.17) | (8.47) |
| Openness | 0.001 | −0.001 | 0.007 *** | −0.000 | 0.007 *** | 0.003 * |
| | (0.80) | (−0.33) | (3.67) | (−1.14) | (5.99) | (1.84) |
| Renew | 0.008 | −0.029 *** | 0.007 | 0.004 | −0.006 ** | −0.006 |
| | (1.20) | (−3.68) | (0.99) | (1.15) | (−2.25) | (−0.90) |
| Labor | −0.020 * | −0.020 | −0.043 ** | −0.023 ** | −0.058 *** | −0.066 *** |
| | (−1.94) | (−1.59) | (−2.42) | (−2.04) | (−9.23) | (−5.85) |
| Constant | −2.430 | 16.058 ** | 14.510 | 23.531 *** | 9.418 | 58.140 *** |
| | (−0.18) | (2.01) | (0.83) | (11.79) | (0.32) | (4.58) |
| Observations | 120 | 100 | 120 | 80 | 80 | 200 |
| R-squared | 0.677 | 0.469 | 0.596 | 0.705 | 0.918 | 0.596 |
| Number of countries | 6 | 5 | 6 | 4 | 4 | 10 |
| Country FE | YES | YES | YES | YES | YES | YES |

Note: *** Statistical significance at $p$-value < 0.01; ** statistical significance at $p$-value < 0.05; * statistical significance at $p$-value < 0.1.

**Table 7.** Temperature effects on the service sector.

| Variables | (1) STD | (2) TDS | (3) TM | (4) WTM | (5) TDR | (6) STM |
|---|---|---|---|---|---|---|
| Temperature$^2$ | −0.004 | −0.004 | −0.047 * | 0.011 ** | −0.064 * | 0.050 * |
| | (−0.36) | (−0.62) | (−1.75) | (2.11) | (−1.96) | (1.75) |
| Temperature | 0.151 | 0.312 | 2.458 * | −0.288 | 3.675 * | −2.343 * |
| | (0.28) | (0.96) | (1.79) | (−1.55) | (1.99) | (−1.86) |
| Lnpre2 | 0.065 | 0.034 | 0.084 | 0.026 | −0.037 | −0.140 * |
| | (1.23) | (1.11) | (0.95) | (0.80) | (−0.98) | (−1.79) |
| $CO_2$ | 0.029 | 0.580 *** | 0.736 *** | 0.031 | 0.030 | 0.112 |
| | (0.50) | (10.14) | (4.20) | (0.73) | (0.20) | (0.83) |
| Urbanization | 0.099 *** | 0.032 *** | 0.071 *** | 0.069 *** | 0.094 *** | 0.070 *** |
| | (26.91) | (7.16) | (6.89) | (11.22) | (20.33) | (8.44) |
| Openness | 0.000 | −0.002 * | 0.002 | −0.001 *** | 0.002 * | 0.003 |
| | (0.13) | (−1.82) | (0.96) | (−2.91) | (1.80) | (1.54) |
| Renew | −0.010 *** | −0.021 *** | 0.019 *** | −0.002 | 0.002 | −0.008 |
| | (−3.20) | (−5.12) | (2.75) | (−0.43) | (0.70) | (−1.10) |
| Labor | 0.007 | −0.029 *** | −0.008 | −0.012 | 0.000 | −0.027 ** |
| | (1.53) | (−4.42) | (−0.45) | (−1.06) | (0.02) | (−2.19) |
| Constant | 16.063 ** | 17.979 *** | −16.250 | 22.215 *** | −32.812 | 51.275 *** |
| | (2.54) | (4.26) | (−0.91) | (10.68) | (−1.26) | (3.72) |
| Observations | 120 | 100 | 120 | 80 | 80 | 200 |
| R-squared | 0.933 | 0.918 | 0.488 | 0.843 | 0.970 | 0.560 |
| Number of countries | 6 | 5 | 6 | 4 | 4 | 10 |
| Country FE | YES | YES | YES | YES | YES | YES |

Note: *** Statistical significance at $p$-value < 0.01; ** statistical significance at $p$-value < 0.05; * statistical significance at $p$-value < 0.1.

