The macroeconomic effects of climate change on human capital development in Africa

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Abstract

Climate change poses a growing threat to sustainable development in Africa, where countries must balance long-term investment in climate-smart practices with urgent human needs. This study investigates how climate variability affects human capital development across the continent, focusing on education, healthcare, and agriculture. Using AR(1), ARDL, and ECM models, it explores both short- and long-term effects of climate change on macroeconomic performance and welfare. Findings suggest that most impacts materialize in the long run, underlining the need for economic diversification and strategic investments in health and education. The paper recommends a pluralistic, region-specific policy approach, recognizing the continent's heterogeneity and the need for tailored, country-level responses.

Keywords: Climate change, Human capital development, Africa, ARDL model, Economic growth, Policy adaptation.

1. Introduction

Recent studies show that the climate crisis of the 21st century is growing enduringly urgent in all regions of the world: concentrations of carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O) in the troposphere have reached record levels, temperatures are increasing, sea levels are rising, and precipitation patterns are changing. According to the Intergovernmental Panel on Climate Change (IPCC), the current rate of greenhouse gas emissions is likely to cause average temperatures to rise by 0.2°C per decade, reaching the threshold of 2°C above pre-industrial levels by 2050[1]. Evidence from the World Bank suggests that rising global temperatures increase the atmosphere's moisture, resulting in more storms and heavy rains. Still, paradoxically, there are also more intense dry spells as more water evaporates from the land and global weather patterns change[2].

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[1] *Climate change widespread, rapid, and intensifying – IPCC — IPCC.* (2021, August 9). IPCC. https://www.ipcc.ch/2021/08/09/ar6-wg1-20210809-pr/

[2] World Bank Group. (2021, June 30). Floods and Droughts: An EPIC response to these hazards in the era of climate change. World Bank. https://www.worldbank.org/en/news/feature/2021/06/17/floods-and-droughts-an-epic-response-to-these-hazards-in-the-era-of-climate-change

In this century, human capital development faces numerous challenges, including the need for biodiversity conservation, food security, education, safe drinking water, renewable energy, and access to economic opportunities, all of which are met with stiff resistance from climatic conditions. The IPCC reports that climate change intensifies the water cycle, resulting in more intense rainfall, increased flooding, and droughts in many regions. Given such a phenomenon, coastal areas are expected to experience continued sea level rise throughout the 21st century, contributing to more frequent and severe coastal flooding in low-lying areas and increased coastal erosion. Extreme sea level events that previously occurred once in 100 years could happen every year by the end of this century[3]. People who depend on freshwater for food, land for agricultural activities, or rivers for drinking may have no alternative for their livelihoods and need help to cope. Just 0.5 per cent of Earth's water is usable and available as freshwater, and these conditions pose a significant threat to this crucial resource. About two billion people worldwide don't have access to safe drinking water today[4], and climate conditions will exacerbate this crisis as water is a crucial element for sustainable livelihood.

Regarding education, many children will experience fewer schooling days, with learning infrastructure at risk due to flooding or uninhabitable classrooms resulting from high humidity levels. The quality of education in many countries across Africa already needs improvement. Yet, the education sector faces significant challenges related to climate disruptions. For example, 25 of 33 countries where children face *extreme* climate vulnerability are on the continent[5]. Health situations will worsen across many parts of the continent, threatening sustainable economic and human development. These effects will be felt across all areas of human livelihood and will be more severe for those in Africa. Beyond its long-term threats to globalization, climate change is a serious risk to poverty reduction and could undo decades of development efforts.

These alarming needs require urgent action. If unaddressed, populations may be wiped out sooner than expected, environments may no longer be able to serve human and animal needs, and the long-term macroeconomic effects may linger for years unsolved. African countries rely heavily on agriculture as the mainstay of their economy and employment, accounting for more than half of their labour force. For context, multiple studies have found the engines of economic growth, development, and poverty reduction in Liberia, in sectors such as agriculture, fisheries, and forestry[6]. However, the climate crisis has recently challenged these prospects across many regions. More than 110 million people on the

[3] Climate change widespread, rapid, and intensifying – IPCC — IPCC. (2021, August 9). IPCC. https://www.ipcc.ch/2021/08/09/ar6-wg1-20210809-pr/

[4] United Nations Statistics Division. (n.d.). — SDG indicators.

[5] Global Center on Adaptation (GCA). (2022). State and Trends in Adaptation 2022: Education. Retrieved from https://gca.org/wp-content/uploads/2023/01/GCA_State-and-Trends-in-Adaptation-2022_Education.pdf

[6] World Bank. (2018). Liberia: From growth to development: Priorities for sustainably reducing poverty and achieving middle-income status by 2030. World Bank. https://documents1.worldbank.org/curated/en/585371528125859387/pdf/Liberia-From-growth-to-development-priorities-for-sustainably-reducing-poverty-and-achieving-middle-income-status-by-2030.pdf

continent were directly affected by weather, climate, and water-related hazards in 2022, resulting in over US$ 8.5 billion in economic damages[7], and this trend is expected to worsen at an increasing rate over the years.

However, the Organization for Economic Cooperation and Development (OECD) analysis suggests that if we act now, we have 10 to 15 years of *"breathing space"* during which action is possible at a relatively modest cost. But every year of delay reduces this breathing space, requiring increasingly stringent measures to make a difference. The OECD's analysis informs us that "current financial turmoil is not a reason to delay. Indeed, its macroeconomic consequences will be resolved relatively quickly, after which growth is expected to resume. In contrast, the consequences of inaction on global warming will continue to grow more and more costly over time." [8].

Human influence on the past and future is evident in the current state of our world, and in the context of climate change, it is no different. "It has been clear for decades that the Earth's climate is changing, and the role of human influence on the climate system is undisputed," says Valerie Masson-Delmotte, Co-Chair of Working Group I at IPCC. It is only essential, then, that these areas of human impacts on climatic conditions be urgently addressed and sustainable solutions reimagined.

Considering such critical needs, this paper will focus on investigating the macroeconomic effects of climate change on human capital development in SubSaharan Africa (SSA), a continent highly vulnerable to climate-induced disruptions yet highly dependent on climate-sensitive sectors for economic activities - agriculture (including fisheries and forestry) and the industrial sector (mining, water, oil and gas, construction, and electricity) which has jointly contributed more than 50 per cent of Gross Domestic Product (GDP) across years in countries like Liberia[9]. The study will examine how climate change affects critical human development sectors, including education, healthcare, agriculture, and employment. By understanding these dynamics, the research will provide a crucial understanding of how climate variability hinders economic growth and development in fragile economies, shedding light on the broader implications for Africa.

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[7] Africa suffers disproportionately from climate change - World. (2023, September 4). ReliefWeb. https://reliefweb.int/report/world/africa-suffers-disproportionately-climate-change

[8] Adedeji, O., Reuben, O., & Olatoye, O. (2014). Global climate change. Journal of Geoscience and Environment Protection, 02(02), 114–122. https://doi.org/10.4236/gep.2014.22016

[9] World Bank. (2018). Liberia: From growth to development: Priorities for sustainably reducing poverty and achieving middle-income status by 2030. World Bank. https://documents1.worldbank.org/curated/en/585371528125859387/pdf/Liberia-From-growth-to-development-priorities-for-sustainably-reducing-poverty-and-achieving-middle-income-status-by-2030.pdf

2. Literature Review

2.1 Climate Change, Poverty, and Inequality in Africa

Multiple studies show that climatic conditions will severely impact Africa due to adverse direct effects such as high agricultural dependence and limited adaptation capacity, undercutting efforts at human capital development[10]. The climate crisis could exacerbate deeply entrenched inequality and poverty across the continent even as the population rises and income grows disproportionately. In 2024, Africa accounted for 16 percent of the world's population, but 67 percent live in extreme poverty. Two-thirds of the world's population in extreme poverty live in Sub-Saharan Africa (SSA) alone, rising to three-quarters when including all fragile and conflict-affected countries[11]. Poverty remains high in comparison with other regions across the world, and even those who no longer fall below the World Bank's poverty line ($2.15 daily) are still vulnerable and far from reasonable aspirations for human prosperity.

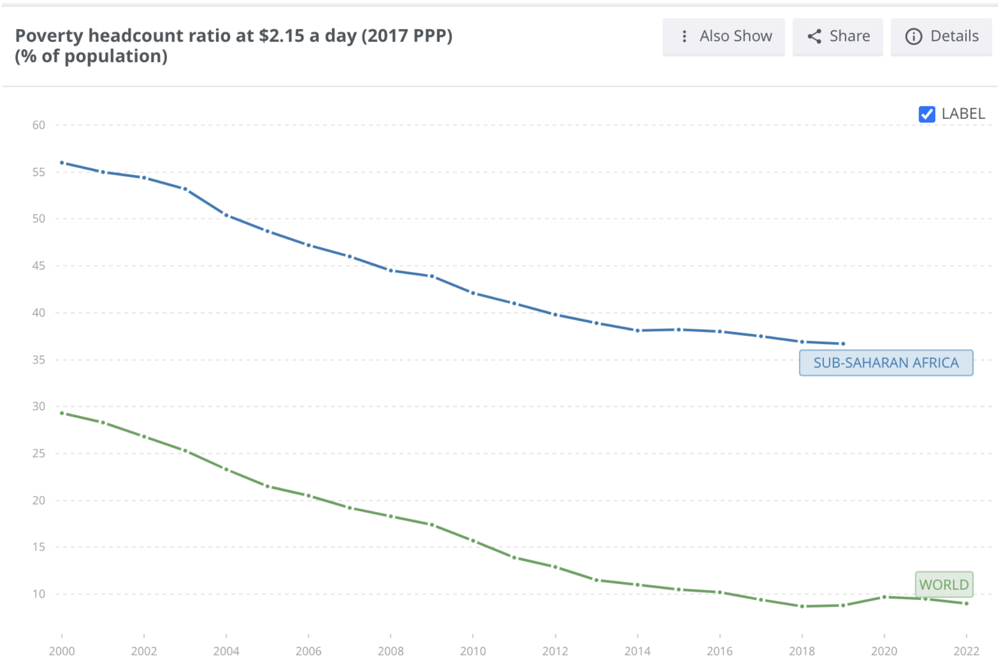

Fig.I. Poverty headcount ratio at $2.15 a day (2017 PPP)
Source: World Bank Data (2022) [12]

Despite the climate challenges and the continent's failure to address its current human capital crisis, population growth continues to rise significantly, increasing demand for access to education, food security, healthcare, social services, welfare, and decent livelihoods. The World Bank estimates that by 2075, one-third of the world's population, including the working-age population, will be African. It is the only region where the workforce will grow continuously in the

[10] Collier, P., Conway, G.R., & Venables, T. (2008). Climate Change and Africa. Oxford Review of Economic Policy, 24, 337-353.
[11] World Bank. (n.d.). Poverty. The World Bank. Retrieved November 19, 2024.
[12] World Bank. (n.d.). Poverty. The World Bank. Retrieved November 19, 2024.

coming decades[13]. In light of all these, the climate crisis is threatening prosperity across the continent. Recent studies suggest that climate change will lead to skyrocketing food prices, toxic air, and polluted water for people in developing countries. It leaves countries just one natural disaster away from poverty, forcing parents to pull children out of school and entire communities to migrate[14]. Given that learning infrastructures are not climate resilient and cities or communities cannot cope with shocks, the educational risks associated with climate change are profound.

