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Abstract

Climate change, one of the world's existential problems, has sparked widespread concern at national and multinational levels. In this study, we deviate from the existing scores of academic literature by investigating heterogenous and time-varying effects of climate change on quality of life at the continent and regional levels in Africa. Towards this end, we utilise carbon emissions and ecological footprint as our climate change variables and human development index to proxy quality of life for 31 African countries over the period 2000 to 2018. Several econometric techniques are then employed to account for cross-sectional dependence, panel unit root, long-term cointegration with structural break, and heterogeneous panel causality, whilst we also present results based on Bayesian panel VAR impulse response functions. The results indicate cross-sectional dependence due to spill-over effects from common factors in Africa, while the panel cointegration test affirms that climate change variables have long-term consequences for quality of life only in sub-Saharan African region. Moreover, our results reveal a uni-directional causality between climate change variables and quality of life at both the continent and sub-Saharan African region levels. However, the test shows a bi-directional causality between these variables in North Africa. This differential impacts of climate change variables on quality of life between Northern and sub-Saharan Africa suggests that policy initiatives toward mitigating the effects of climate crises should consider regional dynamics of the continent.

JEL codes: Q5, I3, R11

Keywords: Climate Change, Carbon emissions, Ecological footprints, Quality of Life, SDGs 3 and 13, Africa

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1 Introduction

To promote world development, the United Nations (2015) established a comprehensive set of seventeen sustainable development goals (SDGs), also known as Global Goals. SDG 3 aims to "ensure healthy lives and promote well-being for all at all ages". This goal focuses on raising living and health standards, lowering maternal mortality, closing socioeconomic gaps, and increasing access to information and knowledge (Hickel, 2020). While considerable progress has been made in several of these criteria, significant achievement of SDG 3 remains elusive due to a variety of issues, the most prominent being climate change. Given the global significance of the climate catastrophe, one of the SDGs, Goal 13, also focuses on urgent global steps to "limit and adapt to the impacts of climate change."

In this study, we consider the interplay between SDG 3 and SDG 13 indicators and investigate the following questions: Does climate change impact the quality of life in Africa? If so, to what degree? Can regional dynamics, heterogeneous factors, and time-varying factors explain the association between climate change and quality of life in Africa? To answer these pertinent questions, we employ data for Africa and its regions from 2000 to 2018 as a point of reference. Importantly, we put the analysis of causation and its direction between climate change, proxied by ecological footprint and carbon emissions, and quality of life, measured by Human Development Index (HDI), at the forefront of our discussions. This is a crucial examination, as the effects of climate change may vary based on regional and national characteristics. In our analysis, we account for cross-sectional dependence, panel unit root, long-term cointegration with structural break, and heterogeneous panel causality, among other econometric techniques.

Failure to mitigate climate change, failure of early warning systems, natural disasters such as hurricanes, extreme temperatures, ecological imbalance, and habitat destruction are all identified as threats to human well-being in the global risks report (WEF, 2023).

Climate change, one of the world's most pressing crises, has far-reaching consequences, including water and food shortages, increased temperatures, storms and floods, loss of livelihood, and even health problems. The direct and indirect effects on human lives also present themselves in a variety of ways, including a decrease in overall quality of life (WEF, 2023) and limited access to critical amenities such as green spaces, clean water and air. Those who are struck the hardest are frequently vulnerable persons who are already at a disadvantage, whether due to their location, socioeconomic status, or demographic traits.

According to WHO (2021), an estimated 250,000 people each year may lose their lives to climate-related causes such as hunger, infectious diseases, and overheating. By 2030, it is anticipated that the annual direct health damage costs will range from 2 to 4 billion US dollars, especially in regions with inadequate medical facilities, such as the majority of African countries and other developing nations (Wreford and Topp, 2020). The United Nations has long acknowledged the significant impact that climate change is having and will continue to have on the African continent, especially on the most vulnerable, including adults and children, through increased food poverty, population displacement, farmers-herders land crisis, and stress on natural resources. In 2021, for instance, climate change decreased food security, resulting in 278 million Africans suffering from famine (FAO, 2022; IPCC, 2023). In addition, projections for 2024 indicate that climate change stressors could increase water levels and coastal erosion in large parts of West Africa, cause catastrophic cyclone events in Southern Africa, and cause drought, hunger, and famine in East Africa (WMO, 2022).

Indeed, the literature considering the effects of climate change on human well-being is large; however, this body of work has tended to focus more on developed economies like the United States (Wright et al., 2023), Europe (Hiscock et al., 2017), Canada (Kipp et al., 2019), Australia (Austin et al., 2020), and Asia (Rasul, 2021). In essence, increased research in prosperous regions may lead to ignorance of the requirements of those who are most at risk from climate change, specifically those in Africa, where six out of ten people become vulnerable due to a lack of early warning signals (IPCC, 2023). Consequently, our investigation focuses on a region that has experienced astounding negative effects of climate change and is predicted to experience even more severe negative effects in the future if responsible multilateral parties do not develop targeted policies and take positive action. Despite contributing less than 3 percent of global greenhouse gas emissions, the African region bears the brunt of climate stressors due to the acute susceptibility of its people and their limited coping mechanisms, as only 40 percent of the African population has access to proactive warning mechanisms against the effects of extreme weather and climate change (IPCC, 2023).

Moreover, extant literature has not always been explicit on how climate change affects quality of life (QoL), but this relationship does exist, with studies employing both subjective and objective measures for QoL (Diffenbaugh and Burke, 2019; Palagi et al., 2022). The trajectory of these studies has been that QoL measures are multidisciplinary, taking into account a variety of socioeconomic, cultural, and other factors. QoL is, for instance, a person's perception of their position in life in relation to their objectives, goals, health, aspirations, comfort of life, standard of living, and concerns within the context of their culture and value systems (W.H.O., 2012). A wide differentiation of the measures of QoL was proposed by Bowling (2004) to include macro and micro variable, as well as the Maslow (1954) hierarchy of needs; which is not too distant from the proposition of Eurostat (2015), which identified a collection of eight core indicators that together comprised of one's standard of living in terms of money and possessions, as well as one's ability to find and keep a job, one's health, one's education, one's social life, one's physical and financial security, and one's freedom.

From a novel perspective, this study offers an empirical contribution to this debate on whether there exists a significant relationship between climate change and indicators of quality of life at the continent and regional levels of Africa. Our empirical investigation reveals the following findings: (i) We find that there is a long-term link between these variables in Africa, especially in the SSA region; (ii) We further explore the causal association between these variables using a panel data approach, revealing the existence of a unidirectional causality between both climate change proxies and quality of life; (iii) We also apply the impulse response functions in a Bayesian panel vector auto-regression (PVAR) framework to inspect the size and time spell of the impact of a shock to one variable (e.g., carbons emissions) on another variable (e.g., quality of life), and vice versa, which results provide additional supports for the connections between our variables of interest; and (iv) Finally, a sensitivity check based on instrumental variable (IV) regression analysis confirms the impact of climate change variables on human development in Africa. In general, we find that ecological footprint and carbon emissions negatively affect quality of life in Africa. On this evidence, our conjecture is that increased mineral extraction, greenhouse gas emissions, and deforestation, amongst other factors, may be driving this result. Hence, reductions in environmental quality in the continent has an increasingly detrimental effects on the well-being and survival of the populace.