We first analyzed the impact of temperature changes on the agricultural sector (Table 5). The results show that temperature had a significant U-shaped impact on agricultural development in the TM and TDR regions. This indicates that increased heat from rising temperatures promotes increased agricultural output, however, when temperatures exceed a critical value, agricultural output will decrease significantly. In the STM and WTM areas, temperature changes had an opposite curve compared with the TM and TDR zones. However, there was no significant effect of temperature change on agricultural output in the STD and TDS areas. Further analysis of the regression results showed that agricultural yields in the STM zone near to the equator were more vulnerable to temperature changes, while agricultural yields in the TDR and TM climate zones away from the equator benefitted from warmer temperatures.

Next, we analyzed the effect of temperature change on industrial output (Table 6). There was a significant inverted U-shaped effect of temperature change on STD industrial output. This indicates that rising temperatures promote increased industrial output; however, when temperatures exceed a critical value, industrial output will decrease significantly. However, temperature had a significant U-shaped effect on industrial output in the STM and WTM climatic zones. There was no significant effect of temperature change on the industrial output of the TDS, TM, and TDR climate zones. A comparison of the regression results shows that industrial production in the STD climatic zone close to the equator was more vulnerable to temperature changes, while industrial production in the STM and WTM climatic zones away from the equator were better affected by warmer temperatures.

Thirdly, we analyzed the effect of temperature change on service output (Table 7). There was a significant inverted U-shaped effect of temperature change on the service output of the TM and TDR regions. This indicates that the rising temperature promotes increased service output, but when temperatures exceed a critical value, service output will decline significantly. Conversely, a change in temperature also conveyed a clear U-shaped pattern in the WTM's and STM's service sectors. However, there was no significant effect in the STD and TDS regions. Further dissection of the regression results shows that service sector output in the TM and TDR climate zones close to the equator were more vulnerable to temperature changes.

Therefore, we can make the following surprising conclusions. (1) Among all six climate zones selected, the WTM and STM zones are more vulnerable to negative impacts from temperature changes; (2) industries close to the equator are more vulnerable to temperature shocks in the STD region; however, industries in climatic zones away from equator benefited from temperature changes in the STM and WTM climatic zones; (3) among all the sectors exposed to temperature shocks, agriculture and industries were most vulnerable to shocks, while services were less vulnerable, with most results being insignificant. Thus, we can conclude that agriculture, industry, and services are more vulnerable to temperature shocks in climate zones closer to the equator, while in other climatic regions, industries are less affected. The hypothesis was powerfully proved.

#### 4.3.2. Locational Heterogeneity Analysis

In this part, we captured the differential impact of climate change on economic growth across geographic locations. There are large differences in the annual precipitation between coastal and inland states in Africa. Generally, coastal areas are more susceptible to changes in temperature and precipitation. Thus, we tended to verify the differential impact of temperature on countries in different geographical locations by dividing 44 African countries into coastal and inland countries.

Table 8 shows the results of the regressions based on different geographical locations, with significant variability in the effect of temperature on economic growth in coastal and inland regions. According to Table 8, the temperature and temperature squared terms had a significant positive impact on the economic growth in the coastal region, where the economy grew by 0.005 percent for one unit change in temperature in the current squared terms. However, the temperature and its squared terms had a different degree of impact on the economic growth for the inland region. There was no significant impact found on economic growth for inland countries. By comparing two sub-samples, this situation may have resulted because when the temperature rose in inland countries, some workers struggled to adapt a new environment. Furthermore, they immigrated from inland countries to coastal countries, or from the equatorial to the tropical countries. Thus, coastal countries obtained more productive workers to promote economic growth.

**Table 8.** Heterogeneous estimation of location.

| Variables | (1) | (2) |
|---|---|---|
| | **Inland Countries** | **Coastal Countries** |
| $Temperature^2$ | 0.007 | 0.005 * |
| | (1.43) | (1.67) |
| Temperature | −0.233 | −0.107 |
| | (−1.02) | (−0.74) |
| Lnpre2 | −0.035 | 0.052 ** |
| | (−0.66) | (2.57) |
| $CO_2$ | 0.243 ** | 0.092 *** |
| | (2.56) | (8.68) |
| Urbanization | 0.056 *** | 0.053 *** |
| | (9.51) | (28.21) |
| Openness | −0.002 *** | 0.000 |
| | (−2.88) | (0.48) |
| Renew | −0.007 | −0.007 *** |
| | (−1.60) | (−5.71) |
| Labor | −0.036 *** | −0.015 *** |
| | (−5.39) | (−5.04) |
| Constant | 26.136 *** | 20.986 *** |
| | (8.55) | (11.80) |
| Observations | 299 | 581 |
| R-squared | 0.509 | 0.798 |

**Table 8.** *Cont.*

| Variables | (1) | (2) |
|---|---|---|
| | Inland Countries | Coastal Countries |
| Number of countries | 15 | 30 |
| Country FE | YES | YES |

Note: *** Statistical significance at $p$-value < 0.01; ** statistical significance at $p$-value < 0.05; * statistical significance at $p$-value < 0.1.

