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Study of the impact of climate change on economic growth in North African and Sahel countries

Said Khalfa Brika[1], Ismail Bengana[2*], Khaled Mili[3]

[1]*Administration Sciences Department, University of Bisha, Saudi Arabia.*
[2,3]*Department of Quantitative Methods, College of Business, King Faisal University, Saudi Arabia.*

Corresponding author: Ismail Bengana (*Email: ibengana@kfu.edu.sa*)

Abstract

This research paper aims to investigate the impact of climate change on economic growth, represented by GDP per capita, for a group of North African and Sahel countries during the period 1965-2020. As part of the Autoregressive Distributed Lag (ARDL) model approach, the study examined this relationship both in the short and long term. The short term utilized static analysis, while the long term employed co-integration analysis. These two analyses revealed a negative effect of temperature rise in the short term and a positive effect of precipitation in the long term. This necessitates that the governments of the sample countries respond appropriately to adapt to environmental phenomena that are harmful to their economies.

Keywords: ARDL, climate change, economic growth, North Africa and Sahel, panel models.

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1. Introduction

The evolution of human lifestyle and population growth has significantly impacted the planet's balance, leading to the major issue of climate change. This phenomenon, primarily caused by increasing greenhouse gas emissions, especially carbon dioxide, has become a critical concern for global organizations due to its potential threats to human security and economies worldwide.

Climate change manifestations, including rising temperatures, fluctuating precipitation, and extreme weather events, pose significant risks to various economic sectors. This is particularly true for developing countries, many of which rely heavily on climate-sensitive sectors like agriculture and tourism. For instance, in African countries, agriculture employs 75% of the workforce and contributes 25% to the GDP, making these economies highly vulnerable to climate fluctuations.

The impacts of climate change extend beyond agriculture, affecting sectors such as tourism and increasing energy costs for cooling in already hot climates. These effects can exacerbate unemployment and poverty and hinder development indicators.

Interestingly, while third world countries contribute minimally to global emissions, they are often the most affected by climate change. In contrast, major industrial countries like China and the United States are the primary contributors to greenhouse gas emissions.

This study aims to investigate the impact of climate change, specifically temperature rise and precipitation fluctuations, on economic growth in North African and Sahel countries. The research examines this relationship in both the short and long term, using per capita GDP as an indicator of economic growth. The study covers eleven countries over a 49-year period (1965-2014), utilizing data from the International Monetary Fund and World Bank.

In the following sections, this paper will first present a review of relevant literature, highlighting key studies that have examined the relationship between climate change and economic growth. Next, we will provide a descriptive analysis of the study variables, including temperature, precipitation, and GDP per capita for the selected North African and Sahel countries. The methodology section will explain how we used econometrics to investigate short- and long-term effects. It will employ both static analysis and the Autoregressive Distributed Lag (ARDL) model. We will present our empirical results and discuss the implications of our findings for the relationship between climate variables and economic growth in the region. Finally, the conclusion will summarize our key findings and discuss their policy implications, offering suggestions for future research in this critical area of study.

2. Literature Review

The relationship between economic growth and environmental factors, particularly climate change, has been a subject of study for decades, evolving in both focus and methodology over time.

2.1. Early Studies on Economic Growth and Emissions

Grossman and Krueger [1] were among the first to explore the relationship between economic growth and gas emissions, proposing that this relationship is initially direct but becomes inverse as countries reach certain development levels. Friedl and Getzner [2] supported this theory with evidence from Australia (1960-1999), while Richmond and Kaufmann [3] found no significant relationship in a study of 20 developed and 16 developing countries (1973-1997).

2.2. Climate Change and Energy Demand

Metalas [4] investigated the impact of climate change on global energy demand. His econometric models showed that increased carbon dioxide emissions did not negatively affect global energy demand, which continued to rise even during the 2008 economic crisis. With a shift towards cleaner energy sources in line with emission reduction policies, we expected this trend to continue.

2.3. Climate Impacts on Agriculture

Adesete et al. [5] investigated the relationship between climate change and food security in Sub-Saharan Africa, finding that greenhouse gas emissions have a significant negative impact on food security, leading to a higher prevalence of malnourishment. Their study emphasizes the high sensitivity of agricultural incomes to climate variations, with changes in temperature and rainfall patterns directly affecting crop yields and farmer incomes.

More recently, Omotoso et al. [6] provided a comprehensive review of climate change impacts on agriculture in sub-Saharan Africa, highlighting significant effects such as temperature and rainfall variability, extreme weather events, and shorter growing seasons. They found that climate change has led to reduced crop yields, food price fluctuations, and limited food availability, exacerbating the region's challenges in achieving food security.

Additionally, Bedeke [7] explored the complex effects of climate change on crop producers in SSA, emphasizing the region's vulnerability to increased temperatures, irregular rainfall, droughts, and floods. These climatic changes not only decrease crop productivity but also exacerbate other challenges like the spread of pests, soil degradation, and loss of moisture. The study highlights the importance of tailored, site-specific adaptation measures to enhance farmers' resilience to climate impacts.