Considering the mounting impacts of climate change on the global ecosystem, our research complements the growing climate literature in a number of ways. To begin with, we provide empirical support for prior works (Acheampong et al., 2019; Aluko et al., 2021) by demonstrating that environmental degradation significantly minimises quality of life in Africa. Additionally, we present new findings on the heterogeneous and long-term causality between the measures of climate change and human development index in Africa and its regions. Finally, by examining the regional dynamics of climate crisis in Africa, our study offers a new perspective to understanding the unique regional solutions to easing the climate calamity.

In sum, we submit that policymakers should be keenly interested in the above-stated findings and offer few policy implications that grant considerable scope for stakeholders world over to foster new alliances for resolving one of the great challenges of our times. In particular, our results have shown that climate change has a deleterious effect on quality of life in Africa. Being aware of this, a key policy prescription is that legislation and legal sanctions should be put in place to effect reductions in the level of environmental degradation in Africa. We especially think this approach to be a more sustainable mechanism for attaining Sustainable Development Goals (SDGs) 3 and 13 (Good Health & Well-being and Climate Action) for African citizens. Besides, our investigation confirms that the climate change-quality of life nexus in Africa is heterogeneous and time-varying. As a result, policy efforts to mitigate the effects of climate change on quality of life has to consider regional dynamics of the continent. On this basis, we recommend that policymakers focus on tailor-made sustainable climate strategies, as in this instance, one-size-fits-all approach may fail African citizens.

The remainder of the paper is organised as follows. Section 2 provides a review of empirical literature. Section 3 presents the data sources and definitions of variables used for analysis, gives the descriptive statistics, and states the models employed for the empirical examination of the relationship between climate change proxies and human development index. Section 4 discusses the various econometric strategies used in generating our results. Section 5 documents and explains the findings from performing various tests. Section 6 concludes with policy recommendations and avenues for future research.

2 Climate change and quality of life

Climate change is one of the many factors affecting and rapidly disrupting the natural environment, ultimately impacting the quality of life in societies (Timlin et al., 2021). As such, all stakeholders are becoming more aware of the realised and imminent effects of climate change on quality of life. This is because of the high value placed on human lives and the potential severity of climate hazards, which pose threats to human existence (Lin et al., 2022). Several studies, such as Albouy et al. (2016) and Huang et al. (2022) focused on developed countries, and many of these studies used human development index as a proxy for quality of life. However, more research must be done on developing or less developed economies.

Several studies have used various parameters to measure the quality of life, and these studies can be divided into two groups. Firstly, those studies that focus on subjective well-being indicators such as happiness, and those that focus on objective well-being indicators, like life expectancy and gross domestic product (Ambrey and Daniels, 2017). The subjective method often relies on opinions that are gleaned through surveys or questionnaires, such as those that measure stress, happiness, and well-being (Wang and Zhou, 2023). Researchers have found that sustainability is generally associated with improvements in subjective well-being (Cloutier et al., 2014; Ambrey and Daniels, 2017). The studies of Noll (2013) and Jahedi and Méndez (2014), however, argue that there are drawbacks to the subjective measures of quality of life, including soft information compared to statistical data, lengthy data gathering process, and difficulties in interpreting the results.

On the other hand, the objective well-being method upholds the idea that a group of people's well-being can be assessed using the outputs of their institutions and the services such organisations provide to their constituents (Lawton et al., 1999). Therefore, it makes sense that quality of life may be evaluated objectively using statistics or institutional factors focused on economic, social, and other indicators. These variables are free from human judgments and are unaffected by opinions (Cummins et al., 2003; Sirgy et al., 2006).

A series of studies have demonstrated that both subjective and objective methods applied individually have their respective drawbacks, and as such, the United Nations Development Program (UNDP) released the Human Development Index (HDI), which is a composite social indicator index built upon necessary measures of developments related to human advancement, education, standards of living, and health (Urda et al., 2017). The integration of both approaches into a single set of quality of life indicators, however, results in an improved, composite, and multi-diverse measurement of the quality of life known as the human development index (Ghislandi et al., 2019).

In addition, human development index is regarded as a leading and most cited social indicator in policy and research, even though it is often criticised. For example, in assessing the quality of life for economically advanced nations, Šoltés and Nováková (2015) utilised the human development index to provide a position on quantifying the quality of life. In the same vein, the study of Pinar et al. (2022) employed the human development index as a base index for well-being with other governance metrics using stochastic dominance techniques. This study also adopts the human development index as its proxy for quality of life and is in line with studies, such as Zhang and Wu (2022), and Kavuran et al. (2023), which applied the UNDP-published human development index as a proxy for quality of life.

2.1 Carbon emissions and quality of life

The study of Bosello et al. (2012) claim that one of the dangers of climate change is the increase of the sea level, and this menace is considered the worst, as it tends to exacerbate the chances of dangerous thunderstorms and downpours to occur, whilst also increasing corrosion and jeopardising the availability of freshwater, with their negative impacts on the economy of any country. Other studies, such as Sheng et al. (2022), and Abeysekara et al. (2023), also reveal that climate change harms economic growth and development. In relation to studies carried out within African context, the study of Liu et al. (2018) confirms the vulnerability of African countries compared to their European counterparts using the fragile state index. Additionally, Rodolfo and Drilona (2022) contend that rising temperatures in weak African nations had a detrimental impact on income per capital growth. However, there have been few efforts to link the African continent's vulnerability to climate change to the quality of life and its connection with macroeconomic factors.

The human race has witnessed increased awareness and consciousness of climate change due to the increase in carbon emissions, rising global heat, soaring world-wide political debate around its urgency, and pressure from various social groups on the government to clamp down on environmentally destructive activities by enacting climate-friendly regulations (Mohommad and Pugacheva, 2022). In contrast, relative to the world's other continents, the consciousness of climate change in Africa is considered low (Helbling et al., 2021). Similarly, some studies argue that Africa's vulnerability to climate change is extreme, even though its percentage contribution to world greenhouse gas emissions is relatively low (Olusanya and Dasauki, 2020).

Several studies have shown that carbon emissions is the primary cause of climate change, and this is because when carbon dioxide and other greenhouse gases are released into the atmosphere, they trap heat from the sun and cause the Earth's temperature to rise. This leads to the melting of glaciers, rising sea levels, more frequent and intense heatwaves, droughts, floods, and extreme weather events, such as hurricanes, cyclones, and typhoons, which will ultimately reduce people's quality of life (Alexander et al., 2012). Similarly, carbon emissions contribute to air pollution, leading to respiratory problems and other health issues.