2.2 Education, Employment, and Migration

Education is one of the most critical areas of human capital development, and climate change has been shown to disrupt educational systems and learning processes in multiple ways. The increased frequency of extreme weather events, such as floods and droughts, can damage schools and infrastructure, thereby eroding the possibility of children attending school regularly. Climate-related disruptions to education are particularly pronounced in regions with high vulnerability, such as SSA, where many schools cannot withstand severe weather events. In countries with inadequate infrastructure, these disruptions can immediately affect retention and have long-lasting effects on learning outcomes, impacting how African youth transition into employment and labor markets. A recent study in ten African countries found that cumulative exposure to climate anomalies has a significant negative impact on primary school completion rates, particularly affecting children from less educated households[15]. School attainment is linked to higher earnings, with estimates suggesting a 9-10 percent return for each additional year of schooling[16].

A recent study on the persistent effects of natural disasters on human development (González, Santos, & London, 2021) revealed that natural disasters reduced, on average, 0.03 years of schooling for those who experienced them within their first year of life compared to those who did not[17]. For example, following Cyclone Idai in 2019 in Zimbabwe, over half of the schools (57%) reported the destruction of some infrastructure, directly affecting the schooling of almost 100,000 children[18]. Each climate-related disaster that pushes students out of school leaves them less capable of the future

[13] World Bank. (2023, June 27). Investing in youth: Transforming AFE Africa. The World Bank. Retrieved November 7, 2024,

[14] World Bank. (n.d.). Climate change overview. The World Bank. Retrieved November 7, 2024, from https://www.worldbank.org/en/topic/climatechange/overview

[15] Sukie, C., & Kai, L. (2023). Mapping the cumulative effects of climate change on children's education in ten African countries. UNESCO Global Education Monitoring Report. Retrieved November 19, 2024, from https://www.unesco.org/gem-report/sites/default/files/medias/fichiers/2023/09/SukieandKai.pdf

[16] Venegas Marin, S., Schwarz, L., & Sabarwal, S. (2024). The impact of climate change on education and what to do about it. World Bank. Retrieved November 19, 2024, from https://documents1.worldbank.org/curated/en/099043024150036726/pdf/P180005171cc7c0c91a8b011d03080e9086.pdf

[17] González, F. A. I., Santos, M. E., & London, S. (2021). Persistent effects of natural disasters on human development: quasi-experimental evidence for Argentina. Environment, Development and Sustainability, 23(7), 10432-10454.

[18] Global Partnership for Education. (n.d.). Zimbabwe: A stronger education system after Cyclone Idai. Retrieved November 19, 2024, from https://www.globalpartnership.org/results/country-journeys/zimbabwe-stronger-education-system-after-cyclone-idai

of work and employment, decreasing long-term earning potential. Given extreme weather circumstances, children who miss school due to flooding or are forced to migrate for food or jobs are less likely to develop the skills necessary to contribute to the labour market as adults, ultimately undermining a country's human capital base. Further studies indicate that climate-induced economic stress can reduce household income, leading to higher dropout rates and fewer children attending school, particularly among disadvantaged communities[19]. As a result, climate change creates a vicious cycle in which reduced educational outcomes exacerbate poverty and limit long-term economic growth prospects.

2.3 Agriculture, Social Livelihood, and Migration

Although Africa has contributed the least to global greenhouse gas emissions, the continent is the most severely affected by the impact of climate change. In context, Africa has a population of approximately 1.2 billion people, of whom nearly 70% rely on agriculture for their livelihood. Of its 3 billion Hectares, an estimated 20,000 hectares are lost annually to desertification. Many economies in the region rely heavily on climate-sensitive sectors for GDP growth, including agriculture, fisheries, and forestry, and their economic and social well-being is affected as the climate crisis evolves. Empirical findings indicate that climate change can reduce families' disposable income through shocks that damage crops, resulting in losses in agricultural income or reduced adult productivity in general, and hence, losses in other earnings[20]. As climate change increasingly affects agricultural productivity and local economies, it also contributes to migration patterns that strain urban areas and complicate the provision of services. Climate impacts on migration in Africa are complex and context-dependent. While environmental factors influence migration, they affect socioeconomic, political, and demographic drivers indirectly.[21, 22] In many African countries, rural-urban migration is already a significant concern, with migrants flocking to urban centers in search of work and improved living conditions. Climate-induced displacement can exacerbate existing urban vulnerabilities by placing additional pressure on already overstretched social services, housing, and employment opportunities. Temperature and rainfall variations can lead to internal and international migration, with an estimated 2.35 million people displaced in Africa from 1960 to 2000 due to climate factors, and a predicted additional 1.4 million per year[23]. Migration due to climate stressors, particularly in rural communities, leads to increased urban poverty and can also reduce the availability of skilled labour in agriculture, further

[19] Sukie, C., & Kai, L. (2023). Mapping the cumulative effects of climate change on children's education in ten African countries. UNESCO Global Education Monitoring Report. Retrieved November 19, 2024, from https://www.unesco.org/gem-report/sites/default/files/medias/fichiers/2023/09/SukieandKai.pdf

[20] Sukie, C., & Kai, L. (2023). Mapping the cumulative effects of climate change on children's education in ten African countries. UNESCO Global Education Monitoring Report. Retrieved November 19, 2024, from https://www.unesco.org/gem-report/sites/default/files/medias/fichiers/2023/09/SukieandKai.pdf

[21] Borderon, M., Sakdapolrak, P., Muttarak, R., Kebede, E.B., Pagogna, R., & Sporer, E. (2018). A systematic review of empirical evidence on migration influenced by environmental change in Africa.

[22] Zickgraf, C. (2018). Climate Change and Migration Crisis in Africa. The Oxford Handbook of Migration Crises.

[23] Marchiori, L., Maystadt, J., & Schumacher, I. (2011). The Impact of Climate Variations on Migration in Africa.

diminishing the productivity in those climate-sensitive sectors. Studies have found that the relationship between climate and migration varies across regions and populations, with rural and farming households more likely to be affected[24, 25]. However, the impact of climate on migration is not linear; some studies suggest a hill-shaped relationship between temperature and precipitation and migration propensity in farming households[26].

As these events unfold, questions arise about the economic livelihoods supported by agricultural activities and growing concerns about supply in global markets. Climate-related adverse effects significantly shrink agricultural outputs, reducing supply on local markets, lowering farmers' incomes, and potentially distorting the availability of particular products worldwide. Many African countries make significant contributions to global trade as key leaders. For example, Côte d'Ivoire leads African exports in the cocoa and cocoa preparations category, holding 55 percent of Africa's share and securing 11 percent of the global market. South Africa, Kenya, and Benin each command at least 3% of the global market in their major export categories. Other countries such as Sudan, Morocco, and Zimbabwe significantly impact global markets for vegetables, animal oils, spices, and tobacco, among others[27]. Climate change affects lower agricultural yields and weakens the economies of large exporters, while impacting overall economic output. Higher temperatures, changing rainfall patterns, droughts, and floods affect harvests. For instance, farmers in Nigeria have seen lower yields due to new pests, disease outbreaks, and the drying up of rivers, which affects overall productivity. A recent estimate suggests that a 25 per cent or more significant drop in corn yields would reduce Mozambique's GDP by 2.5 per cent[28]. This highlights the substantial vulnerability of agricultural productivity to climate change, with far-reaching economic consequences for nations heavily reliant on the sector. In 2020 alone, 770 million people faced hunger, predominantly in Africa and Asia. Climate change affects food availability, quality, and diversity, exacerbating food and nutrition crises[29]. Addressing these challenges is crucial for safeguarding food security and economic stability, while ensuring safe and sustainable human livelihoods.

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[24] Cattaneo, C., & Massetti, E. (2015). Migration and Climate Change in Rural Africa. Environmental Anthropology eJournal.
[25] Marchiori, L., Maystadt, J., & Schumacher, I. (2011). The Impact of Climate Variations on Migration in Africa!
[26] Cattaneo, C., & Massetti, E. (2015). Migration and Climate Change in Rural Africa. Environmental Anthropology eJournal.
[27] Business Day. (2024, November 19). Top African countries driving global exports in key agricultural products. Business Day. Retrieved November 19, 2024, from https://businessday.ng/news/article/top-african-countries-driving-global-exports-in-key-agricultural-products/
[28] McKinsey & Company. (n.d.). How will African farmers adjust to changing patterns of precipitation? McKinsey & Company. Retrieved November 19, 2024, from https://www.mckinsey.com/~/media/mckinsey/business%20functions/sustainability/our%20insights/how%20will%20african%20farmers%20adjust%20to%20changing%20patterns%20of%20precipitation/svgz_mgi-climatecasestudyafrica-web_exh2.svgz?cq=50&cpy=Center
[29] World Health Organization. (n.d.). Climate change and health. World Health Organization. Retrieved November 19, 2024, from https://www.who.int/news-room/fact-sheets/detail/climate-change-and-health

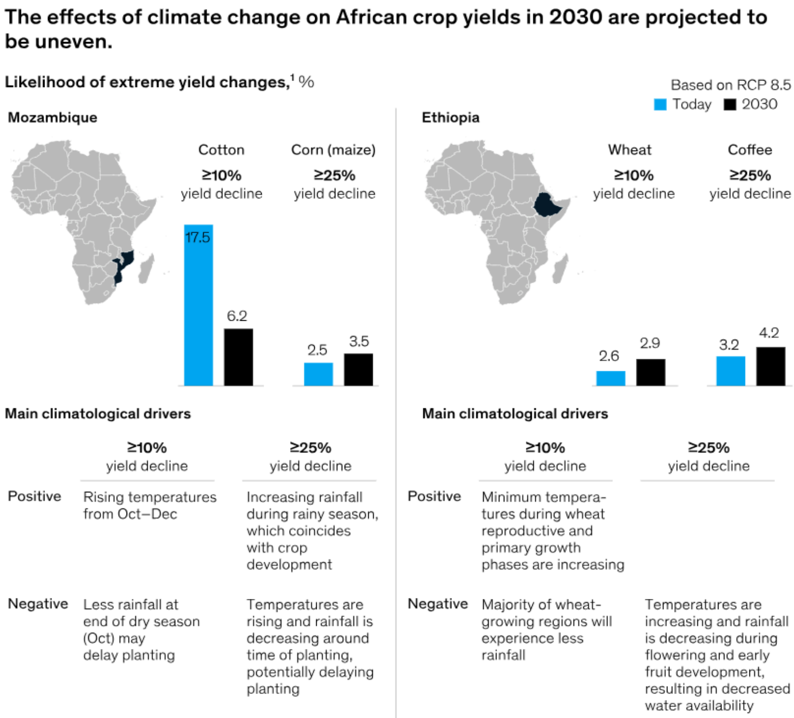

Fig.2. The effects of climate change on African crop yields in 2030
Source: McKinsey & Company (2020)[30]