2.4. Climate Change and Economic Growth

Berg et al. [8] examined the impact of temperature and precipitation on GDP and sectoral added value across countries, finding substantial heterogeneity in how countries respond to temperature shocks. Their analysis revealed negative growth responses in G-7 countries but positive responses in some poorer countries to global temperature increases, challenging previous assumptions about uniform negative effects.

Bilal and Känzig [9] used advanced econometric modeling to analyze the relationship between climate variables and economic growth. Their study estimated that a 1°C rise in global temperature reduces global GDP by 12%, a much larger impact than prior estimates. They calculate the Social Cost of Carbon (SCC) at $1,065 per ton, significantly higher than previous estimates.

2.5. Regional Studies

Zhao and Liu [10] explored climate change effects on economic growth across 44 African countries, finding varying impacts across different climatic zones. This highlighted the importance of region-specific policies.

2.6. Climate Change, Energy, and Financial Stability

Recent studies have also explored the intersection of climate change with energy and financial systems. Jurasz et al. [11] analyzed the complementarity of wind and solar power in North Africa, while Kotsompolis et al. [12] examined the determinants of carbon emission returns. [13] investigated the relationship between environmental degradation, energy consumption, and financial instability in Sub-Saharan Africa.

2.7. Policy Implications and Adaptation Strategies

Newman and Noy [14] quantified the costs of extreme weather events attributable to climate change, emphasizing the importance of adaptation policies. Magesa et al. [15] reviewed adaptation strategies employed by smallholder farmers in Africa, recommending transformative changes. Löscher and Kaltenbrunner [16] examined how climate change, combined with dependence on external finance, restricts the ability of peripheral countries to pursue independent macroeconomic policies.

2.8. Our Contribution

While these studies provide valuable insights, our research contributes uniquely by focusing specifically on North African and Sahelian countries, a region that has received relatively less attention. We employ a combination of static analysis and the ARDL model to examine both short-term and long-term effects of climate variables on economic growth. Our study incorporates both temperature and precipitation variables over a longer period (1965-2020), allowing for a more comprehensive understanding of climate-economy dynamics in the region. By using per capita GDP as our economic indicator, we provide insights into how climate change affects individual economic well-being, not just aggregate economic output. These aspects of our study fill important gaps in the literature and offer valuable insights for regional policymakers grappling with the economic challenges posed by climate change.

3. Methodology

3.1. Data and Sample

Our study examines the impact of climate change on economic growth in 11 North African and Sahel countries over the period 1965-2020. The countries included in our sample are Algeria, Burkina Faso, Chad, Egypt, Mauritania, Morocco, Niger, Nigeria, Senegal, Sudan, and Tunisia.

3.2. Variables

3.2.1. Dependent Variable

- GDP per capita (LnGDPPC): We use the natural logarithm of GDP per capita as our measure of economic growth.

3.2.2. Independent Variables

- Temperature (TEMP): Average annual temperature in degrees Celsius.
- Precipitation (PR): Annual precipitation in millimeters.

3.2.4. Data Sources

We obtained our data from multiple reliable sources:

- Economic data: International Monetary Fund and World Bank databases
- Climate data: CRU-UEA (Climate Research Unit - University of East Anglia)

4. Results and Discussion

4.1. Descriptive Statistics

We begin our analysis by presenting descriptive statistics for our key variables across the 11 countries in our sample for the period 1965-2020.

Air temperatures are considered one of the main indicators for studying the climate of any region in the world. Their averages vary from season to season and between different regions. Reports indicate that the Earth's temperature, as an average between land and ocean, has risen by a rate ranging from 0.65 to 1.06 degrees Celsius in the period between 1880 and 2012 [17]. As for the countries in the studied sample, there are clear variations in their temperatures according to Table 1.

Table 1.
Descriptive analysis of temperatures for the study sample countries for the years 1965-2014 (Prepared by researchers based on CRU-UEA data).

Country	Highest Temperature	Lowest Temperature	Average Temperature	Increase Amount
Algeria	24	21.5	22.9	1.5
Burkina Faso	29.3	27.6	28.52	1.1
Chad	28.4	25.9	27.05	1.7
Egypt	24.7	21.4	22.52	1.6
Mauritania	29.4	26.7	28.03	1.4
Morocco	18.7	16	17.45	1.5
Niger	28.7	26.6	27.52	1.7
Nigeria	27.8	26.2	27.02	1
Senegal	29.1	27.2	28.19	1.3
Sudan	29	24	27.11	1.8
Tunisia	20.9	18.3	19.74	2

Figure 1 illustrates the average temperatures for the studied countries over the period from 1965 to 2014. This graph shows a general upward trend in temperatures across the region during the study period.