## 5. Extended Research

The panel fixed effects regression model clearly demonstrated a significant effect of temperature on economic growth. However, the economic impact of climate change was characterized by its long-term nature. When estimating the long-term impacts of temperature on economic growth, using a fixed effect model is inappropriate. Thus, it would be better to take an intuitive and visualized approach to present the impact of temperature changes on economic growth. Heuristically, we took a long-term view of temperature change, and used the PVAR [69] model to test the long-term impacts of temperature change on economic growth. First, the PVAR approach takes dynamic equilibrium theory as the background of macroeconomic theory. Combining the non-parametric economic theory, dynamic stochastic general equilibrium (DSGE), with the parametric economic model PVAR, this can effectively solve and test many problems in an economic system. Second, the PVAR model does not distinguish between endogenous and exogenous variables; instead, all variables are treated as endogenous. Therefore, it can more powerfully address the bidirectional causality in endogeneity.

Before we could use the PVAR model, the first step of the estimation process was to solve pseudo-regression problems, so we had to examine the data properties of all the series in terms of stationarity. Firstly, we used three simultaneous tests, the LLC, the IPS, and the Fisher-ADF test to test unit root problems. The results showed that the first difference was sufficient to make all of the series stationary, allowing for the construction of PVAR model. Secondly, we determined the optimal lag order of the model based on the AIC (Akaike information criterion), BIC (Bayesian information criterion), and HQIC (Hannan–Quinn information criterion) minimum information criteria, with different sub-samples exhibiting different lag orders. In addition, Figure 5 shows that the characteristic roots of the companion matrix all fell within the unit circle, so the impulse response was robust [70]. Thirdly, we carried out a dynamic analysis of temperature change and economic growth using a Monte Carlo method, using 200 simulations to obtain lagging impulse response plots for the six climate zones. Impulse response plots are used to visualize the effect of a positive standard deviation shock to a random disturbance term on the current and future values of the endogenous variables.

Figure 6 shows the pulse effect results for the six samples. Economic growth and temperature change both showed significant positive effects when faced with a shock of one standard deviation of their own, suggesting they have relative economic inertia. In this part, we mainly focused on the impact of temperature shocks on economic growth.

We found that the impact of temperature changes on economic growth showed the same impulse characteristics in the STD, TM, TDR, and WTM areas. In these samples, temperature changes in the base period had a positive impact on economic growth, but the TDR region was significantly more affected than the others. In particular, the positive pulse shock to growth tended to be zero in the STD zone in period 2, and only tended to be zero in the TDR, TM, and WTM zones in period 4.

From the perspective of the STM climatic zone, the impulse results show that when the temperature changes, economic growth capacity will be modestly impacted; the results were also proved by Wiebelt et al. (2015) [71], who confirmed a combined impact of fluctuations in climatic temperatures leading to reductions in Tunisian GDP of 0.2% and 0.4%. Temperature changes in the base period had a slightly negative impact on economic growth, and in period 4 the impulse only tended to be zero.