2.4 Healthcare and Social Wellbeing

The growing number of climate-induced health crises significantly strains already weak healthcare systems. Changes in ecosystems contribute to the spread of vector-borne diseases such as malaria, cholera, and dengue fever. Warmer temperatures and increased rainfall create favourable conditions for mosquitoes, which are vectors for malaria, leading to its spread in areas previously unaffected by the disease. Recent literature highlights African health systems' challenges in preparedness and resilience, with inadequate resources and infrastructure to respond effectively to climate-related health risks[31]. Considering the effects on agriculture, household income, and overall GDP, climate impacts also exacerbate the financial burden on households, leading to higher out-of-pocket health expenditures[32]. The deterioration of public health increases mortality and morbidity rates while reducing the labour force's productivity and disrupting economic

[30] Opoku, S.K., Leal Filho, W., Hubert, F., & Adejumo, O.O. (2021). Climate Change and Health Preparedness in Africa: Analysing Trends in Six African Countries. International Journal of Environmental Research and Public Health, 18.
[31] Ezeruigbo, C.F., & Ezeoha, A. (2023). Climate change and the burden of healthcare financing in African households. African Journal of Primary Health Care & Family Medicine, 15.
[32] National Institute of Environmental Health Sciences. (n.d.). Health impacts on vulnerable people. Retrieved December 18, 2023, from https://www.niehs.nih.gov/research/programs/climatechange/health_impacts/vulnerable_people#:~:text=In%20general%2C%20children%20and%20pregnant,events1%20%2C%202%20%2C%203%20.

activities. Climate change disproportionately affects vulnerable groups, including women, children, and the elderly[33]. In many African societies, women are responsible for collecting water and growing food. Climate change-related disruptions to water supplies and agricultural productivity place additional burdens on women, reducing their access to healthcare and education. Evidence suggests that in vulnerable regions, the death rate from extreme weather events in the last decade was 15 times higher than in less vulnerable ones[34]. While many Africans struggle to afford necessities and cannot access quality public healthcare, they often face a tradeoff between daily sustenance and healthcare spending, with the former prevailing most frequently. Recent studies revealed that over 930 million people – approximately 12% of the world's population – spend at least 10% of their household budget on healthcare[35]. With the poorest people (broadly across Africa) largely uninsured, health shocks and stresses already push around 100 million people into poverty every year, with the impacts of climate change worsening this trend[36]. A decline in health outcomes ultimately reduces the capacity of individuals to participate effectively in the workforce, further hindering economic development.

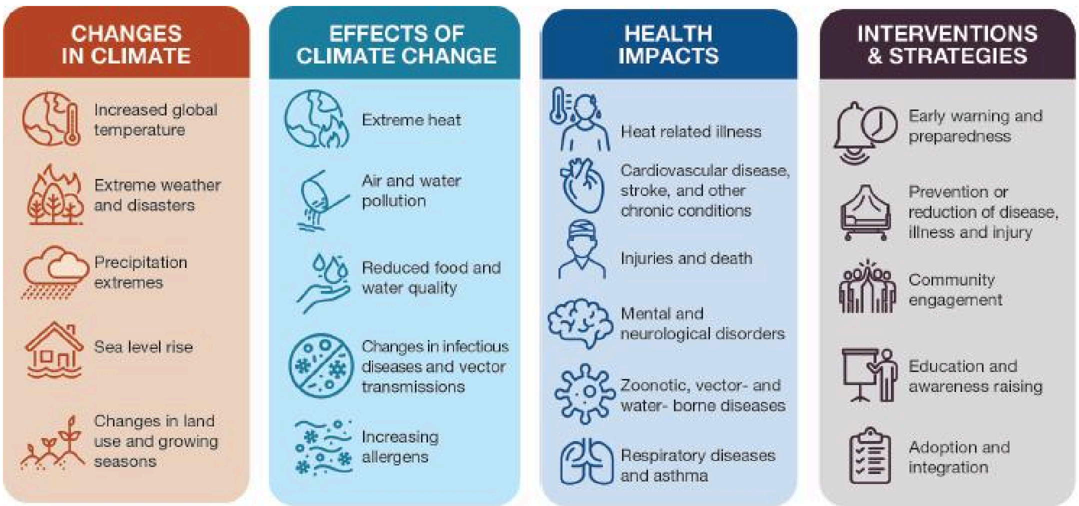

Fig.3. Changes in Climate, Effects, Health Impacts, Interventions & Strategies
Source: National Institute of Environmental Sciences (2022)

3. Data and Methodology

The study aggregated secondary data from the World Bank, the Food and Agriculture Organization, the Human Development Index Reports, and the National Climate Development Indicators for Africa over the past twenty-two

[33] World Health Organization. (n.d.). Climate change and health. World Health Organization. Retrieved November 19, 2024, from https://www.who.int/news-room/fact-sheets/detail/climate-change-and-health
[34] World Health Organization. (n.d.). Climate change and health. World Health Organization. Retrieved November 19, 2024, from https://www.who.int/news-room/fact-sheets/detail/climate-change-and-health
[35] National Institute of Environmental Health Sciences. (n.d.). Climate change and health impacts. Retrieved November 19, 2024, from https://www.niehs.nih.gov/research/programs/climatechange/health_impacts
[36] Natsiopoulos, K., & Tzeremes, N.G. (2022). ARDL: An R package for the analysis of level relationships. J. Open Source Softw., 7, 3496.

years, with human capital development as the dependent variable. It modeled how climatic factors influence its evolution, while controlling for key economic variables. The following sections systematically present the empirical estimation process and results conducted using R (R Core Team, 2024), following a reproducible pipeline for time series modeling.

3.1 Model Selection and Rationale

For initial modeling, we adopted the Autoregressive (AR) model, following Yule, G. U. (1927), formally known as the AR(p) model [37]. In this time series model, the current value of a variable depends linearly on its previous values (also known as lagged outcomes), primarily used for modeling persistence or inertia in a variable over time (Gujarati & Porter, 2009) [38]. We utilize the equation below for the estimation of the AR(p):

$$HDI_t=\alpha+\beta_1 HDI_{t-1}+\beta_2 HDI_{t-2}+\cdots+\beta_p HDI_{t-p}+\varepsilon_t$$

From the Equation, Y_t represents the given levels of human capital development (HDI) across each year, as determined from the collected data, and is the dependent variable. The intercept, α (or constant term), captures the baseline value of HDI in its base term when all lagged terms are zero.

The variables $\beta_1 HDI_{t-1}+\beta_2 HDI_{t-2}+\cdots+\beta_p HDI_{t-p}$ are lagged values of the dependent variable (HDI), multiplied by their respective autoregressive coefficients, β. They measure the effects of past HDI levels on current HDI. For example, β_1 shows the impact of HDI last year on HDI this year (lag 1), and β_2 helps us see the effect of HDI two years ago (lag 2), and so on. This enables us to understand the evolutionary pattern of HDI over time, to its previous value. Finally, ε_t in the model represents the white noise, or error term, which captures the random shocks or variations in HDI that past values cannot explain. These may include other random effects, such as political unrest or external aid.

3.1.1Descriptive Analysis

A descriptive summary (Table 1) reveals a low average HDI (0.501), moderate GDP growth (4.04%), and stable unemployment rate (6%), while on average, agriculture contributed around 10% to GDP. The final correlation heatmap

[37] Yule, G. U. (1927). On a method of investigating periodicities in disturbed series, with special reference to Wolfer's sunspot numbers. Philosophical Transactions of the Royal Society of London. Series A, Containing Papers of a Mathematical or Physical Character, 226, 267–298. https://doi.org/10.1098/rsta.1927.0007

[38] Gujarati, D. N., & Porter, D. C. (2009). *Basic econometrics* (5th ed.). McGraw-Hill Education.

(Figure 6) indicated multicollinearity risks; as a result, variables such as malaria, water, and immunization were dropped from the final model to avoid distortion.

4. Data Analysis

4.1 Human Development Index (HDI)

The average HDI from the data (0.501) reflects low levels of human development in Africa. The continent continues to face significant barriers to the development of human capital. Limited infrastructure, climate shocks, and poverty remain critical challenges, contributing to the modest HDI scores and low variability evident from the Standard Deviation (0.038), suggesting a slow and stable growth trend. Countries are categorized into four tiers based on their HDI values[40] and on average. Africa belongs to the low human development:

- Significantly High Human Development: 0.800 – 1.000
- High Human Development: 0.700 – 0.799
- Medium Human Development: 0.550 – 0.699
- Low Human Development: Below 0.550

4.2 Climate Indicators: Temperature Change and Precipitation

Climate-related variables, such as temperature change and precipitation levels, highlighted in the table, underscore the environmental vulnerabilities across the continent. The average temperature change in the region is approximately a yearly increase of 1.078 (Degrees Celsius), reflecting a subtle yet steady warming trend, with a narrow standard deviation (0.233) and a range spanning from 0.724 to 1.501. Though these fluctuations appear minimal, their long-term cumulative effects, such as desertification, agricultural losses, and forced migration, pose significant threats to human development. Likewise, precipitation averages around 1003.564 mm annually, indicating generally sufficient rainfall. However, the standard deviation of 39.289 mm, along with a range of 900 mm to 1100 mm, suggests regional and temporal disparities. These shifts in rainfall patterns contribute to climate-induced challenges, where droughts jeopardize food security and livelihoods, and excessive rainfall damages infrastructure and increases the spread of waterborne diseases.

4.2 Economic Indicators: GDP Growth Rate, Unemployment, and Agriculture Share of GDP

The average GDP growth rate across the continent is 4.04%, with moderate variability (standard deviation of 2) and a range of -1.97% to 6.60%. This indicates an overall positive economic outlook, albeit with intermittent contractions that reflect economic shocks, policy fluctuations, and global market volatility. Unemployment levels average around 6%, with a relatively low variation (standard deviation of 0.057) and a stable range (min: 0.003, max: 0.067). These figures suggest that shared labor market challenges exist across Africa, with underemployment and informality prevalent throughout the region. Agriculture's contribution to GDP averages about 10%, with a slight standard deviation (0.652) and a range of 9 to 11, highlighting its persistent role as both a source of livelihood and vulnerability. The sector's dependence on climate-sensitive inputs makes it particularly vulnerable to external shocks, such as droughts or floods, which can amplify food insecurity and economic fragility.