According to the studies by Margolis (2021), prolonged heat waves can make certain places uninhabitable. Because of this, the local population has seen a high incidence of sickness and death. Naturally, this has impacted daily living, well-being, and behavioral responses to various social, environmental, and economic contexts (Kaniasty, 2012). In addition, farmers' incapacity to adapt to climate change may also result in challenges, including forced migration, social disruption, illness, and death (Masud et al., 2017). Furthermore, Telesca et al. (2018) argue that carbon emissions could lead to ocean acidification, which can have detrimental effects on marine life, including coral reefs, shellfish, and other organisms that rely on calcium carbonate to build their shells and skeletons. In the same vein, Quinn et al. (2019) stated that carbon emissions could lead to the loss of habitats and ecosystems, and as such, this can reduce the biodiversity of plants and animals. Indeed, such losses have negative implications for human's quality of life.

Moreover, carbon emissions can also lead to social and political unrest as people compete for scarce resources or are displaced from their homes due to extreme weather events or rising sea levels. This can exacerbate existing conflicts and lead to instability in vulnerable regions of the world, especially African countries (Hino et al., 2017). However, available literature needs to show more evidence to establish the effect of carbon emissions on the quality of life in Africa. Consequently, we identify the need to expand the academic literature on climate change and quality of life in African countries, where the vulnerability to climate degradation impact remains high. Based on this, our paper employs human development index in Africa as a proxy for the quality of life, and investigate the impact of carbon emissions on it.

2.2 Ecological footprint and quality of life

There is no universally accepted definition for the term ecological footprint, and the debate over this has persisted for at least a decade in academia. This is mainly due to the relevance of ecological footprint, as a concept, to manifold academic disciplines, including economics, engineering, health, politics, psychology, and sociology. Several studies have shown that the African continent accounts for less than 3% of the world's total greenhouse gas emissions because of its underdeveloped industrial infrastructure. For the same reason, Africa is the continent most in danger from its consequences, even though it contributes the least to the factors that lead to regional and global climate change.

The study of Rees and Wackernagel (1996) propound the theory on ecological footprint, and it is a technique for assessing how much impact people have on the environment. The method has gained considerable academic acceptance and application due to providing a novel point of view in assessing regional sustainable development. According to some researchers, ecological footprint is a valuable indicator of the ecosystem's overall health since it demonstrates how the environment is deteriorating, directly affecting people's living conditions. In addition, laws governing land use, carbon emissions levies, and subsidies for renewable energy can help to create a cleaner and healthier environment (Solarin and Bello, 2018).

The ecological footprint is a way to assess the sustainability of human activities and their impact on the planet. It has been developed to demonstrate a potential to exceed the sustainability threshold by comparing the level of consumption with the quantity of bio-productive land and sea area that is now accessible. The ecological footprint incorporates the following: (i) the land needed to produce goods from plants, animals, and forests; (ii) the space needed to absorb atmospheric CO_2 emissions, which are mainly brought on by the burning of fossil fuels; and (iii) the acreage needed to meet nuclear energy demand

(Wackernagel et al., 2002).

2.3 Empirical review

Numerous studies have shown that extreme weather fluctuations, often brought on by climate change, would have various unfavorable effects. For instance, climate change has been shown to have global warming consequences (Ranson, 2014), plausibly leading to environmental catastrophes (Benevolenza and DeRigne, 2019). Additionally, Woodward et al. (2014), in outlining and explaining the preparation of the IPCC report and its main findings, opine that climate change could aggravate health-related problems and raise the likelihood of conflicts and crises amongst nations. For Tanahara et al. (2021), they argue that climate change can lower water quality of communities through several factors, such as changes in rainfall, temperature, sunshine, and sea levels. In the remainder of this section, we survey the existing empirical literature, highlighting the relationship between climate change proxies and our indicator for quality of life. In particular, we review the literature on the interconnectedness of carbon emissions and ecological footprint with human development index and state the hypotheses to be tested.

The review of the empirical literature carried out here dissects existing studies between African-focused and non-Africa-focused ones. Academic studies conducted on Africa have adopted different variables for measuring climate change. Olusanya and Dasauki (2020) study validates the positive association between CO_2 emissions and African gross domestic product (GDP). In 79% of the 43 countries sampled in Africa, GDP and CO_2 emissions move in a positive direction in contrast to the other 21% with a negative relationship between GDP and CO_2 emissions. Acheampong et al. (2019) show that carbon emissions react differently to macroeconomic variables in Africa. In applying a panel data methodology, trade liberalisation, population growth, and financial development impact CO_2 emissions negatively, while FDI and renewable energy reduces carbon emissions in the 46 African countries used in their study.

Using the ARDL and NARDL methods to measure the relationship between environmental sustainability and government effectiveness, Yang et al. (2022) apply ecological footprint as one of the variables in 27 African countries. The result shows that renewable energy usage impacts environmental quality, while GDP growth negatively affects environmental quality. Using panel data methodology, Ergun et al. (2019) study the contributing factors to renewable energy usage for over 20 African states. The result corroborates Yang et al. (2022) on the negative relationship between GDP growth and renewable energy. Regarding the relationship between energy usage and quality of life in sub-Saharan African countries, Ibrahim et al. (2021) proxy quality of life with human development index and employ GMM methodology. The result shows a negative relationship of the quality of life with non-renewable energy usage in SSA.

Considering studies in a different geographical location from Africa, Pata (2021) applies ecological footprint and carbon emissions as a proxy for climate change, while performing causality and cointegration tests for the BRIC nations. The results show a mixed relationship among the BRIC countries. On the causality front, the result shows a bidirectional relationship between agriculture and environmental degradation, a one-way direction from globalisation to the climate change variables, and from renewable energy to climate change variables. This result is in tandem with the thinking that human activities cause climate change. Still, in the BRICS countries and N-11 nations, Nawaz et al. (2021) apply probit regression analysis and difference-in-difference (DiD) methodology to study the linkage between climate change and green finance. The result shows that carbon dioxide emissions considerably impacts sustainable finance. Also, the result from the probit method demonstrates that CO_2 and HDI affect 'green financing' and climate change improvements in the studied countries.

Altıntaş and Kassouri (2020) argue that the Environmental Kuznet Curve (EKC) hypothesis does not hold in 14 European countries, with only CO_2 variables, but is valid for using ecological footprint. This finding underscores the importance of considering and applying different climate change variables. One-way causal direction holds from GDP per capita to climate change and fossil fuel to climate change. Ansari (2022) corroborates the result of Altıntaş and Kassouri (2020) that ecological footprint, not CO_2, holds for the EKC hypothesis in the Association of Southeast Asian Nations (ASEAN). In a similar study on the EKC hypothesis for China, Hussain et al. (2022) argue that economic growth decreases carbon emissions and ecological footprint. In addition, carbon emissions and ecological footprint are reduced by financial development, whereas population density, natural resources, and inflation raise the climate change variables.

The study of Lenzen and Cummins (2013) use survey data on Australian lifestyles to discover common elements of subjective well-being and carbon footprint. They reveal that high-income levels of residents are highly correlated with higher emissions. However, the research done by Verhofstadt et al. (2016) employ survey data from an area in northern Belgium to investigate the connection between an individual's environmental sustainability of their lifestyle as measured by their ecological footprint and their subjective sense of well-being. According to the results of their investigation, there is no statistically significant association between ecological footprint and level of subjective well-being.