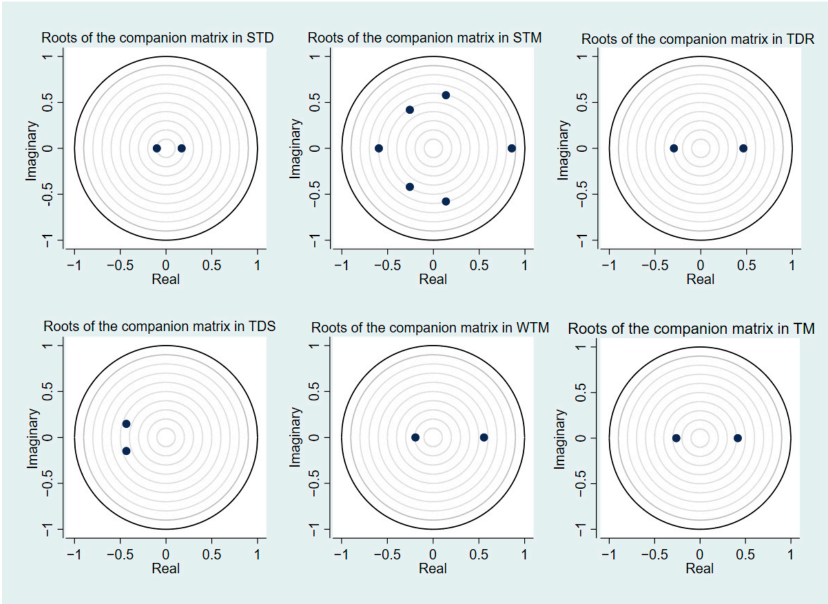


**Figure 5.** Roots of the companion matrix in the six climate regions. Note: We determined the optimal lag order of the model based on the MAIC, MBIC, and MQIC minimum information criteria; to ensure the validity of the robustness test, we included the lag order in the unit circle.

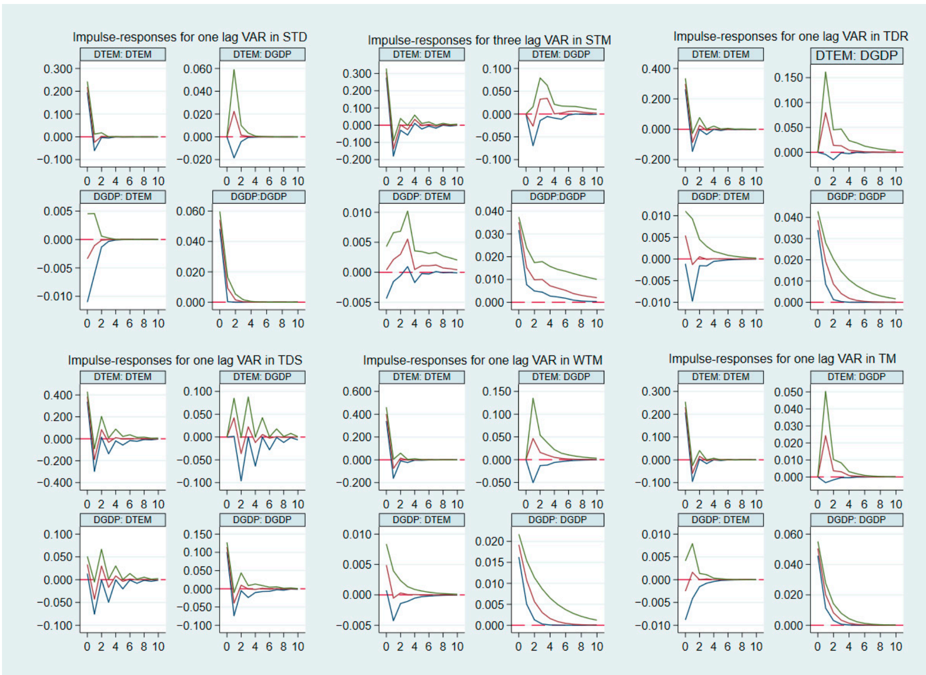


**Figure 6.** Impulse responses in the six different climate regions. Note: We found that the six climatic regions had different levels of economic development that were sensitive to temperature. We adjusted the pulse duration for different samples in PVAR.

Unlike previous studies that showed a significant linear decrease between economic growth and climate change [72,73], our research found that the impact of temperature change on economic growth showed an interannual fluctuation in TDS. When a shock to temperature occurred in the base period, the temperature shock boosted economic growth, but a two-period lagging effect inhibited the growth; when the second-period shock was over, a third-period lagging effect in temperature boosted growth again. This shock exhibited a cyclical characteristic. The shock tended towards zero only after the sixth period.

In conclusion, when temperature shocks occurred in the six climate zones, (1) the STD, TM, TDR, and WTM zones' economic growth were significantly boosted; (2) STM was the first to be negatively affected, but greater economic resilience allowed the economy to return to its original level of output, and eventually become boosted economic growth; (3) the TDS region's economic growth capacity showed interannual fluctuating characteristics.