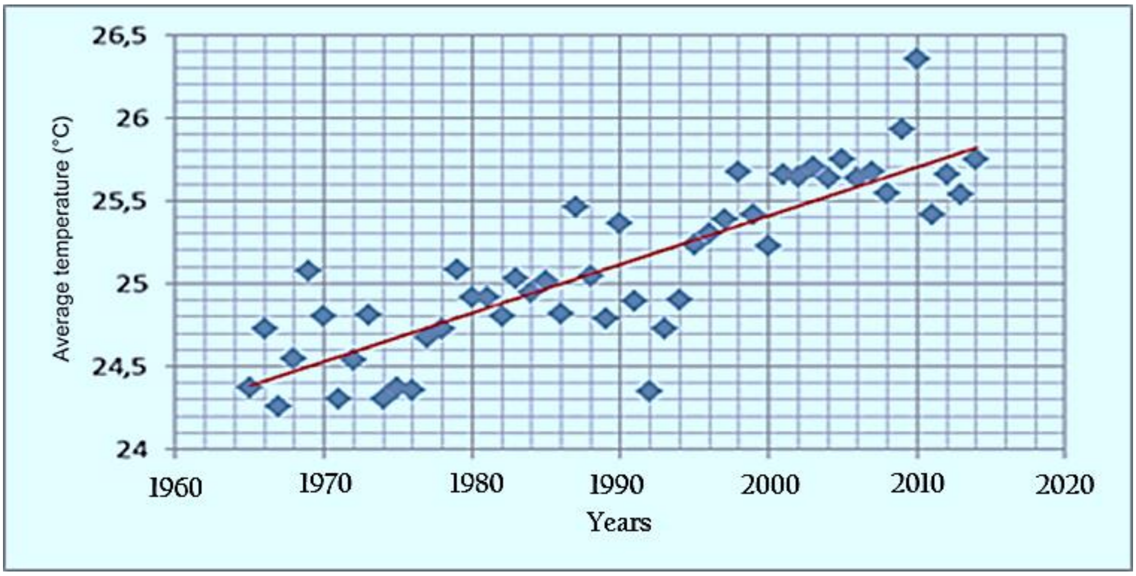

Figure 1.
Average temperatures for the countries studied over the study period.

As is the case with temperatures, rainfall quantities are considered one of the main climatic indicators expressing the variation between climatic regions on one hand and the climatic changes occurring within a single climatic region on the other hand This change can be seen in two ways: first, the general trend of the precipitation data series going down; second, the fact that this precipitation is being thrown off, happening at odd times and in large amounts, causing floods that damage property and kill people. Table 2 represents a descriptive analysis of the precipitation data series for the countries in the study sample:

Table 2.
Descriptive analysis of rainfall amounts in the study sample countries for the years 1965-2014.

Country	Highest Precipitation (mm)	Lowest Precipitation (mm)	Average Precipitation (mm)	Change (mm)
Algeria	479.65	178.85	317.48	-23
Burkina Faso	948.7	570.2	744.92	13.21
Chad	401.4	222.6	313.64	25.45
Egypt	68.7	25.8	40.13	-9.69
Mauritania	148	45.8	89.66	11.05
Morocco	557.1	164	326.05	-42.27
Niger	214.9	66.5	149.94	21.03
Nigeria	1323.5	893.7	1145.446	-1.41
Senegal	919.2	430.3	679.01	72
Sudan	499.1	267.9	412.61	26.45
Tunisia	509.5	174.2	308.9	-12

This table provides a comprehensive overview of precipitation statistics for each country in your sample over the period 1965–2014, including the highest and lowest precipitation amounts recorded, the average precipitation, and the total change in precipitation over the study period.

In the sample of countries that were studied, there seems to be a clear difference in the general trend of the annual precipitation series in these countries. However, it looks like there is no significant trend in any of the sample countries that were studied, as shown in Figure 2.

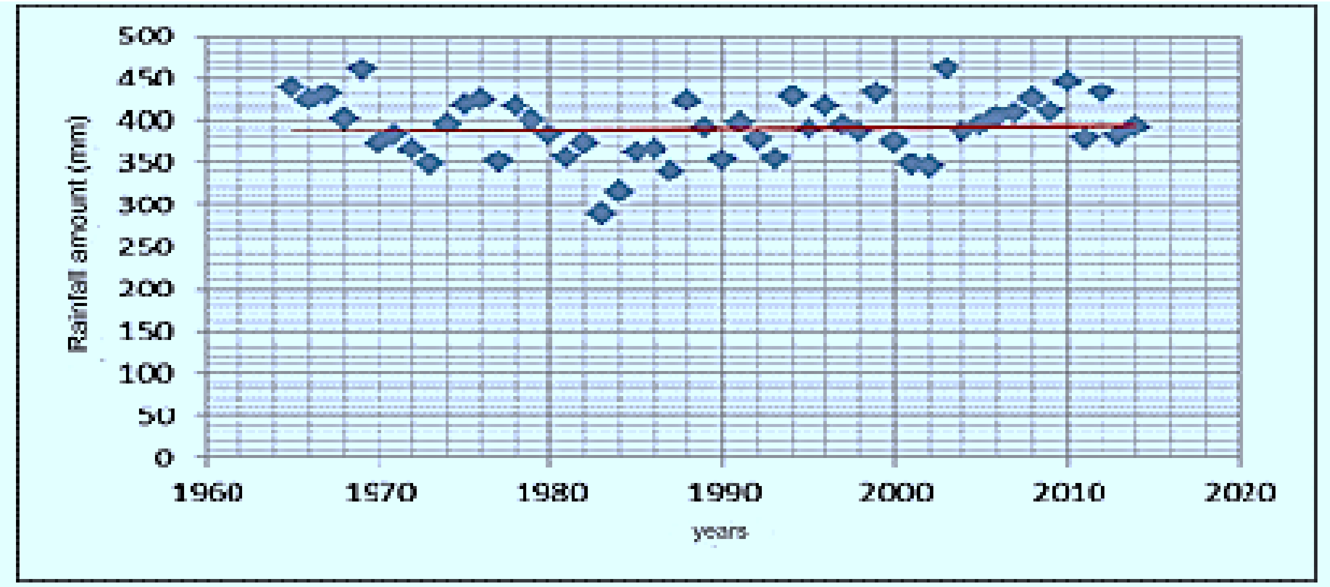

Figure 2.
Annual precipitation amounts for the countries studied during the study period.