Using an advanced decision-making support toolkit, such as the Macro-Adaptation Resilience Toolkit (MART), the research conducted by Friedman et al. (2023) investigate the impact of climate change on the quality of life in Miami-Dade County, as well as adaptation strategies for the county. Furthermore, the results from participant dialogues also show that the socioeconomic disparities brought on by urbanisation, such as gentrification, affect the kind of climate threats deemed to be of utmost concern to communities.

In the study that was carried out by Clement et al. (2021), a quantitative analysis was performed by integrating data on quality of life with information on the average carbon footprint left by each family in continental United States to determine whether there was a correlation between the two factors. According to the study's results, a significant relationship works in the opposite direction between a person's total carbon footprint and quality of life. In addition, the study's outcomes reveal the potential advantages of using rigorous, objective measures of quality of life that go beyond simple considerations of economic well-being and life expectancy alone.

2.4 Theoretical Framework

Diverse theories have been put out to explain the connections between climate change and quality of life, and some of these theories posited a connection between the quality of life and climate change. Some of the theories are physical causation and ecopsychology. Firstly, the physical causation theory holds that the natural changes caused by climate degradation factors impact people, plants, and societal structures. According to Zhang et al. (2011), massive human calamity was directly attributed to climatic change throughout the pre-industrial age in Europe and the North Hemisphere. The legal context is used by Lloyd and Shepherd (2021) to demonstrate the connection between climate change and its impact and refute the hypothesis that humans cause it. Additionally, the studies of Shepherd (2021) and Dhakal et al. (2023) were comparable and similar research that also adopted the physical causation theory.

Secondly, the ecopsychology theory connects climate change to psychological and emotional problems in people's life and ties it to the subjective quality of life approach (Bechtoldt et al., 2021). The positive psychological and emotional effects on human existence may motivate people to take action to slow down climate change, while adverse effects can depress spirits and encourage indifference and denial of reality (Tam et al., 2021). In addition, the environmental justice theory also states that vulnerable low-income countries could be subjected to uneven climate change effects after experiencing inequality, poverty, food shortages, heightened health risks, poor productivity, and other consequences of climate change that can affect people's quality of life (Islam and Winkel, 2017).

Furthermore, Adger et al. (2014) used the human security theory from the issue of conflict, shortage in basic infrastructure, displacement, and migration to establish the relationship between climate change and quality of life. The theory buttresses the inability of the State to provide the needed minimum infrastructure requirement for survival forced through climate change challenges human life security (Adger et al., 2014). The research by Nan et al. (2023) demonstrated that ecological footprint suggests that human actions have an environmental trajectory that supports climate transformation activities, contradicting the idea that the causation goes from climate change to quality of life. Desertification and burning fossil fuels as a consequence of human production activities raise EF and are related to living quality (Nan et al., 2023).

3 Data and model specification

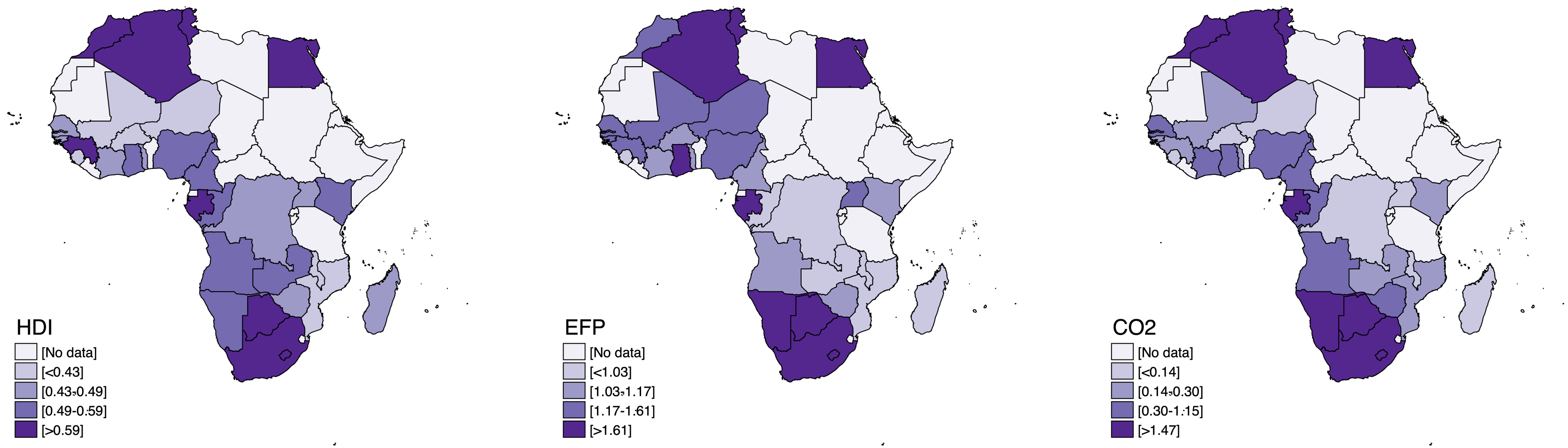
3.1 Data description

In this study, we use data for 31 African countries covering the period 2000 to 2018 due to the availability of data. We also classify these African countries into two regions: Northern Africa (NA) and sub-Saharan Africa (SSA). Details of the sampled countries are shown in the Appendix. For empirical purpose, our dependent variable is the quality of life (QoL) for the whole continent and the defined regions. We use human development index (HDI) to measure QoL, following Nikolaev (2014). The HDI data was obtained from the United Nations Development Programme (UNDP) database. To proxy climate change, we follow the approach of Aluko et al. (2021) by using data for ecological footprint (EFP) and carbon emissions (CO_2) at the aggregate and regional levels. Data for both EFP and CO_2 were respectively sourced from the Global Footprint Network (GFN) and World Development Indicators (WDI).

Figure 1 depicts the distribution of these three main variables in maps. Figure 1a plots human development index for each of the 31 countries in our sample, over the period 2000 to 2018. Covering the same number of countries and sample period, Figures 1b and 1c display the two climate change variables (ecological footprint and carbon emissions, respectively). For Figures 1a-c, darker regions indicate higher values, with the lightest shades signifying countries with missing data. As can be seen in Figure 1, there exists substantial variations in each of human development index, ecological footprint, and carbon emissions across the 31 countries represented in our sample.

We conduct robustness checks to affirm the veracity of our baseline findings. In particular, we follow prior studies in the literature, such as Acheampong et al. (2019) and Aluko et al. (2021), as we control for country-specific economic and development (E&D) factors, including renewable energy consumption, GDP per capita, economic freedom, FDI, trade openness, inflation, and population growth. Furthermore, we account for political, governance and institutional (PGI) factors that may influence a country's HDI. These measures include control of corruption, political stability, regulatory quality, rule of law, and government effectiveness. The PGI variables were gathered from the World Governance Indicators (WGI) database. In extending our estimating equation to control for both the E&G and PGI factors, we have reduced the propensity for omitted variable bias. Table 1 shows all the variables adopted in the study, their definitions, and sources.