## 6. Discussion

The issues of climate change and economic growth have always been important factors restricting economic innovation and sustainable development in Africa. Although the GDP in Africa has improved, it is still at a relatively low level. The results of this study show that economic growth is influenced by climate change. The six climate zones are affected by climate change to different degrees. Our study also shows that climate change heterogeneously affects the industrial development of African countries, and inhibits the sustainable development paths of different sectors in African countries. Therefore, the main task for Africa to address climate change is to integrate sustainable development goals into national climate change adaptation and mitigation frameworks in the future.

There are some limitations to this study. Owing to data limitations, our sample data were only available from 2000 to 2019. As a result of a lack of economic data in some countries, our analysis of economic growth and climate change in Africa only covered the main regions. Thus, we were forced to select 44 African samples for the study. In addition, our study analyzed the short- and long-term effects of climate change on economic growth, but with different approaches. It would be desirable for future studies to include both long- and short-term effects in the same model for analysis. Therefore, in the future, a more time-sensitive and comprehensive analysis should be conducted for all of Africa.

## 7. Conclusions and Policy Implications

### *7.1. Conclusions*

In recent years, climate change has imposed itself as a frontier topic of interest for scholars and policymakers. It requires scholars to fully dissect the impact of climate change on economic development. The current study examined the impact of climate change on economic growth in a sample group of 44 African countries, based on World Bank statistics from 2000 to 2019. We first sorted out the transmission mechanisms by which climate change affects economic growth. Then, we applied panel regression methods to estimate the extent and characteristics of the impact of climate change on economic growth.

We made three contributions to understanding the impact of climate change on economic growth in Africa. It is the first time that we analyzed the impact of climate change on economic growth in Africa from the perspective of climate heterogeneity. We found that in climatic zones near the equator (TM, TDR), temperature tends to have an inverted U-shaped impact on economic growth. On the contrary, we found that in climatic zones far from the equator (WTM), temperature tends to have a U-shaped impact on economic growth. Furthermore, temperature has no significant effect on economic growth in the STD, STM, and TDS regions. It is evident that climate change influences economic development in heterogeneous climate zones.

The second novelty in this study is that we provided a sub-sample based on industrial and geographical perspectives. We sought to examine whether some geographical and industrial effects exist in the relation between climate change and economic growth across African countries. We found that agricultural output is most vulnerable to climate change, especially in the TM and TDR regions. Additionally, the results indicate that temperature has a significant contribution to economic growth in coastal areas. However, in inland countries, the temperature has no significant influence on economic growth.

The third contribution of this study is that we used a PVAR model to test the shock effect of temperature fluctuations on economic growth. We found that the impact of temperature change on economic growth showed different impulse characteristics and different degrees in the six climatic zones. In the STD, TM, TDR, STM, and WTM regions, economic growth was significantly boosted in the long term, while economic growth capacity showed interannual fluctuating characteristics in the TDS region.

### *7.2. Policy Implications*

Climate change is both a challenge and rare opportunity for Africa. The formation of a common position for African countries on climate change will help Africa to take the initiative in future international climate negotiations, and to effectively address the negative impacts of climate change, giving impetus to its economic development. In order to promote economic growth and mitigate climate change, we propose the following policy recommendations.

First, Africa needs to integrate climate change objectives into its sustainable development framework. Countries can undertake climate change mitigation and adaptation actions through climate policy, technology transfer, and capacity building. These new evaluation findings will provide a new scientific basis for governments to adopt more equitable and pragmatic response decisions, and achieve sustainable development. Concretely, governments should expand private sector activity and public–private partnerships, such as in agriculture, industry, and service; construct climate-informed advisories and early warnings; and develop climate-resilient and low-emission practices and technologies.

Second, a macro policy framework to promote climate adaptation should be built. Regional cooperation organizations require policy frameworks to be developed, which play a necessary role in linking the institutional arrangements of individual African countries to the policy creations of other countries. This framework should involve scaling-up funding for Africa to address climate change, increasing international humanitarian assistance, and reducing the burden of carbon development on African countries, etc.

Third, communities should emphasize environmental and climate change mitigation and adaptation. Traditional communities in sub-Saharan African countries, i.e., rural and peri-urban farming communities, are linked by family, village community, tribe, etc. Communities play a key role in using customs to protect the environment and adapt to climate change. Governments need to restore the functions of traditional communities and recreate new functions of traditional communities, for example, by giving them indigenous knowledge protection functions, including communities in national adaptation plans of action, and giving local governments the function of connecting communities to the state.

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