Figure 2 presents the annual precipitation amounts for the countries in our study from 1965 to 2014. Unlike temperature, precipitation shows more variability and less of a clear trend over time.

As we mentioned, many studies have relied on the change in GDP per capita to study the impact of climate change on economic growth or development among countries in different regions. For the sample we have chosen, most countries experienced growth in GDP per capita throughout the study period (see Table 3):

Table 3.
Descriptive analysis of the per capita share of the GDP of the sample countries.

Country	Average GDP per Capita (USD)	Standard Deviation	Highest Value	Lowest Value	Growth Rate During Study Period (%)
Algeria	3,535.00	661.24	4,700.87	2,108.45	1.6
Burkina Faso	388.62	110.19	637.88	255.52	1.9
Chad	603.61	149.66	965.84	405.91	1.15
Egypt	1,588.31	624.38	2,668.03	738.56	2.61
Mauritania	1,115.16	99.99	1,316.31	961.33	0.37
Morocco	1,774.18	647.15	3,141.85	814.17	2.91
Niger	433.39	112.36	714.61	325.83	-1.08
Nigeria	1,638.53	404.55	2,548.42	1,086.41	1.49
Senegal	923.34	68.57	1,044.18	791.82	-0.002
Sudan	977.45	281.45	1,761.86	703.63	1.64
Tunisia	2,492.06	962.07	4,329.25	1,084.87	2.9

Morocco and Tunisia achieved the highest growth rates with an average of 2.9%, while Niger and Senegal witnessed negative average annual growth rates of -1.08 and -0.002%, respectively, while Algeria achieved the highest per capita GDP on average at $3,535.

4.2. The Econometric Model

Our analysis employs two complementary approaches to capture both short-term and long-term effects of climate variables on economic growth:

4.2.1. Static Analysis Models

The three known models are the linear model, the semi-logarithmic model, and the logarithmic model. To find the mathematical form of the study model, we will compare their statistical indicators using the EViews 9 software. We will then choose the model that achieves the highest values for R^2 and DW, and the lowest values for AIC, SIC, HQ, and SE.

Table 4.
Selection of the Most Appropriate Mathematical Model Format.

Model Format	**Statistical Criteria for Selecting the Appropriate Model**							
	AIC	**SIC**	**H&Q**	**F**	**DW**	R^2	$\bar{R}2$	**SE**
GDPPC = f (PR, TEMP)	16.36	16.38	16.37	112.68	0.015	0.29	0.28	862.99
LnGDPPC = f (PR, TEMP)	1.75	1.77	1.76	142.96	0.018	0.34	0.34	0.58
LnGDPPC = f (LnPR, LnTEMP)	1.77	1.8	1.78	133.29	0.016	0.32	0.32	0.58

From Table 5, it appears clear that the semi-logarithmic form is the most appropriate form for the model:

$$LnGDPPC_{i,t} = \alpha + \beta_1 TEMP_{i,t} + \beta_2 PR_{i,t} + \varepsilon_{i,t}$$

Where:
$LnGDPPC_{i,t}$ represents the logarithm of GDP per capita in country i during year t.
$TEMP_{i,t}$ represents the average temperature in country i during year t.
$PR_{i,t}$ represents the amount of precipitation in country i during year t.
α, $\beta 1$, $\beta 2$ are the parameters of the model.
$\varepsilon_{i,t}$ is the random error term.
By inputting the cross-sectional data according to the pooled regression model, we obtain the following results:
$LnGDPPC_{i,t} = 9.886668 - 0.116440 * TEMP_{i,t} + (9.46E-05) * PR_{i,t} + \varepsilon_{i,t}$ (0.0000) (0.0000)
(0.2339)

Table 5.
Testing the statistical significance and auto-correlation of errors for the first panel model.

F-statistic	142.9637	Durbin-Watson stat	0.018873
Prob(F-statistic)	0.000000	R-squared	0.344106

It appears from the estimated model that the effect of temperature was negative on the economic growth of the studied countries, and this effect is significant at the 5% significance level, unlike precipitation, which was positive but not statistically significant. However, can we rely on this econometric model in the analysis? Before this, we must conduct a Lagrange multiplier test (Breusch-Pagan LM) and then make the appropriate judgment according to the following hypotheses:

- Null Hypothesis H0: The pooled model is the appropriate one.
- Alternative Hypothesis H1: The model is not appropriate.