5. ARDL Regression Results

5.1 Autoregressive Model - Estimation and Discussions

We first ran the estimation using a simple Autoregressive model on the variables (*Table 2, Appendix*) to understand the persistence of human development over time, with one lag selected based on the AIC, given the focus on prediction and the sample size to avoid underfitting. The model's output shows that past HDI strongly predicts current HDI ($\beta = 0.949$, $p < 0.001$), consistent with theoretical expectations of development path dependency (Gujarati & Porter, 2009)[39]. Expanding to an AR(1) model with climate variables—emissions, temperature change, and precipitation—slightly improved model fit but yielded no statistically significant effects. (Dell, Jones, & Olken, 2014)[40] research explains that other factors may limit or mediate the short-run influence on HDI. We therefore proceeded to include other economic variables for control (GDP, unemployment, and agriculture), and this approach showed the best performance across fit metrics (AIC = -230.2, RMSE = 0.0011), with unemployment emerging as a significant negative predictor of HDI ($p < 0.001$). Yearly unemployment, as highlighted by Todaro & Smith (2020), [41] is a major socioeconomic channel through which development is affected. However, though AR dynamics provide the foundation through structural controls and the autocorrelation diagnostics confirmed model adequacy *(see images here)* with no evidence of serial correlation in residuals (Durbin & Watson, 1950; Breusch, 1978)[42], the exceptionally high R-Squared and Adjusted R-squared with insignificant predictors risks overfitting and multicollinearity - most especially with HDI - though the mean VIF is acceptable. (*see VIF table here*). This necessitated further estimation through an ARDL model (*see justification below*).

5.2 Autoregressive Distributed Lag Model and Error Correction Model - Selection and Estimation

The Autoregressive Distributed Lag (ARDL) model separates short-run and long-run effects, allowing for a mix of I(0) and I(1) variables, which is important when variables might be related over time (such as HDI and economic or climate factors). ARDL and Error Correction Model (ECM) are widely used in economic analysis, offering flexibility through

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[39] Gujarati, D.N. and Porter, D.C. (2009) Basic Econometrics. 5th Edition, McGraw Hill Inc., New York.

[40] Dell, M., Jones, B. F., & Olken, B. A. (2014). What Do We Learn from the Weather? The New Climate–Economy Literature. *Journal of Economic Literature*, 52(3), 740–798.

[41] Todaro, M. P., & Smith, S. C. (2020). *Economic Development* (13th ed.). Pearson.

[42] Durbin, J., & Watson, G. S. (1950). Testing for Serial Correlation in Least Squares Regression. *Biometrika*, 37(3/4), 409–428.

autoregressive and distributed lag terms [43]. This is important because the model uses its past values to predict future outcomes, a normative assumption that explains how human potential evolves. At the same time, distributed lag incorporates past values of one or more independent variables to examine their effect on a dependent variable over time. It helps address dynamics in the short run, establish lags for delayed effects, and explain long-run relationships. The ARDL framework, introduced by Pesaran and Shin (1999),[44] is appropriate for small-sample time series data and accommodates variables integrated at different orders (I(0) and I(1)). The dataset, comprising 20 observations from 2002 to 2022, is well-suited for the ARDL model, which allows for flexibility in lag lengths.

Additionally, it is important to incorporate lagged levels and differences of regressors. The model also estimates the speed of adjustment to long-run equilibrium through an error correction mechanism, making it especially useful for analyzing the gradual effects of policy and climate changes on human development. Methodological evidence provided by Pesaran, Shin, and Smith (2001)[45] shows that this handles mixed-integration orders. While some variables (e.g., HDI, preci) were stationary at levels, others displayed random walks (i.e., temperature change) and became stationary after differencing, making ARDL and ECM appropriate. The model is also beneficial for examining cointegration and long-run relationships between variables, with the bounds test being a popular method for this purpose. [46] Finally, the error correction representation of the ARDL model separates long-run and short-run effects, which is useful when it is suspected that variables might be related over time (as with HDI and economic or climate factors).[47] For our estimation, the general form of the ARDL(p, q) model was specified as:

$$Y_t = \alpha_0 + \sum_{i=1}^{p} \beta_i Y_{t-i} + \sum_{j=0}^{q} \delta_j X_{t-j} + \varepsilon_t$$

Where Y_t denotes the dependent variable (HDI) at time t, X_{t-j} represents explanatory variables such as emissions, temperature change, or precipitation, α_0 is the constant term, β_i, δ_j are short-run dynamic coefficients, and ε_t is the error term. Consistent with theoretical literature and feasibility, after confirming cointegration using the Engle-Granger

[43] Kripfganz, S., & Schneider, D.C. (2018). ardl: Estimating autoregressive distributed lag and equilibrium correction models. The Stata Journal, 23, 983 - 1019.

[44] Pesaran, M. H., & Shin, Y. (1999). An autoregressive distributed lag modelling approach to cointegration analysis. In S. Strøm (Ed.), Econometrics and economic theory in the 20th century: The Ragnar Frisch centennial symposium (pp. 371–413). Cambridge University Press.

[45] Pesaran, M. H., Shin, Y., & Smith, R. J. (2001). Bounds testing approaches to the analysis of level relationships. Journal of Applied Econometrics, 16(3), 289–326. https://doi.org/10.1002/jae.616

[46] Kripfganz, S., & Schneider, D.C. (2018). ardl: Estimating autoregressive distributed lag and equilibrium correction models. The Stata Journal, 23, 983 - 1019.

[47] Shittu, O.I., Yemitan, R.A., & Yaya, O.S. (2012). ON AUTOREGRESSIVE DISTRIBUTED LAG, COINTEGRATION AND ERROR CORRECTION MODEL: An Application to Some Nigeria Macroeconomic Variables. Australian Journal of Business and Management Research.

approach, the ARDL model was reparametrized into an Error Correction Model (ECM) form to separate short-run and long-run dynamics:

$$\Delta Y_t = \alpha + \sum_{i=1}^{p-1} \phi_i \Delta Y_{t-i} + \sum_{j=0}^{q-1} \theta_j \Delta X_{t-j} + \lambda ECT_{t-1} + \mu_t$$

In the ECM, ΔY_t is the first difference of HDI, and ΔX_{t-j} are the first differences of the regressors. This also considers lagging the error correction term (residual from the long-run relationship) as ECT_{t-1} and λ in the equation represents the speed of adjustment coefficient, with μ_t as the white noise error term. Within the ECM, the sign and significance of λ (speed of adjustment coefficient) indicate how quickly deviations from long-run equilibrium are corrected, which is necessary to understand how controls (such as unemployment and GDP growth rate) correct HDI over time. The negative statistical significance of λ from the regression output confirms the existence of a stable long-run relationship among the variables.

6. Discussions

6.1 Short-Run Dynamics: Climate and Economic Indicators

From the model's estimation, the climate index and its lagged outcomes are insignificant. Yet, a key insight is revealed by the PCA Loading (Figure 10), as well as the significant negative relationship between HDI and unemployment. Possible explanations could be that climatic impact accumulates over time, as the data series represents a small sample, with limited lags. Nonetheless, emissions loading from the Climate PCA and unemployment coefficients align with theoretical arguments. This may reflect the association between emissions and industrial or economic modernization activities that temporarily boost HDI. In Nordhaus's (Nordhaus, 2019) analysis of the circular flow of global warming, climate change, and policy, he argues that economic growth leads to increased CO2 emissions. Rising CO2 concentrations and other forces impose ecological and economic impacts, which may occur notably in the long run.[48] It is also important to note that the GDP growth rate is not significant in any of the estimated models, suggesting that short-term fluctuations in output do not immediately translate into human development gains, possibly due to structural labor market inefficiencies across Africa and a weak link between employment levels and HDI components in the short run. However, the lag of the GDP growth rate in the ARDL Full Model is marginally significant, suggesting possible delayed effects over several years.

[48] Nordhaus, W. D. (2019). Climate change: The ultimate challenge for economics. American Economic Review, 109(6), 1991-2014. Retrieved from https://williamnordhaus.com/files/williamdnordhaus/files/p157-2019-nordhaus--nobellecture-aer.pdf

5.2 Long-Run Adjustment Mechanism: Error Correction Term (L.resid)

The error correction adjustment coefficient (λ = -0.0469) obtained from the model indicates a statistically significant and negative response to deviations from long-run equilibrium. This implies that approximately 4.7% of the disequilibrium is corrected each period, supporting a stable, gradual convergence mechanism. When compared with a simulated adjustment path (λ = -0.05), the empirical path demonstrates a slightly faster speed of adjustment. Though both curves exhibit a consistent path toward equilibrium, the estimated model suggests that external or policy-induced shocks are partially absorbed in the short run, with long-run stability restored progressively over time. This dynamic reinforces the system's inherent resilience and highlights the role of structural forces such as economic or climate variables in shaping the adjustment process (Figure 12).

5.3 HDI and System Equilibrium

All outputs across the HDI (L.hdi) show a high and statistically significant coefficient, with values ranging from 1.00 to 0.953 ($p < 0.001$), confirming the HDI's high persistence and path dependence: past levels of human development have a strong predictive power for current levels. This long-run persistence suggests that human capital investments compound over time and can be improved through investments in services and infrastructures that build resilience. In contrast, weak health care and education systems increase vulnerability across the population, especially among women and children, due to inadequate infrastructure and social protection systems. Moreover, the lag of residuals from the cointegration regression (L.resid) is negative as expected (−0.0469) and significant. This indicates instability or noise in short-run dynamics, and slow convergence to equilibrium, implying that deviations from long-run HDI determinants may not self-correct within the sample period (22 years). We simulated thirty years ahead (on the given adjustment term). It aligns with the arguments that while some African regions are gradually developing adaptive infrastructure, population growth increases the demand for education and healthcare[49], the returns may not be immediate given current HDI levels (low-income), but serve as a significant investment in the future (See Figure 14).

7. Policy Implications & Recommendations

Investments in climate adaptation, such as resilient schools and healthcare facilities, can capitalize on the observed adaptive potential of temperature changes. The cyclical relationship between poor health, reduced Human Development Index (HDI), and limited economic growth necessitates comprehensive strategies to strengthen health systems, mitigate diseases, and mitigate health-related poverty shocks. Building climate-resilient educational infrastructure is critical.