Tables 2 shows the descriptive statistics of the variables used in our study. It is shown that the average quality of life, ecological footprint, and carbon emissions within the African continent are 0.51, 1.45, and 1.05, respectively. For the regions, Northern Africa



(a) Human development index (HDI)

(b) Ecological footprint (EFP)

(c) Carbon emissions (CO_2)

Figure 1: Distribution of human development index, ecological footprint, and carbon emissions in Africa.

Notes: This figure plots the mean human development index, ecological footprint, and carbon emissions (2000-2018) for the 31 African countries in our sample.

Table 1: Definitions of variables and data sources.

Variable	Definition	Source
Dependent variable		
HDI	Human development index, used to proxy quality of life.	UNDP
Climate change measures		
EFP	Ecological footprint per capita global hectares.	GFN
CO_2	Carbon emissions per capita.	WDI
Economic and development (E&D) indicators		
Renewable	Renewable energy consumption (% of total energy consumed).	WDI
GDP per capita	Log of GDP per capita.	WDI
Economic freedom	Overall index of the four economic freedom proxies.	HF
FDI	Net inflows of foreign direct investment (% of GDP).	WDI
Trade openness	Trade as a percentage of GDP.	WDI
Inflation	Percentage change in the consumer price index.	WDI
Population growth	Annual growth rate of population.	WDI
Political, governance, and institutional (PGI) factors		
Control of corruption	Control of corruption score.	WGI
Political stability	Political stability and absence of violence/ terrorism score.	WGI
Regulatory quality	Regulatory quality score.	WGI
Rule of law	Rule of law score.	WGI
Voice and accountability	Voice and accountability score.	WGI
Government effectiveness	Government effectiveness score.	WGI

Notes: UNDP: United Nations Development Program; GFN: Global Footprint Network; WDI: World Development Indicators; HF: Heritage Foundation; WGI: World Governance Indicators.

appears to have higher average quality of life (0.67) than the SSA region (0.49). This is not surprising given the level of infrastructural development, educational attainment, and other socio-economic indices of the countries in North-African region compared to other countries in Africa. Meanwhile, table 2 also reveals that the average carbon emissions (2.36) and ecological footprint (1.88) in the North-African region are much higher than the counterpart values in the SSA region (0.85; 1.38). We infer that these observations are due to the level of manufacturing and heavy industrial activities witnessed by the countries in the Northern region. More specifically, 5 out of the top 10 largest and most

Table 2: Descriptive statistics

	Panel A: Full sample				Panel B: Sub-Saharan countries				Panel C: Northern countries			
Variable	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Min	Max
HDI	0.51	0.11	0.25	0.75	0.49	0.10	0.25	0.72	0.67	0.05	0.53	0.75
EFP	1.45	0.63	0.66	3.82	1.38	0.64	0.66	3.82	1.88	0.31	1.22	2.65
CO_2	1.05	1.59	0.03	8.57	0.85	1.59	0.03	8.57	2.36	0.68	1.14	3.93
Renewable	63.50	28.96	0.06	98.34	71.44	21.29	10.19	98.34	9.92	11.72	0.06	95.22
LogGDP	3.05	0.42	2.14	4.03	2.99	0.42	2.14	4.03	3.42	0.21	2.38	3.74
Economic freedom	54.27	8.13	21.4	72.00	53.94	8.55	21.4	72.00	56.49	3.72	44.70	63.9
FDI	3.77	5.17	-10.72	39.81	3.94	5.42	-10.72	39.81	2.59	2.72	-2.54	18.82
Trade openness	66.81	23.80	20.72	156.86	66.40	24.43	20.72	156.86	69.61	18.90	30.25	114.34
Inflation	9.44	30.52	-3.5	513.91	10.11	32.6	-3.50	513.91	4.87	4.61	0.34	29.51
Population growth	2.53	0.76	0.39	5.79	2.67	0.68	0.39	5.79	1.53	0.43	0.91	2.34
Control of corruption	-0.63	0.64	-1.85	1.42	-0.83	0.54	-1.67	1.38	0.47	0.32	-0.45	1.62
Political stability	-0.55	0.92	-3.31	1.28	-0.65	0.71	-3.22	1.53	-0.67	1.49	-2.46	3.18
Regulatory quality	-0.71	0.64	-2.55	1.20	-0.73	0.53	-2.45	1.37	-0.55	0.74	-1.42	2.30
Rule of law	-0.712	0.66	-2.59	1.02	-0.51	0.65	-2.51	1.04	-0.23	0.95	-3.61	2.87
Government effectiveness	-0.78	0.63	-2.45	1.16	-0.81	0.59	-2.41	1.32	-0.59	0.76	-2.32	2.70

Notes: This table presents descriptive statistics of all the variables used in the analysis. Our base sample consists of 31 countries in Africa, further separated into North and sub-Saharan Africa.

industrialised economies in Africa are situated in the North of Africa.

3.2 Model description

To achieve the objectives of this study, we first specify quality of life as a function of climate change for both Africa and its identified regions as shown below:

$$
\begin{aligned}
&\mathrm{HDI}_{i,t} = f(\mathrm{EFP}_{i,t}, \mathrm{CO}_{2i,t}) \\
&\mathrm{HDINA}_{i,t} = f(\mathrm{EFPNA}_{i,t}, \mathrm{CO_2NA}_{i,t}) \\
&\mathrm{HDISSA}_{i,t} = f(\mathrm{EFPSSA}_{i,t}, \mathrm{CO_2SSA}_{i,t})
\end{aligned}
\tag{1}
$$

where HDI is human development index (a proxy for quality of life) at the aggregate African level, HDINA and HDISSA represent human development index for Northern African region and sub-Saharan African region, respectively. EFP, EFPNA, EFPSSA, CO_2, CO_2NA, and CO_2SSA are the climate change measures, which refer to the ecological footprint and carbon emissions of Africa at the aggregate level and by regions (Northern and sub-Saharan African), respectively. In Eq. (1) above, country and time are shown by the subscripts i and t, respectively.

Our specific empirical model is now stated below:

$$
\begin{aligned}
&\mathrm{HDI}_{i,t} = \beta_1 \mathrm{EFP}_{i,t} + \beta_2 \mathrm{CO}_{2i,t} + \alpha_i + \alpha_t + \varepsilon_{i,t} \\
&\mathrm{HDINA}_{i,t} = \gamma_1 \mathrm{EFPNA}_{i,t} + \gamma_2 \mathrm{CO_2NA}_{i,t} + \alpha_i + \alpha_t + \varepsilon_{i,t} \\
&\mathrm{HDISSA}_{i,t} = \delta_1 \mathrm{EFPSSA}_{i,t} + \delta_2 \mathrm{CO_2SSA}_{i,t} + \alpha_i + \alpha_t + \varepsilon_{i,t}
\end{aligned}
\tag{2}
$$

where $\beta_1, \beta_2, \gamma_1, \gamma_2, \delta_1,$ and δ_2 represent the slopes of the climate change proxies, while the fixed effects for country and year are denoted by α_i and α_t, respectively. $\varepsilon_{i,t}$ is the stochastic error term.