Table 6.
Results of Lagrange Multiplier Tests for Pooled Regression.

	Test Hypothesis		
	Cross-section	**Time**	**Both**
Breusch-Pagan	6708.887	9.514373	6718.401
sig	(0.0000)	(0.0020)	(0.0000)
Honda	81.90780	3.084538	60.09866
sig	(0.0000)	(0.0010)	(0.0000)

The results of the Lagrange multiplier test shown in Table 6 show that all statistics are significant, which means rejecting the null hypothesis and accepting the alternative hypothesis, stating that one of the two models (the random effects model or the fixed effects model) is the most appropriate for estimating the relationship.

Between climate indicators and economic growth in this cross-sectional series, the following results represent the estimation of this relationship through the random effects model:

$$LnGDPPC_{i,t} = 2.808032 + 0.164127 * TEMP_{i,t} + 0.000187 * PR_{i,t} + \varepsilon_{i,t}$$

(0.0000) (0.0000) (0.2293)

Table 7.
Testing the statistical significance and auto-correlation of errors for the second panel model.

F-statistic	48.98612	Durbin-Watson stat	0.175251
Prob(F-statistic)	0	R-squared	0.152374

In this model, the constant term and the average temperature show significance and appear to have a positive impact on economic growth in these countries, in contrast to the pooled model. However, the effect of precipitation remains statistically insignificant. By applying the Hausman test represented in Table 8, we test whether we can rely on this model as appropriate or move to the fixed effects model, where the test result shows us:

Table 8.
Results of Hausman test for random effects regression.

Correlated Random Effects - Hausman Test			
Test cross-section random effects			
Test Summary	**Chi-Sq. Statistic**	**Chi-Sq. d.f.**	**Prob.**
Cross-section random	43.606341	2	0.0000

The statistical significance is evident, implying that the null hypothesis that the random effects model is suitable for estimating the regression relationship is rejected. Therefore, the fixed effects model is the appropriate model for estimation, and its results are given as follows:

$$LnGDPPC_{i,t} = 1.777761 + 0.202947 * TEMP_{i,t} + 0.000323 * PR_{i,t} + \varepsilon_{i,t}$$

(0.0001)
(0.0000) (0.0477)

Table 9.
Testing the statistical significance and auto-correlation of errors for the third panel model.

F-statistic	347.4366	Durbin-Watson stat	0.264070
Prob(F-statistic)	0.000000	R-squared	0.886273

This model shows the significant positive effect of both the average temperature and the volume of precipitation on the economic growth of the studied countries. While the positive effect of rain seems logical, as most similar studies have found, the effect of temperature came out positive, contrary to expectations and contrary to many studies. We had to estimate the long-term relationship in order to study it, since these kinds of relationships do not always remain the same, and the way they affect each other changes over time. This is why it was important to ensure that these variables were cointegrated.

4.3. Study of Concurrent Integration

As a first step, we will test the stationarity of these time series and determine the levels at which they become stationary. This will help us choose the appropriate method to verify the existence of cointegration.

4.3.1. Study of Variables Stationarity (Unit Root Test)

We need to check if the time series of the variables are stationary before we can test for cointegration. This is because time series aren't always stationary at their levels, which means that regression analysis is incorrect and gives false results. This kind of regression is called spurious regression (Supérius Régression). Several tests verify these series' stationarity and determine their stationary levels. The tests in Table 10 show that the series of the logarithm of GDP per capita (LnGDPPC) is not stationary and only becomes stationary when the first difference is taken. Because of this, it is integrated of order one I(1). On the other hand, the series of variables PR and TEMP are stationary at the level, so they are integrated of order zero I(0).

Table 10.
Results of the stationarity test for study variables.

Variable/Test			LLC	ADF/F	PP/F	IPS
LnGDPPC	Level	Model with Constant	-0.6869 (0.2461)	13.383 (0.9219)	10.567 (0.9804)	2.6302 (0.9957)
		Model with Constant and Trend	0.2646 (0.6044)	14.817 (0.8700)	10.480 (0.9814)	1.9409 (0.9739)
	First Difference	Model with Constant	-22.157 (0.0000)	329.81 (0.0000)	325.54 (0.0000)	-21.228 (0.0000)
		Model with Constant and Trend		343.67 (0.0000)	347.13 (0.0000)	-21.780 (0.0000)
PR	Level	Model with Constant	-18.0332 (0.0000)	282.11 (0.0000)	286.85 (0.0000)	-17.979 (0.0000)
		Model with Constant and Trend	-18.0118 (0.0000)	251.05 (0.0000)	256.46 (0.0000)	-18.011 (0.0000)
TEMP	Level	Model with Constant	-3.57534 (0.0002)	39.775 (0.0115)	84.607 (0.0000)	-2.1417 (0.0161)
		Model with Constant and Trend	-16.9005 (0.0000)	210.91 (0.0000)	208.50 (0.0000)	-15.142 (0.0000)

4.3.2. Testing for Cointegration

After finding out that the integration orders of the three variables are different, we can now determine how to test for cointegration between them. We will choose the Autoregressive Distributed Lag (ARDL) approach due to its advantages that make it superior to other methods, such as the Engle-Granger methodology and the Johansen-Juselius methodology.