[49] Aladejare, S.A. (2022). Population Health, Infrastructure Development and FDI Inflows to Africa: A Regional Comparative Analysis. Asian Journal of Economic Modelling.

Programs targeting rural and vulnerable communities must ensure continuity in learning despite adverse weather events. Climate-smart agriculture initiatives should incorporate environmental and social safeguards at the agricultural and food system levels to ensure sustainability.[50] Expanding access to new technologies can stabilize these short-term gains and transform them into sustained improvements in livelihoods. This includes investments in agricultural practices that help farmers adapt to specific climatic factors [51], from storage mechanisms to research and development to understand different trends and patterns that support crop rotation while enhancing transportation and road infrastructures for market access and supply chain mobility, while incorporating environmental and social safeguards at agricultural and food system levels to for sustainability [52].

Adaptation involves adjustments in natural or human systems in response to actual or expected climatic stimuli, aiming to mitigate harm or capitalize on opportunities. [53] Strengthening institutional frameworks and investing in long-term resilience measures is crucial for accelerating recovery and stabilizing the HDI. Keeney & McDaniels (2001) propose an adaptive framework for climate policy analysis, emphasizing the importance of learning over time and considering both near-term and long-term objectives, as well as how to achieve equilibria. Considering the adjustment term in this model and the structural barriers it reflects, African countries can also leverage the Adaptation Policy Framework (APF) introduced by UNDP as it provides a structured approach for developing countries to create climate change adaptation policies.[54] This framework consists of five basic steps and two cross-cutting elements, focusing on project design, vulnerability assessment, risk evaluation, strategy development, and implementation. The persistence of shocks over time and their unpredictability requires governments to reach a balance with the interplay between technological innovation, economic policies, and systemic adjustments needed to address climate change impacts effectively. This includes climate financing for education, investment in health systems and infrastructures to enhance access to healthcare, climate-smart agriculture practices consistent with the need for food security, and household welfare to enhance resilience. These interventions can alleviate climate burdens on human capital in the short run, create systemic returns to equilibrium, and enhance corrections yearly in the long run. Critical infrastructures alone are not enough to enhance the speed of adjustment; they must be accompanied by human potential to ensure alternative responses to labor market opportunities during shocks while enhancing coping mechanisms.

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[50] Torquebiau, E.F., Rosenzweig, C., Chatrchyan, A.M., Andrieu, N., & Khosla, R. (2018). Identifying Climate-Smart Agriculture Research Needs. Cahiers Agricultures, 27, 26001.
[51] Kumari, S., Singh, T.P., & Prasad, S. (2019). Climate Smart Agriculture and Climate Change. International Journal of Current Microbiology and Applied Sciences.
[52] Torquebiau, E.F., Rosenzweig, C., Chatrchyan, A.M., Andrieu, N., & Khosla, R. (2018). Identifying Climate-Smart Agriculture Research Needs. Cahiers Agricultures, 27, 26001.
[53] Burroughs, W.J. (2001). Climate Change: Glossary.
[54] Shm, I., Lee, E., Kwon, W., & Lim, J.A. (2005). UNDP's Adaptation Policy Framework for Climate Change. Atmosphere, 15, 59-68.

8. Limitations

Understanding the impact of climate change on HDI across the study period is difficult, given that climate impacts can be explained through shocks over time, and the impacts may be lagged. This could possibly lead to a loss of country-level heterogeneity, and time-specific effects may be different, requiring a more pluralistic approach to understanding these dynamics across quantiles. African countries differ significantly across indicators, and aggregated data (e.g., continent-wide GDP, HDI, or emissions) shield these differences, creating difficulty in capturing country-specific lags, shocks, or feedback effects especially in time series models like ARDL or ECM which are sensitive to dynamics, possibly misrepresent the true relationship between variables and yield biased even when diagnostic tests are accurate via robustness checks (Figure 13, and Table 4). Another issue warranting consideration is spurious causality. Aggregated data often introduces artificial correlations, for example, rising GDP in Nigeria and falling GDP in Sudan could average out to "stable GDP." At the same time, both countries could be headed in different economic directions; thus, the model may have detected significance where none exists or missed significance that is country-specific. The third factor to consider is the violation of the stationarity assumption. Many countries may have different orders of integration for the same variable (e.g., I(1) in Kenya, I(0) in Ghana). When aggregated, the model may have given a strange mixed process that doesn't meet ARDL/ECM assumptions (e.g., no clear I(0)/I(1) structure). In ARDL, it is important to confirm that none of the series is I(2) — but the possibility of verifying this is difficult. Given inconsistent aggregates, this leads to undetected measurement and aggregation errors, and introduces noise, especially if some countries are missing or have poor data quality. Next, it becomes difficult to clearly understand structural breaks and inconsistencies. For example, countries experience events like conflicts, pandemics, policy reforms, and regime changes across different periods. When aggregated, these structural breaks are smoothed over or lost, and the time series model may fail to meet the assumption of structural stability. And finally, this could lead to policy irrelevance. Even if the model output is statistically sound, its policy relevance may be weak, as an Africa-wide estimate may not apply to the context of specific countries; likewise, a significant ECM coefficient for Africa may not hold for other regions.

It is therefore essential to continue research in this area using a panel data approach, while maintaining country-level heterogeneity and estimating long-run relationships. This is necessary because countries may be similar in the long-term equilibrium but differ in their short-term dynamics. Estimating country-specific models (ARDL/ECM/AR) for each country separately and then comparing, clustering, or meta-analyzing the results may provide more insight, including the use of region-specific models. It is crucial to understand that countries differ across regions, such as the five African countries North of the Sahara, the politically unstable Sahel Countries, and the relatively promising Eastern and Southern nations. Estimating another model based on these premises may offer a better understanding of the climate's impact on HDI across Africa.

9. Bibliography

Adedeji, O., Reuben, O., & Olatoye, O. (2014). Global climate change. *Journal of Geoscience and Environment Protection, 02(02), 114–122.* https://doi.org/10.4236/gep.2014.22016

Africa suffers disproportionately from climate change - World. (2023, September 4). ReliefWeb. https://reliefweb.int/report/world/africa-suffers-disproportionately-climate-change

Aladejare, S.A. (2022). Population Health, Infrastructure Development and FDI Inflows to Africa: A Regional Comparative Analysis. Asian Journal of Economic Modelling.

Borderon, M., Sakdapolrak, P., Muttarak, R., Kebede, E.B., Pagogna, R., & Sporer, E. (2018). A systematic review of empirical evidence on migration influenced by environmental change in Africa.

Burroughs, W.J. (2001). Climate Change: Glossary.

Business Day. (2024, November 19). Top African countries driving global exports in key agricultural products. Business Day. Retrieved November 19, 2024, from https://businessday.ng/news/article/top-african-countries-driving-global-exports-in-key-agricultural-products/

Cattaneo, C., & Massetti, E. (2015). Migration and Climate Change in Rural Africa. Environmental Anthropology eJournal.

Collier, P., Conway, G.R., & Venables, T. (2008). Climate Change and Africa. Oxford Review of Economic Policy, 24, 337-353.

Climate change widespread, rapid, and intensifying – IPCC — IPCC. (2021, August 9). IPCC. https://www.ipcc.ch/2021/08/09/ar6-wg1-20210809-pr/

Climate change widespread, rapid, and intensifying – IPCC — IPCC. (2021, August 9). IPCC. https://www.ipcc.ch/2021/08/09/ar6-wg1-20210809-pr/

Ewolo Bitoto, F., Nchinda Mbognou, C., & Amougou Manga, R.J. (2024). Climate change and income inequality in Africa (SSA): effects and transmission channels. International Journal of Development Issues.

Ezeruigbo, C.F., & Ezeoha, A. (2023). Climate change and the burden of healthcare financing in African households. African Journal of Primary Health Care & Family Medicine, 15.

González, F. A. I., Santos, M. E., & London, S. (2021). Persistent effects of natural disasters on human development: quasi-experimental evidence for Argentina. Environment, Development and Sustainability, 23(7), 10432-10454.

Global Center on Adaptation (GCA). (2022). State and Trends in Adaptation 2022: Education. Retrieved from https://gca.org/wp-content/uploads/2023/01/GCA_State-and-Trends-in-Adaptation-2022_Education.pdf

Global Initiative for Sustainable Development and Ecosystems Protection (GIFSEP). (n.d.). Climate change and Africa's agricultural soils. Retrieved November 19, 2024, from https://gifsep4climate.org/climate-change-and-africas-agricultural-soils/

Global Partnership for Education. (n.d.). Zimbabwe: A stronger education system after Cyclone Idai. Retrieved November 19, 2024, from https://www.globalpartnership.org/results/country-journeys/zimbabwe-stronger-education-system-after-cyclone-idai

Kripfganz, S., & Schneider, D.C. (2018). ardl: Estimating autoregressive distributed lag and equilibrium correction models. The Stata Journal, 23, 983 - 1019.

Kumari, S., Singh, T.P., & Prasad, S. (2019). Climate Smart Agriculture and Climate Change. International Journal of Current Microbiology and Applied Sciences.

Marchiori, L., Maystadt, J., & Schumacher, I. (2011). The Impact of Climate Variations on Migration in Africa!

McKinsey & Company. (n.d.). How will African farmers adjust to changing patterns of precipitation? McKinsey & Company. Retrieved November 19, 2024, from https://www.mckinsey.com/~/media/mckinsey/business%20functions/sustainability/our%20insights/how%20will%20african%20farmers%20adjust%20to%20changing%20patterns%20of%20precipitation/svgz_mgi-climatecasestudyafrica-web_exh2.svgz?cq=50&cpy=Center

Méjean, A., Collins-Sowah, P.A., Guivarch, C., Piontek, F., Soergel, B., & Taconet, N. (2024). Climate change impacts increase economic inequality: evidence from a systematic literature review. Environmental Research Letters, 19.

National Institute of Environmental Health Sciences. (n.d.). Health impacts on vulnerable people. Retrieved December 18, 2023, from https://www.niehs.nih.gov/research/programs/climatechange/health_impacts/vulnerable_people#:~:text=In%20general%2C%20children%20and%20pregnant,events1%20%2C%202%20%2C%203%20.

National Institute of Environmental Health Sciences. (n.d.). Climate change and health impacts. Retrieved November 19, 2024, from https://www.niehs.nih.gov/research/programs/climatechange/health_impacts

Nordhaus, W. D. (2019). Climate change: The ultimate challenge for economics. American Economic Review, 109(6), 1991-2014. Retrieved from https://williamnordhaus.com/files/williamdnordhaus/files/p157-2019-nordhaus--nobellecture-aer.pdf

Natsiopoulos, K., & Tzeremes, N.G. (2022). ARDL: An R package for the analysis of level relationships. J. Open Source Softw., 7, 3496.