In explaining the heterogeneous and long-term relationships between climate change and quality of life in Africa, we employ a few steps in the estimation procedure. First, we explain the unit root and cross-sectional dependence of the variables. Second, we analyse long-run cointegration relationship of the variables. Next, we check for heterogeneous causality amongst the variables. Finally, we conduct a series of robustness checks by investigating the magnitude of impact of the climate change proxies on the quality of life using regression analysis. The next section details the analytical procedures.

4 Estimation methods

4.1 Accounting for cross-sectional dependence and unit root in the panel

In empirical economics, it is common to assume the presence of unit root and cross-sectional dependence among the individual series in a panel data. Unit root in panel data tests for the stationarity (or otherwise) of the series, whilst cross-sectional dependence of series may occur due to unobserved shocks. Over the years, econometricians have had to contend with these duo in heterogeneous panel data structures. If present in a series, it poses a problem to the validity of results generated as they may be biased. Hence, it is pertinent to investigate these situations before embarking on the main analysis (Afonso and Jalles, 2015; Menyah et al., 2014).

Recognising these issues, we cater for cross-sectional dependence (CD) in the series by employing the test developed by Pesaran (2004). More specifically, we account for unit root at both the level and first-difference forms, using three different techniques. We start with the tests proposed by Pesaran (2007) and Pesaran and Yamagata (2008) called Cross-sectionally Augmented Dickey-Fuller (CADF) test and Cross-sectionally Augmented Im-Pesaran-Shin (CIPS) unit root test. Then, we use Hadri (2000) panel stationarity test to further confirm the validity of the other two stationarity models.

Given the possibility of a conflicting outcome amongst the three methods, we further employ the Nazlioglu and Karul (2017) panel stationarity test, which captures structural break. We are conscious of the existence of structural breaks in the series because its presence could affect the reliability of the results. Hence, we allow the date of the break to be endogenously determined using a simple Monte-Carlo experiment. Should our variables be integrated at level form, then there may be no need to proceed to differencing the variables; otherwise, stationarity may be achieved in the first-order difference [$I(1)$]. The latter case would, therefore, require further investigation of long-run relationships using cross-sectional dependence cointegration (CDC) test. The CADF and CIPS equations are shown below, where $t_i(N,T)$ denotes the CADF and CIPS ADF-statistic for the aggregate and regional observations:

$$\Delta y_{i,t} = a_i + b_i y_{i,t-1} + c_i \overline{y}_{i,t-1} + d_i \Delta \overline{y}_{i,t} + \varepsilon_{i,t} \tag{3}$$

$$CIPS(N,T) = N^{-1} \sum_{i=1}^{N} t_i(N,T) \tag{4}$$

4.2 Accounting for long-run relationship: panel cointegration tests

The use of long-run cointegration test is warranted when the relationship between climate change and quality of life is established to be cointegrated at order one (that is, $I(1)$). In this study, we use two different cointegration tests to substantiate our conjecture. First, we use the Westerlund (2006, 2007) test for cointegration and panel cointegration test developed by Westerlund and Edgerton (2008). The latter test has superiority over the former because it eliminates the proposition of a unique restriction. Besides, it is designed to handle the specific intercept of individual series and situations where the residuals, gradients, and trends are autocorrelated. Additionally, it accounts for unknown structural breaks and cross-sectional dependence.

Using four specific parameters at both panel and group forms, the Westerlund and

Edgerton (2008) cointegration test explains how the panel can be integrated as a group rather than individual series. It also indicates the possibility of regime, level, and endogenous structural changes in a longitudinal data. Importantly, Westerlund and Edgerton (2008) test allows us to understand the heterogeneity within the regions and the propensity for macroeconomic factors to influence the relationship between quality of life and climate change. The regression equation for the cointegration test is specified below:

$$y_{i,t} = \alpha_i + \delta_{i,t} + \beta_1 x_{1i,t} + \beta_2 x_{2i,t} + ... + \beta_k x_{ki,t} + \varepsilon_{i,t} \tag{5}$$

In Eq. (5) above, we expect x and y to cointegrate at order $I(1)$, where α is a constant term, β denotes the slope, t represents observations, ε is the residual term, and the number of explanatory variables are denoted by k. From Eq. (5), we further derive the residuals of cointegration since they ought to be cointegrated at order $I(1)$:

$$e_{i,t} = \rho_i e_{i,t-1} + \sum_{j=1}^{\rho_i} \phi_{i,j} \Delta e_{i,t-1} + \nu_{i,t} \tag{6}$$

Next, we specify the cointegration test accounts for cross-sectional homogeneity in the intercept and slopes. Here, our null hypothesis is equally specified as no cointegration as shown below:

$$y_{i,t} = \alpha_i + \beta x_{i,t} + \varepsilon_{i,t}, i = 1, 2, ..., N; t = 1, 2, ..., T \tag{7}$$

where $y, x,$ and e are the HDI proxy, matrix of explanatory variables, and residuals, respectively, for each country.

4.3 Accounting for causality in heterogeneous panels

Econometric modelling assumes that the presence of a causal relationship between two or more time series variables can further be efficiently extended to panel observations, whilst simultaneously considering the individual differences (heterogeneity) in the panel. The existence of a long-term relationship does not translate to causality. Although cointegration tests deal with the former, the latter is best handled using causality tests. Most studies have used Granger (1969) causality test to explain the direction of causality between variables. The drawback with the use of this approach is its inability to cater for causality and heterogeneity in a panel context. Hence, in this study, we ascertain the direction of causality between climate change and quality of life using the heterogeneous panel causality test developed by Dumitrescu and Hurlin (2012), which is basically an extension of Granger (1969).

Indeed, both approaches are similar in the sense that they check if the present observation of the dependent variable y can be significantly explained by the past observations of the explanatory variable/s X. However, in contrast to Granger (1969), the method of Dumitrescu and Hurlin (2012) is specifically designed to detect causality in panel models. Moreover, it uses both bootstrap and Monte Carlo simulations to show that the Wald statistic is adequate to detect causality at panel levels given independent, identical, and standard normal distribution of observations. We compute the mean of the Wald statistics to ascertain the panel test value.

Furthermore, the Dumitrescu and Hurlin (2012) model breaks a specific group into subgroups, such that it accounts for the possibility of the existence of causal relationship in subgroups, whilst absent in other subgroups. This implies that two variables may have causality at the aggregate level, but at the individual levels, they may not. This is particularly important given the dynamics of short- and long-term causal relationships between variables in a panel. Eq. (8) below describes the causality test proposed by Dumitrescu and Hurlin (2012):

$$y_{i,t} = a_i + \sum_{k=1}^{K} \gamma_{i,k} y_{i,t-k} + \sum_{k=1}^{K} \beta_{i,k} x_{i,t-k} + \varepsilon_{i,t} \tag{8}$$

In the above equation, $x_{i,t}$ and $y_{i,t}$ are the series of both climate change and quality of life for each country/region at a given period, respectively. The i subscript for each coefficient indicates that the coefficients remain the same for each period, but can vary across countries. Essentially, this model works for a panel where the lag order K remains the same for each country. Although this could pose an empirical obstacle, it is nevertheless resolved by choosing the appropriate lags using one of the information criteria of AIC, BIC or HQIC, thereby allowing estimations to have a common nested sample.