While the latter two require variables integrated of the same order, the ARDL methodology allows for the integration of variables of different orders I(0) or I(1). The ARDL is also considered more suitable for small samples and allows for different numbers of lags for each variable within the model. The resulting model is denoted as ARDL(p,q1,q2,...), for example, where p, q1, q2,... are the required lag orders for the dependent variable and independent variables, respectively. Under our use of the ARDL methodology, our model will take the following form:

$$\Delta(LnGDPPC)_{i,t} = \sum_{j=1}^{p-1} \lambda_{ij}\,\Delta(LnGDPPC)_{i,t-j} + \sum_{j=0}^{q_1-1} \gamma_{ij}\,\Delta(TEMP)_{i,t-j} + \sum_{j=0}^{q_2-1} \delta_{ij}\,\Delta(PR)_{i,t-j} + \phi_i\big(LnGDPPC_{i,t-1} - \beta_0 - \beta_1 TEMP_{i,t-1} - \beta_2\,PR_{i,t-1}\big) + \mu_i + \varepsilon_{it}$$

Where:

Δ: is the first difference in the time series λ_{ij}, γ_{ij}, δ_{ij}: parameters of the study variables in the short term for country *i* and lag *j*

$\beta_0, \beta_1, \beta_2$: parameters of the long-term model

ϕ_i: speed of adjustment to long-term equilibrium for country *i*, which is required to be significant and negative to judge the existence of cointegration between the study variables.

p, q1, and q2 are the appropriate lag orders for each variable, through which we obtain the final form of the model.

We determine the optimal lag orders according to the lowest values that most comparison criteria can reach, such as AIC, SC, and HQ. The following shows the result of AIC criterion values, where the ideal model is ARDL (2,1,1).

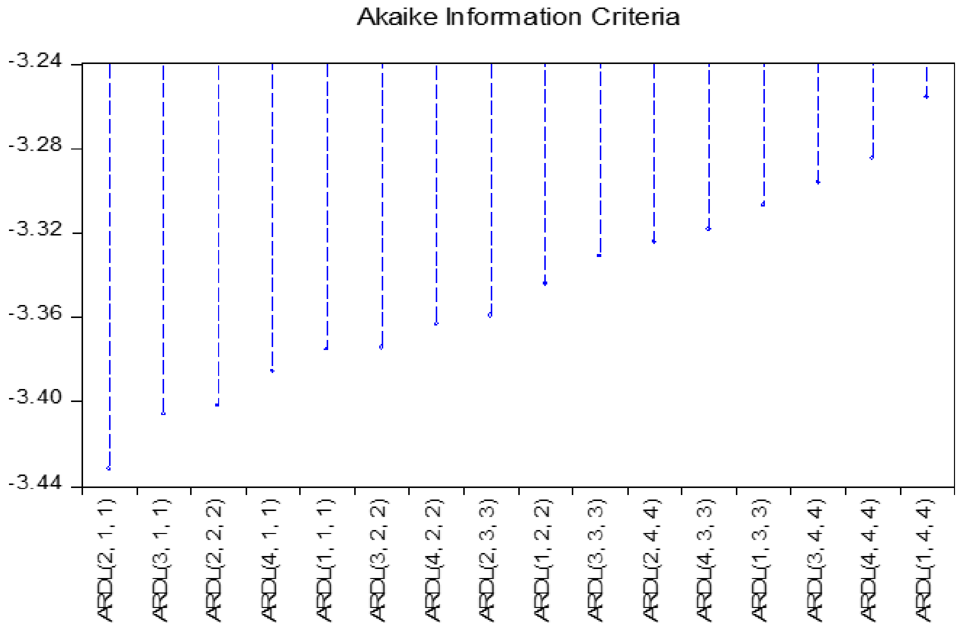

Figure 3.
Degrees of delay of study variables and the appropriate model.

The model obtained is estimated using Ordinary Least Squares (OLS) and the Pooled Mean Group (PMG) regression approach. Accordingly, the estimation results are as follows:

Table 11.
Results of estimating long-term and short-term relationships.

Dependent Variable: DLOG(GDPPC)				
Selected Model: ARDL (2, 1, 1)				
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob. ***
	Long Run Equation			
PR	0.009441	0.002935	3.216305	0.0014
TEMP	0.108729	0.075080	1.448178	0.1482
	Short Run Equation			
COINTEQ01	-0.039736	0.010862	-3.658266	0.0003
DLOG (GDPPC (-1))	0.020508	0.096187	0.213209	0.8313
D(PR)	-9.47E-05	0.000120	-0.787505	0.4314
D(TEMP)	-0.006848	0.002353	-2.910914	0.0038
C	0.086208	0.055627	1.549754	0.1218
Log likelihood	956.8710			

In these results, the negative and significant effect of temperature on economic growth appears in the group of countries in the short term, while the effect of precipitation is absent here, only to appear positively and significantly in the long term. Initially, there appears to be cointegration between the variables through the negative and significant value of the error correction speed (COINTEQ01 = -0.039). The Bounds test and the Wald test verify the existence of this integration. The first test provided us with inconclusive results to judge the significance of the temperature and precipitation parameters in the long-term relationship, as they fall between the lower and upper bounds at all significance levels of 90%, 95%, and 99% according to Pesaran tables, as shown in the following table:

Table 12.
Results of the Bounds test

		90% CI		95% CI		99% CI	
Variable	**Coefficient**	**Low**	**High**	**Low**	**High**	**Low**	**High**
PR	0.009441	0.004603	0.014278	0.003673	0.015208	0.001850	0.017031
TEMP	0.108729	-0.015000	0.232459	-0.038789	0.256247	-0.085419	0.302878

For this reason, we will resort to the Wald test, which allows us to test the following hypotheses:
H_0: The parameters of the two independent variables are not significant in the long term, i.e., $\theta = \lambda = 0$
H_1: At least one of the parameters is different from zero.

Table 13.
Results of the Wald test.

Test Statistic	**Value**	**df**	**Probability**
F-statistic	5.537597	(2, 491)	0.0042
Chi-square	11.07519	2	0.0039
Null Hypothesis: C (1) = C (2) = 0			
Null Hypothesis Summary:			
Normalized Restriction (= 0)		Value	Std. Err.
C (1)		0.009441	0.002935
C (2)		0.108729	0.075080

The test results confirm the rejection of the null hypothesis and the acceptance of the alternative hypothesis. So, at least one of the parameters is not zero, which proves that the climate indicators and economic growth, as measured by GDP per capita, are linked over a long period of time.

5. Interpretation of Results

While most studies conducted on the relationship between economic growth and climate change have pointed to the negative effect of rising temperatures on GDP per capita, our static analysis indicated the opposite. An increase of one degree Celsius in temperature leads to an increase in growth by 0.2%. However, the results of the integrated concurrent analysis appeared more accurate and logical, as there was a negative effect of rising temperatures on the economic growth of the sample countries in the short term.

An increase of one degree Celsius leads to a decrease in per capita income by 0.0068%. This is likely due to many African countries' reliance on the agricultural sector, where some crops are affected by rising temperatures, leading to their damage or reduced yield. Other sectors may also be indirectly affected by this increase, as heat waves negatively impact human activity in various fields, including the industry and services sectors, not to mention the effect of high temperatures on attracting tourists for countries that depend on the tourism sector.

Short-term efforts to adapt to rising temperatures have a negative effect on growth because they require more money to be spent on things like air conditioning, cooling, and using heat-resistant crops and expensive hybrid seeds. However, this negative effect diminishes over time as plants adapt to these small temperature increases. Meanwhile, the significant effect of precipitation is absent in the short term because the negative effect of temperature overcomes the expected positive effect of precipitation in this context.

However, the situation does not remain the same in the long term. We already talked about how adaptations to high temperatures can cancel out the big negative effect of those temperatures and make room for the big positive effect of rain in the long term. For example, every 100 mm of rain leads to a 0.9% rise in per capita income.

6. Conclusion

This study has examined the impact of climate change on economic growth in North African and Sahel countries from 1965 to 2020, using both static analysis and an Autoregressive Distributed Lag (ARDL) model. Our findings reveal complex relationships between climate variables and economic growth, highlighting the importance of considering both short-term and long-term effects.

In the short term, our results indicate a negative effect of rising temperatures on economic growth. Specifically, a one-degree Celsius increase in temperature leads to a 0.0068% decrease in per capita income. This finding aligns with much of the existing literature and underscores the immediate challenges that climate change poses to economies in the region. The negative short-term impact is likely due to the region's heavy reliance on climate-sensitive sectors such as agriculture and tourism. Rising temperatures can lead to reduced crop yields, increased water scarcity, and diminished appeal for tourism, all of which can hamper economic growth.

However, our long-term analysis reveals a more nuanced picture. While the negative effect of temperature persists, we also found a positive and significant effect of precipitation on economic growth in the long run. Every 100 mm increase in precipitation contributes to a 0.9% increase in per capita income. This suggests that adaptation measures and long-term adjustments in economic structures can potentially mitigate some of the negative impacts of climate change.

The contrast between short-term and long-term effects underscores the importance of adaptive strategies. In the short term, rising temperatures necessitate increased spending on cooling and climate-resistant agricultural varieties, which can strain economic resources. However, over time, these adaptations, along with structural changes in the economy, may help offset some of the negative impacts of higher temperatures.

Our findings have several important implications for policymakers in North African and Sahel countries:

- Immediate Action on Climate Mitigation: The significant short-term negative impact of rising temperatures highlights the urgent need for climate mitigation efforts. Countries in the region should prioritize policies that reduce greenhouse gas emissions and limit further temperature increases.
- Investment in Adaptation: While mitigation is crucial, our long-term findings suggest that adaptation strategies can be effective. Governments should invest in climate-resilient infrastructure, drought-resistant crop varieties, and water management systems to better cope with changing climate conditions.
- Diversification of Economies: The vulnerability of agriculture and tourism to climate change underscores the need for economic diversification. Policymakers should encourage the development of sectors that are less sensitive to climate variations to build more resilient economies.
- Regional Cooperation: Given the transboundary nature of climate impacts, enhanced regional cooperation on climate adaptation and mitigation strategies could yield significant benefits.
- Integration of Climate Considerations in Economic Planning: Our study demonstrates the strong link between climate variables and economic performance. As such, climate considerations should be fully integrated into economic planning and development strategies.