Opoku, S.K., Leal Filho, W., Hubert, F., & Adejumo, O.O. (2021). Climate Change and Health Preparedness in Africa: Analysing Trends in Six African Countries. International Journal of Environmental Research and Public Health, 18.

Shittu, O.I., Yemitan, R.A., & Yaya, O.S. (2012). ON AUTOREGRESSIVE DISTRIBUTED LAG, COINTEGRATION AND ERROR CORRECTION MODEL: An Application to Some Nigeria Macroeconomic Variables. Australian Journal of Business and Management Research.

Sukie, C., & Kai, L. (2023). Mapping the cumulative effects of climate change on children's education in ten African countries. UNESCO Global Education Monitoring Report. Retrieved November 19, 2024, from https://www.unesco.org/gem-report/sites/default/files/medias/fichiers/2023/09/SukieandKai.pdf

Sukie, C., & Kai, L. (2023). Mapping the cumulative effects of climate change on children's education in ten African countries. UNESCO Global Education Monitoring Report. Retrieved November 19, 2024, from https://www.unesco.org/gem-report/sites/default/files/medias/fichiers/2023/09/SukieandKai.pdf

Shm, I., Lee, E., Kwon, W., & Lim, J.A. (2005). UNDP's Adaptation Policy Framework for Climate Change. Atmosphere, 15, 59-68.

Torquebiau, E.F., Rosenzweig, C., Chatrchyan, A.M., Andrieu, N., & Khosla, R. (2018). Identifying Climate-Smart Agriculture Research Needs. Cahiers Agricultures, 27, 26001.

United Nations Development Programme. (n.d.). Human Development Index (HDI). Retrieved December 1, 2024, from https://hdr.undp.org/data-center/human-development-index#/indicies/HDI

United Nations Statistics Division. (n.d.). — SDG indicators. https://unstats.un.org/sdgs/report/2022/Goal-06/?_gl=1*vrm2bg*_ga*MTgxMjIyNjc3MC4xNzA0OTA4ODU4*_ga_TK9BQL5X7Z*MTcwNjEwMjkxNy4xLjEuMTcwNjEwNDc5MS4wLjAuMA

Venegas Marin, S., Schwarz, L., & Sabarwal, S. (2024). The impact of climate change on education and what to do about it. World Bank. Retrieved November 19, 2024, from https://documents1.worldbank.org/curated/en/099043024150036726/pdf/P180005171cc7c0c91a8b011d03080e9086.pdf

World Bank. (2018). Liberia: From growth to development: Priorities for sustainably reducing poverty and achieving middle-income status by 2030. World Bank. https://documents1.worldbank.org/curated/en/585371528125859387/pdf/Liberia-From-growth-to-development-priorities-for-sustainably-reducing-poverty-and-achieving-middle-income-status-by-2030.pdf

World Bank. (2018). Liberia: From growth to development: Priorities for sustainably reducing poverty and achieving

middle-income status by 2030. World Bank. https://documents1.worldbank.org/curated/en/585371528125859387/pdf/Liberia-From-growth-to-development-priorities-for-sustainably-reducing-poverty-and-achieving-middle-income-status-by-2030.pdf
World Bank. (2023, June 27). Investing in youth: Transforming AFE Africa. The World Bank. Retrieved November 7, 2024, from https://www.worldbank.org/en/news/feature/2023/06/27/investing-in-youth-transforming-afe-africa
World Bank. (n.d.). Climate change overview. The World Bank. Retrieved November 7, 2024, from https://www.worldbank.org/en/topic/climatechange/overview
World Bank. (n.d.). Poverty. The World Bank. Retrieved November 19, 2024, from https://data.worldbank.org/topic/poverty?end=2022&locations=ZG-1W&start=2000
World Health Organization. (n.d.). Climate change and health. World Health Organization. Retrieved November 19, 2024, from https://www.who.int/news-room/fact-sheets/detail/climate-change-and-health
Zickgraf, C. (2018). Climate Change and Migration Crisis in Africa. The Oxford Handbook of Migration Crises.