4.4 Bayesian panel vector autoregression (PVAR) and impulse response functions

To better understand and interpret how quality of life in Africa is affected by climate change, we adopt a panel vector autoregressive (PVAR) for fixed effects model, which allows us to decompose the dynamic behaviour of the variables based on *cause* and *effect*. At first, we follow prior studies (Lof and Malinen, 2014; Abrigo and Love, 2015) by using the standard PVAR which introduces all variables as endogenous factors and provides insights into the time-invariant features of the variables for each country. This method also includes instruments into the PVAR framework using the lags of the regressors. Moreover, the standard PVAR framework follows a dynamic GMM approach (fixed T, large N) in estimating its model and uses first-order lag. This, however, leads to a shortfall in the framework as the degree of freedom is reduced for each endogenous variable introduced. Furthermore, the technique assumes that errors are not serially correlated and there is no cross-sectional dependence, which contradicts our data structure. Besides, we have a relatively small T and N in our study.

To cater for the above snags, we follow the approach of Comunale (2022) by employing the Bayesian PVAR which accounts for heterogeneity through a partial pooling process in the framework, rather than exact pooling that may not handle the dynamic heterogeneity, especially given our small T and N. Canova and Ciccarelli (2013) have also shown that partial pooling provides reliable and efficient estimates. Hence, given that our $T = 18$ and $N = 31$, to establish the cause and effect of climate change on quality of life in Africa and its regions, we use a Bayesian PVAR fixed effect model with a partial pooling that accounts for the heterogeneity across the observations. To ensure identification in the estimation of the PVAR, we use the Choleski decomposition approach, which introduces the variables into the PVAR from least to most endogenous. Furthermore, we use the Helmet transformation technique to transform the variables to cater for country-specific fixed effects u_i. This technique follows a forward-average deduction process and is particularly useful for cross-country panel when there are missing observations.

The PVAR equation is shown below:

$$Y_{i,t} = u_i + \sum_{j=1}^{n} \beta_j Y_{i,t-j} + \varepsilon_{i,t} \tag{9}$$

From the above Eq. (9), the endogenous variables: human development index, carbon emissions, and ecological footprint are represented by $\mathrm{Y}_{i,t}$, which is a vector of form 1×3. The output of the Bayesian PVAR also incorporates impulse response functions (IRFs), which analyses the response of one variable following shocks to or innovations in other variables. It also indicates the magnitude and direction of the effect and whether it is statistically significant. Accordingly, we account for the effect, direction, magnitude, and significance of shocks in climate change proxies on the imbalances in quality of life in

Africa and its regions.

The IRF equation is shown below:

$$GI_{pr}(h, \Gamma, \lambda_t) = E(Pr_{t+h}|\lambda_t = \Gamma, \psi_{t-1} = \lambda_{t-1}) - E(Pr_{t+h}|\psi_{t-1}\lambda_{t-1}) \tag{10}$$

In Eq. (10) above, the confidence intervals and standard errors follow 1000 Monte Carlo simulations with a burn-in percentage of 0.1 and 10 years horizon. This ensures the variables are in the right order and allows us to generate a reliable posterior average, thus identifying the main source of the shocks. This is important to understand both the instantaneous and long-run impulse responses of quality of life to climate change.

4.5 Robustness checks

We conduct additional analyses to authenticate our baseline results. To this end, we first apply an instrumental variable (IV) approach using Lewbel (2012) two-stage least squares (IV-Lewbel 2SLS) to test the effect of climate change and other explanatory variables on the quality of life in Africa and across its regions. In the face of weak or few instruments and identification problems, the Lewbel (2012) approach is designed to overcome such model specifications as it generates internal instruments like those constructed in the model.

Moreover, to overcome issues associated with autocorrelation, cross-sectional dependence, endogeneity, missing data points, and panel heteroscedasticity, we employ Prais-Winstein regression as a further robustness check. This approach is suitable for both balanced and unbalanced panel data. Our regression equation is shown below:

$$\mathrm{HDI}_{i,t} = \alpha_0 + \beta_1 \mathrm{EFP}_{i,t} + \beta_2 \mathrm{CO}_{2i,t} + \beta_3 X_{i,t} + \varepsilon_{i,t} \tag{11}$$

where $X_{i,t}$ represents a matrix of control variables included in the empirical model to prevent omitted variable bias; see the data description section above for more detail. All remaining variables and parameters have been previously defined.

5 Results

5.1 Results of cross-sectional dependence and unit root tests

We report the output of the cross-sectional dependence (CD) test in tables 3 and 4. Table 3 specifically shows the output of the Breusch and Pagan (1980) test and the Pesaran (2004) CD test for individual variables. Table 4 shows the CD tests for the entire panel model. The results in both tables reveal that the data series of the variables in our study exhibit strong cross-sectional dependence, thus leading to the rejection of the null hypothesis at high significance levels. We opine that the sampled regions show cross-sectional dependence due to spill-over effects from common factors, including macroeconomic conditions, geographical location, and political climate (Smiech and Papież, 2014; Shahbaz et al., 2017). For example, the quality of life across countries within a region can be affected by underlying factors such as migration due to climate change, social unrest, and terrorism. Other factors may include poverty, infrastructure decay, and lack of access to basic amenities.

Additionally, countries could witness spill-over impact of climate change due to geography and resource-sharing. For instance, recent evidence suggests that countries in the West of Africa have continued to experience acute displacement due to severe flooding arising from climate change (Avom et al., 2020), while countries in the North are ravaged with persistent wildfires. There is also an unprecedented cycle of clones in the South and countries in the Horn of Africa are facing acute famine. These incidences may appear sequestered; however, they are interwoven due to spill-over effects from the climate crises.

Table 3: The Breusch-Pagan and Pesaran CD tests for individual variables

Variable	Breusch-Pagan	Pesaran LM	Bias-corrected LM	Pesaran CD
HDI	2665.19**	301.19**	301.55**	71.09**
HDINA	511.30**	188.01**	211.90**	69.15**
HDISSA	2011.00**	160.59**	301.56**	71.65**
EFP	3318.51**	194.27**	175.03**	78.91**
EFPNA	209.04**	255.78**	188.30**	75.03**
EFPSSA	1981.323**	180.33**	195.22**	68.20**
CO_2	1706.209**	209.16**	203.67**	74.11**
CO_2NA	154.77**	177.30**	134.09**	65.09**
CO_2SSA	1330.67**	205.64**	186.45**	93.22**

Notes: This table shows the Breusch-Pagan LM and Pesaran CD tests for the individual variables. H_0: The variable is not dependent (not correlated) across the cross-sections. H_0 is rejected if the coefficient is significant.