However, it is important to acknowledge the limitations of our study. While we focused on temperature and precipitation as key climate variables, future research could incorporate additional climate indicators such as extreme weather events or sea-level rise. Furthermore, country-specific case studies could provide more detailed insights into how different economies within the region are affected by and are adapting to climate change.

References

[1] G. M. Grossman and A. B. Krueger, "Environmental impacts of a North American free trade agreement," National Bureau of Economics Research Working Paper, No. 3194. NBER, Cambridge. https://doi.org/10.3386/w3914, 1991.

[2] B. Friedl and M. Getzner, "Determinants of CO2 emissions in a small open economy," *Ecological Economics,* vol. 45, no. 1, pp. 133-148, 2003. https://doi.org/10.1016/S0921-8009(03)00008-9

[3] A. K. Richmond and R. K. Kaufmann, "Is there a turning point in the relationship between income and energy use and/or carbon emissions?," *Ecological Economics,* vol. 56, no. 2, pp. 176-189, 2006. https://doi.org/10.1016/j.ecolecon.2005.01.011

[4] A. Metalas, "The impact of climate change on global energy markets," Unpublished Doctoral Dissertation, University of Algiers, 2012.

[5] A. A. Adesete, O. E. Olanubi, and R. O. Dauda, "Climate change and food security in selected Sub-Saharan African Countries," *Environment, Development and Sustainability,* vol. 25, no. 12, pp. 14623-14641, 2023. https://doi.org/10.1007/s10668-022-02681-0

[6] A. B. Omotoso, S. Letsoalo, K. O. Olagunju, C. S. Tshwene, and A. O. Omotayo, "Climate change and variability in sub-Saharan Africa: A systematic review of trends and impacts on agriculture," *Journal of Cleaner Production,* vol. 414, p. 137487, 2023. https://doi.org/10.1016/j.jclepro.2023.137487

[7] S. B. Bedeke, "Climate change vulnerability and adaptation of crop producers in sub-Saharan Africa: A review on concepts, approaches and methods," *Environment, Development and Sustainability,* vol. 25, no. 2, pp. 1017-1051, 2023. https://doi.org/10.1007/s10668-022-02118-8

[8] K. A. Berg, C. C. Curtis, and N. C. Mark, "Gdp and temperature: Evidence on cross-country response heterogeneity," *European Economic Review,* vol. 169, p. 104833, 2024. https://doi.org/10.1016/j.euroecorev.2024.104833

[9] A. Bilal and D. R. Känzig, "The macroeconomic impact of climate change: Global vs. local temperature," National Bureau of Economic Research. (No. w32450), 2024.

[10] Y. Zhao and S. Liu, "Effects of climate change on economic growth: A perspective of the heterogeneous climate regions in Africa," *Sustainability,* vol. 15, no. 9, p. 7136, 2023. https://doi.org/10.3390/su15097136

[11] J. Jurasz *et al.*, "Complementarity of wind and solar power in North Africa: Potential for alleviating energy droughts and impacts of the North Atlantic Oscillation," *Renewable and Sustainable Energy Reviews,* vol. 191, p. 114181, 2024. https://doi.org/10.1016/j.rser.2023.114181

[12] G. Kotsompolis, K. N. Konstantakis, P. Xidonas, P. G. Michaelides, and D. D. Thomakos, "Climate change economics and the determinants of carbon emissions' futures returns: A regime-driven ARDL model," *Finance Research Letters,* vol. 58, p. 104485, 2023. https://doi.org/10.1016/j.frl.2023.104485

[13] D. Aloui, B. Gaies, and R. Hchaichi, "Exploring environmental degradation spillovers in Sub-Saharan Africa: the energy–financial instability nexus," *Economic Change and Restructuring,* vol. 56, no. 3, pp. 1699-1724, 2023. https://doi.org/10.1007/s10644-023-09489-6

[14] R. Newman and I. Noy, "The global costs of extreme weather that are attributable to climate change," *Nature Communications,* vol. 14, no. 1, p. 6103, 2023. https://doi.org/10.1038/s41467-023-41888-1

[15] B. A. Magesa, G. Mohan, H. Matsuda, I. Melts, M. Kefi, and K. Fukushi, "Understanding the farmers' choices and adoption of adaptation strategies, and plans to climate change impact in Africa: A systematic review," *Climate Services*, vol. 30, p. 100362, 2023. https://doi.org/10.1016/j.cliser.2023.100362

[16] A. Löscher and A. Kaltenbrunner, "Climate change and macroeconomic policy space in developing and emerging economies," *Journal of Post Keynesian Economics*, vol. 46, no. 1, pp. 113-141, 2023. https://doi.org/10.1080/01603477.2022.2084630

[17] IPCC, "AR5 synthesis report: Climate change 2014. Intergovernmental Panel on Climate Change (IPCC)," Retrieved: https://www.ipcc.ch/report/ar5/syr/, 2014.