10. Appendix

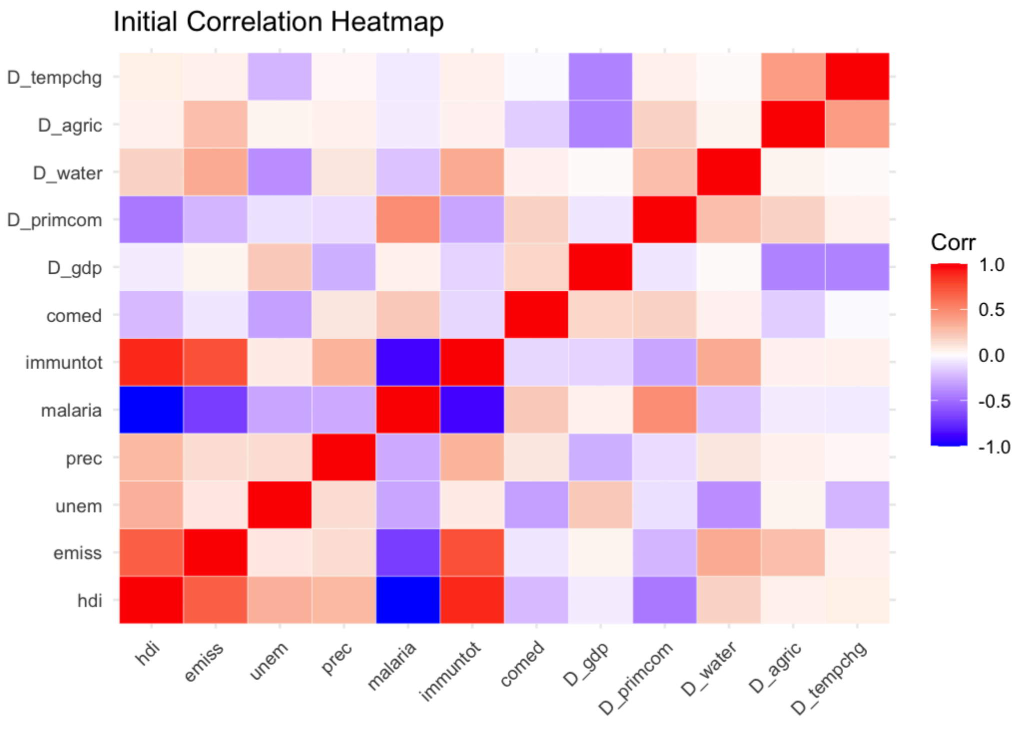

Fig.4. Correlation matrix from initial modeling

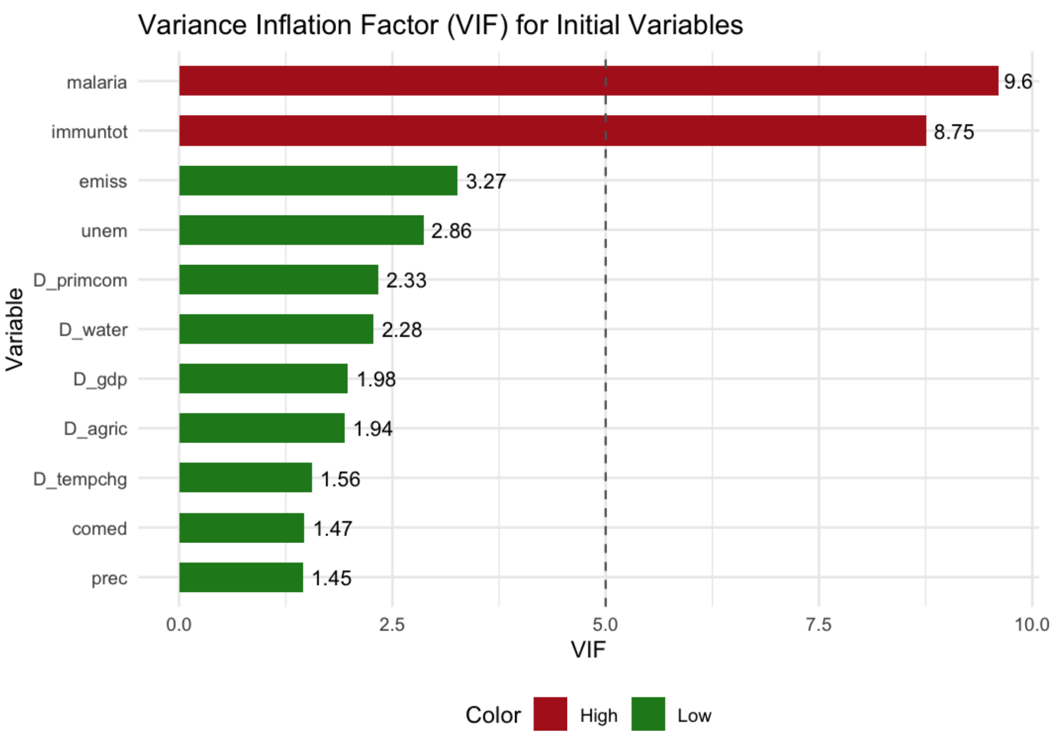

Fig.5. Variance Inflation Factor (VIF) for Initial Variables

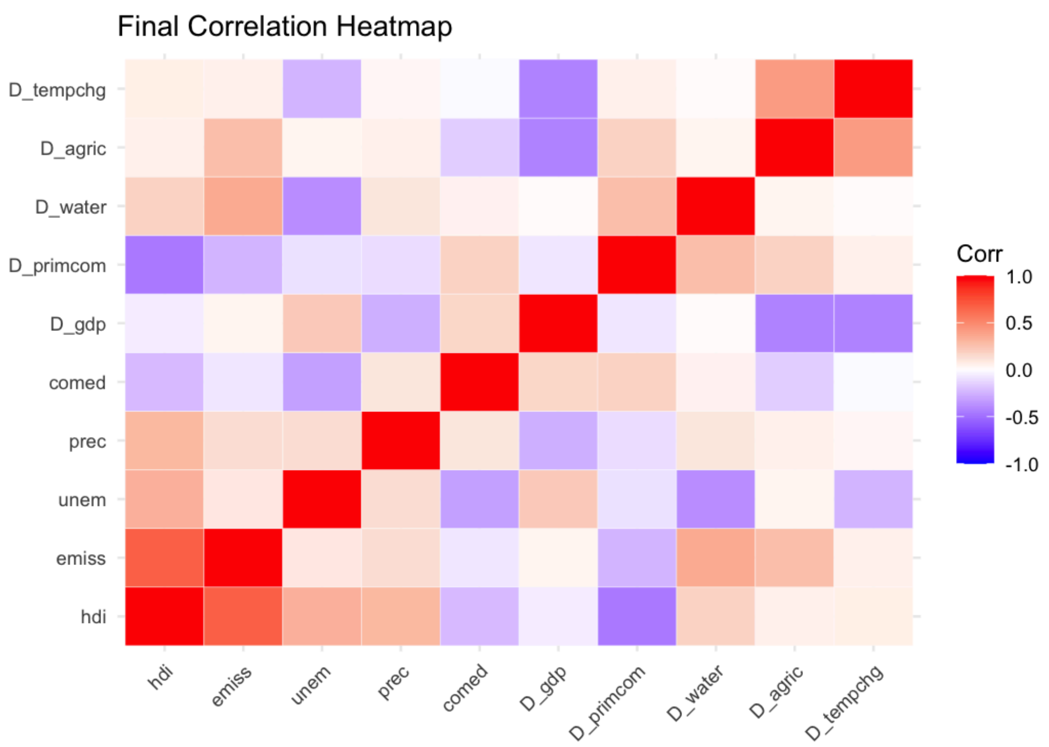

Fig.6 Final Correlation Matrix

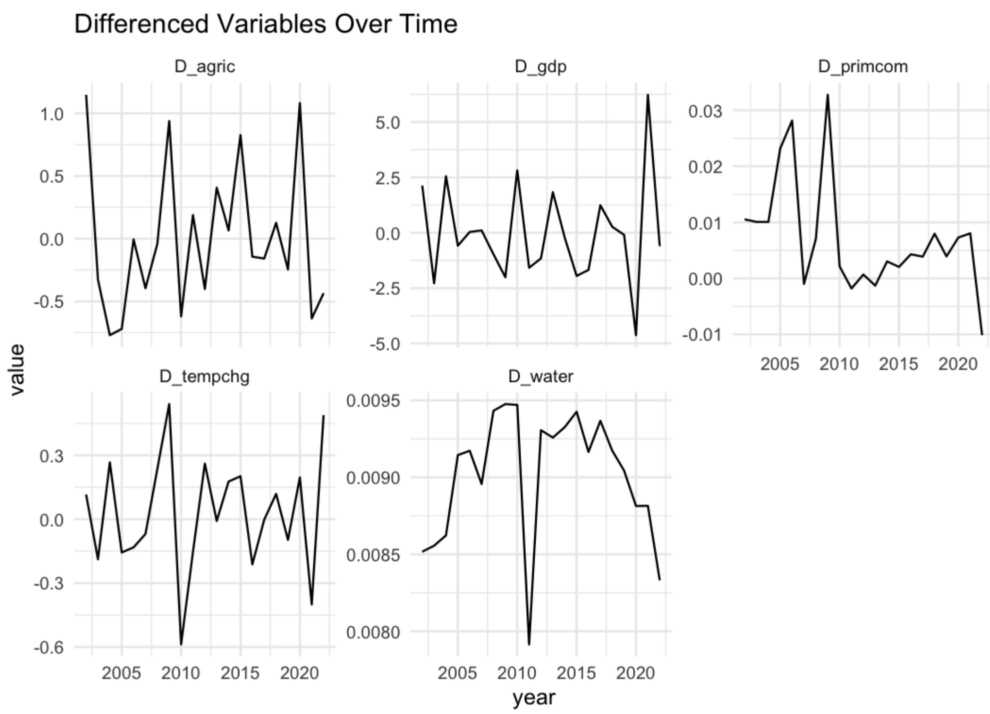

Fig.7. Line plots of differenced variables confirm stationarity post-transformation.

Descriptive Statistics Table

Variable	Mean	Std. Dev.	Min	Max
hdi	0.508	0.035	0.442	0.549
gdp	4.059	2.050	-1.967	6.602
unem	0.060	0.003	0.057	0.067
agric	10.126	0.652	9.188	11.449
emiss	35.362	0.960	32.592	36.345
tempchg	1.087	0.235	0.724	1.501
prec	1004.874	39.764	926.875	1095.889

Table 1. Descriptive Statistics Summary

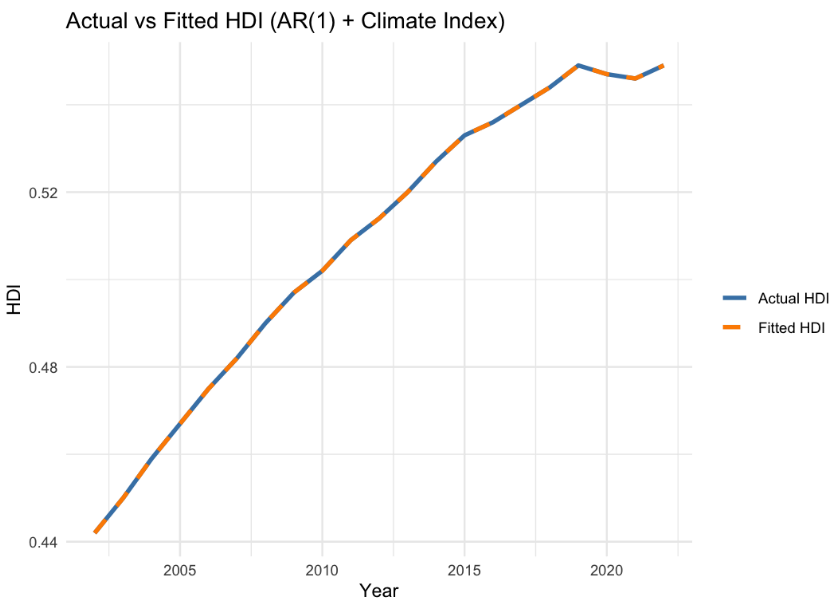

Fig.8. Line plots of differenced variables confirm stationarity post-transformation.

Variables	AR(1)	AR Climate	AR Full	ARDL	ECM Full
L.hdi 1	1.0*** (4.96e-17)	1.0*** (6.27e-17)	1.00*** (8.01e-17)	0.953 *** (0.0121)	-0.0469 ** (0.0121)
d.Lhdi 1					-0.912 (0.421)
climate_index				0.0000963 (0.000378)	0.0000963 (0.000378)
L.climate_index 1		-2.41e-18 (2.05e-18)	-2.15e-18 (2.39e-18)		
d.L_climate_index 1					-0.000127 (0.000342)
D_gdp				0.000351 (0.000184)	
D.d_gdp					0.000351 (0.000184)
L.(D_gdp 1)			-1.66e-18 (9.16e-19)	0.000339 (0.000176)	0.000690 (0.000327)

D(L.d_gdp 1)					-0.000454
					(0.000185)
L(D_primcom 1)			-7.16e-17		
			(2.33e-16)		
L(D_water 1)			3.41e-15		
			(5.72e-15)		
unem				-0.580 *	
				(0.206)	
d_unem				-0.367	-0.580 **
				(0.225)	(0.206)
L.unem 1			6.51e-16	-0.214	-0.794 ***
			(9.23e-16)	(0.187)	(0.162)
D(L.unem 1)					-0.117
					(0.259)
agric				0.000919	0.000919
				(0.000730)	(0.000730)
d_agric				-0.0110	-0.107
				(0.0186)	(0.0530)
L.agric 1			-3.42e-18	-0.0118	-0.121
			(3.46e-18)	(0.0153)	(0.0725)
d(L.agric 1)					0.00186
					(0.0147)
L(comed)			-7.46e-18		
			(5.87e-18)		
_cons	1.13e-16 ***	4.96e-17***	2.10e-16	0.0674 ***	0.0674 ***
	(2.53e-17)	(3.19e-17)	(1.13e-16)	(0.00659)	(0.00659)
R-Squared	1.0000	1.000	1.0000	0.9994	0.9165
Adjusted R-Squared	1.0000	1.0000	1.0000	0.9990	0.8678
AIC	-1591.06	-1590.62	-1588.41	-209.30	-209.30
BIC	-1587.93	-1586.44	-1577.96	-200.34	-200.34
LL	798.53	799.31	804.20	113.65	113.65
RMSE	0.00000	0.00000	0.00000	0.00082	0.00082
F-Stat (*P-Value*)	< 2.2e-16 ***	< 2.2e-16 ***	< 2.2e-16 ***	1.473-08 ***	0.002281**

Observations	**23**

*Standard errors in parentheses, * p<0.05, ** p<0.01, *** p<0.001*

Table 2. Model Comparison
Source: Own elaboration: R-Studio

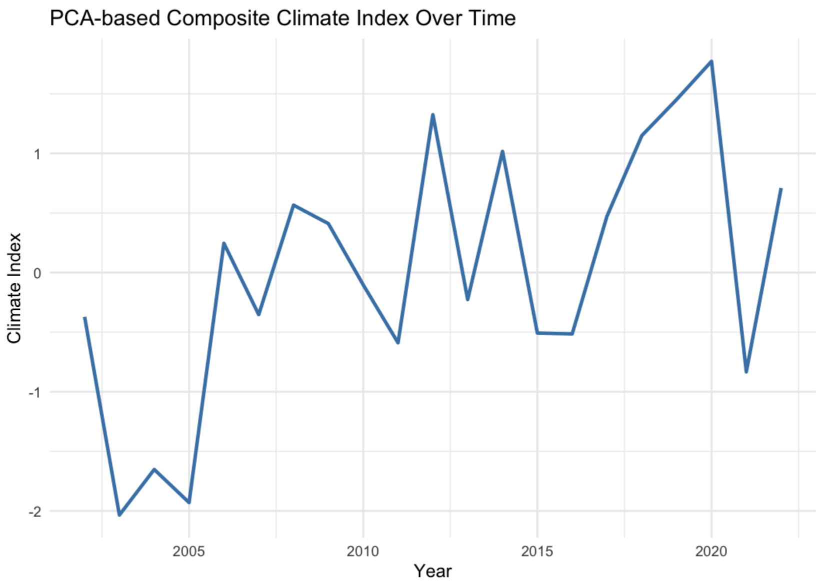

Fig.9. PCA-based Composite Climate Index Over Time

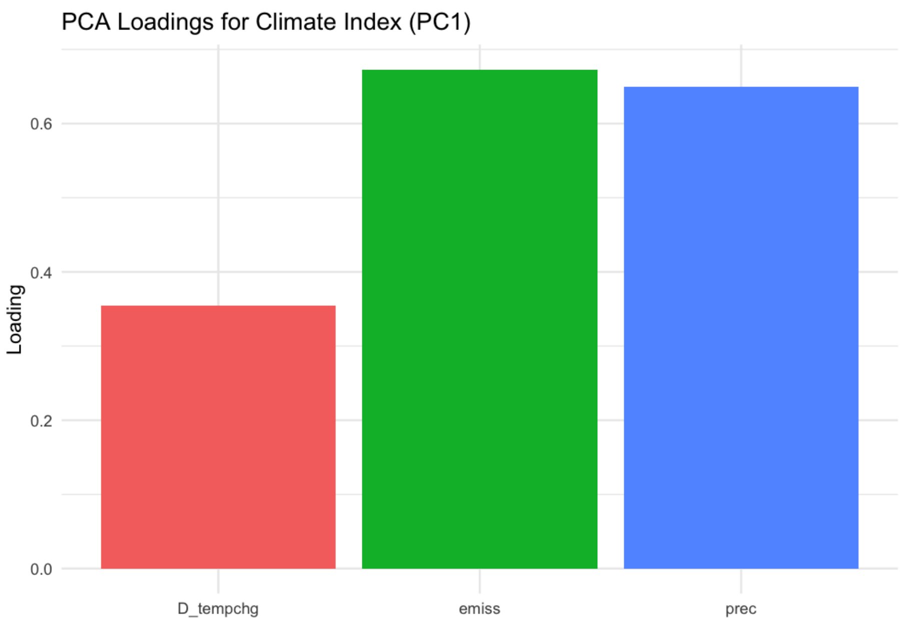

Fig.10. PCA Loading for Climate Index (PC1)

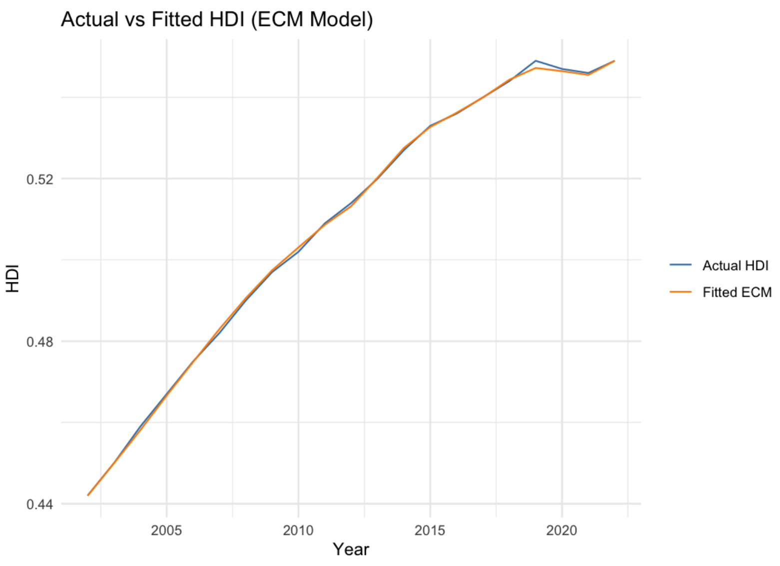

Fig.11. Actual vs Fitted HDI (ECM Model)

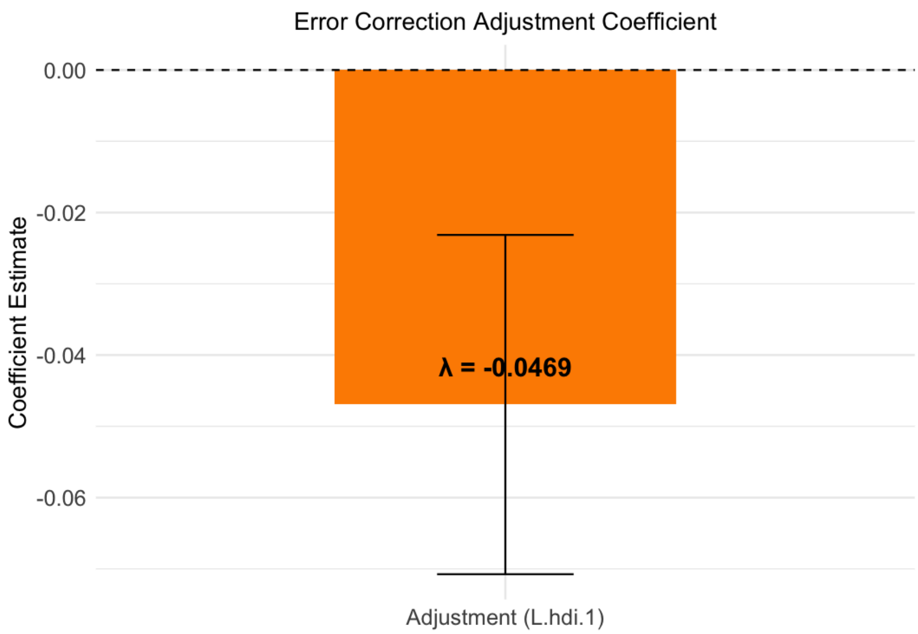

Fig.12. Error Correction Adjustment Coefficient

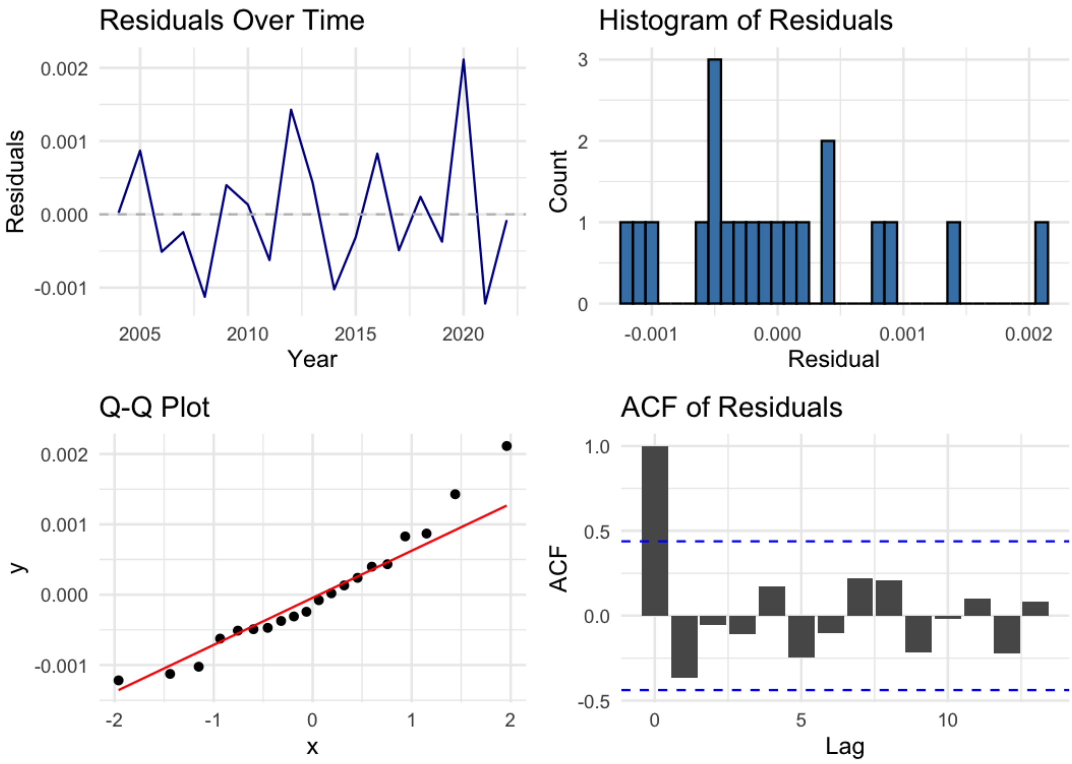

Fig.13. Diagnostic Plots

Diagnostic Test Results

	Test	Test.Statistic	p.value	Conclusion
W	Shapiro-Wilk (Normality)	0.948	0.3329	Normal
LM test	Breusch-Godfrey (Autocorrelation)	5.277	0.0715	No autocorrelation
BP	Breusch-Pagan (Heteroskedasticity)	3.041	0.8811	No heteroskedasticity

Table 3. Diagnostic Test Results

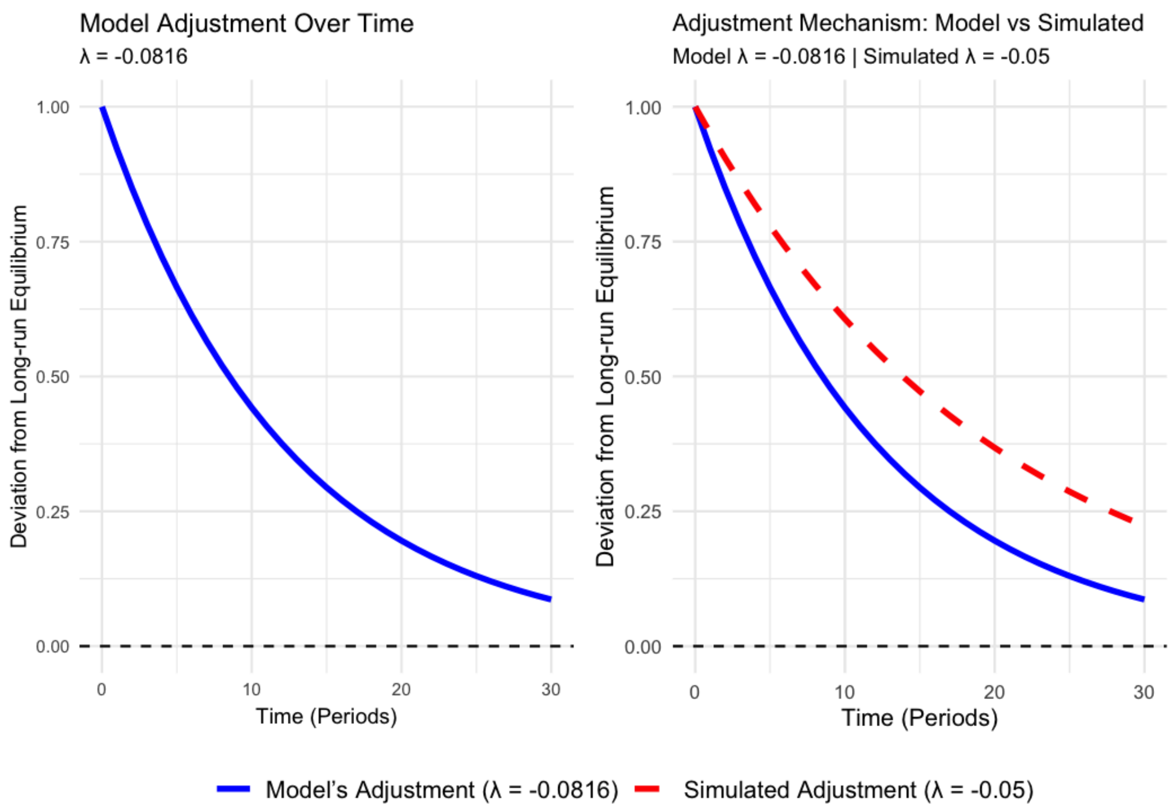

Fig.14. Model Adjustment and Adjustment Mechanism