Table 4: Cross-sectional dependence tests for the entire model

Test	T-statistic	p-value
Model 1: $\text{HDI}_{i,t} = f(\text{EFP}_{i,t}, \text{CO}_{2i,t})$		
Breush and Pagan (1980)	394.10***	0.000
Pesaran and Yamagata (2008)	251.06***	0.000
Pesaran (2004)	21.39***	0.000
Model 2: $\text{HDINA}_{i,t} = f(\text{EFPNA}_{i,t}, \text{CO}_2\text{NA}_{i,t})$		
Breush and Pagan (1980)	151.00***	0.000
Pesaran and Yamagata (2008)	135.21***	0.000
Pesaran (2004)	13.19***	0.000
Model 3: $\text{HDISSA}_{i,t} = f(\text{EFPSSA}_{i,t}, \text{CO}_2\text{SSA}_{i,t})$		
Breush and Pagan (1980)	311.20***	0.000
Pesaran and Yamagata (2008)	231.11***	0.000
Pesaran (2004)	25.44***	0.000

Notes: This table shows the cross-sectional dependence tests for the entire model using fixed-effect model. H_0: Model is not dependent (not correlated) across the cross-sections. H_0 is rejected if the test statistic is significant.

The fact that it is peculiar to a particular region makes countries in that region and the whole continent more susceptible because of cross-sectional dependence.

With regards to the results of the unit root tests shown in table 5, the output of the Hadri and CIPS tests suggests the presence of unit root in the variables. On the other hand, the output of CADF reveals evidence of stationarity. The contradictory position of these methods can best be resolved using the output of the Nazlioglu and Karul (2017)

Table 5: Panel unit root test

Variables	CADF	CIPS	Hadri	NK level shift	NK level and trend shift
HDI	-1.59	-3.19*	15.35*	310.59*	1367.09*
HDINA	-1.03	-1.88*	11.29*	215.11*	2218.33*
HDISSA	-2.11	-2.60	13.25*	236.45*	2019.45*
EFP	-1.85	-1.94*	15.43*	187.10*	1187.10*
EFPNA	-2.00	-2.57*	13.40*	425.43*	3301.45*
EFPSSA	-1.83	-1.83	15.29*	120.68*	1924.11*
CO_2	-1.76	-2.01	23.34*	345.09*	2201.69*
CO_2NA	-1.57	-1.77*	14.91*	254.33*	1925.18*
CO_2SSA	-2.06	-2.05	16.50*	123.02*	1655.01*

Notes: This table shows the output for the stationarity tests using CADF, CIPS, Hadri and NK. H_0 is rejected if the test statistic is significant.

stationarity test, as already discussed in the previous section. The output from this test shows strong evidence to reject the null hypothesis of stationarity. This implies that the variables, in their level form, exhibit unit root.

5.2 Results of panel cointegration tests for time-varying relationship

We report the results of both the Westerlund (2006, 2007) and Westerlund and Edgerton (2008) heterogeneous panel cointegration tests in tables 6 and 7, respectively. In table 6, our results suggest the presence of cointegrating relationship between climate change and quality of life in SSA. For this reason, the null hypothesis of no cointegration is rejected. However, this result does not hold for the whole of Africa and the North African region, as there appears to be no cointegrating relationship in the long run. Furthermore, using panel cointegration level and regime change approaches provided by Westerlund and Edgerton (2008), as shown in table 7, we consider the likelihood of structural breaks in the output. Our findings further confirm the absence of long run cointegrating relationship in the aggregate for Africa and the Northern region, whilst affirming its presence for the SSA.

Overall, our findings indicate that climate change effects have long term consequences on the socio-economic development in Africa, particularly the SSA region. This is not surprising considering the heavy reliance of countries in this region on incomes from min-

Table 6: Panel cointegration results using Westerlund (2007) approach

Statistics	Value	Z-value	p-value	Robust p-value
Model 1: $\text{HDI}_{i,t} = f(\text{EFP}_{i,t},\ \text{CO}_{2i,t})$				
G_t	-4.259	1.08	0.4	0.37
G_a	-4.33	2.14	0.32	0.28
P_t	-6.17	1.18	0.2	0.25
P_a	-3.1	1.09	0.65	0.61
Model 2: $\text{HDINA}_{i,t} = f(\text{EFPNA}_{i,t},\ \text{CO}_2\text{NA}_{i,t})$				
G_t	-11.51	-1.06	0.45	0.49
G_a	-23.34	0.54	0.61	0.58
P_t	-15.69	0.99	0.19	0.3
P_a	-10.38	0.23	0.38	0.45
Model 3: $\text{HDISSA}_{i,t} = f(\text{EFPSSA}_{i,t},\ \text{CO}_2\text{SSA}_{i,t})$				
G_t	-1.51	-2.16*	0.00	0.01
G_a	-3.24	-1.04**	0.00	0.04
P_t	-3.9	-1.34*	0.00	0.01
P_a	-5.66	-1.09*	0.00	0.05

Notes: This table shows the panel cointegration test of long-run relationship for the entire model. H_0: Model is not cointegrated in the long run. H_0 is rejected if the p-value is less than 0.01, indicating the presence of long-run cointegration.

eral extraction, deforestation, and land cultivation, which constitute part of the climate crises. A large population of African citizens live in rural areas, with agriculture being the predominant occupation. The effect of climate change on their development has worsened over the years due to increased mineral extraction and industrialisation, which contribute significantly to global warming. The ripple effect also includes loss of fertile land, farmers-herders conflict, and low quantity and quality of harvests.

In the absence of modern agricultural mechanisms, farmers have had to abandon their farms and migrate to urban areas for low paying jobs, such as factory workers, commercial bus drivers, and tricycle operators, as well as site labourers. The lack of decent wages aggravates their living standards and undermines their socio-economic development in the long run. Furthermore, the migration of people from rural to urban areas, in search of a better life, puts pressure on the population density and infrastructural facilities in the urban ecosystem. For example, access to quality health care, which is a key measure of

Table 7: Panel cointegration results using Westerlund and Edgerton (2008) approach

	Level shift		Regime shift		
Statistics	Estimate	P-value	Estimate	P-value	Cointegrated
Model 1: $HDI_{i,t} = f(EFP_{i,t}, CO_{2i,t})$					
$Z_t(N)$	0.39	0.18	0.15	0.10	No
$Z_a(N)$	-0.27	0.11	0.26	0.22	No
Model 2: $HDINA_{i,t} = f(EFPNA_{i,t}, CO_2NA_{i,t})$					
$Z_t(N)$	-1.41	0.26	-0.51	0.11	No
$Z_a(N)$	-1.33	0.12	-1.23	0.19	No
Model 3: $HDISSA_{i,t} = f(EFPSSA_{i,t}, CO_2SSA_{i,t})$					
$Z_t(N)$	-0.76*	0.00	-0.68	0.02	Yes
$Z_a(N)$	-0.43*	0.04	-0.50	0.00	Yes

Notes: This table shows the Westerlund and Edgerton (2008) panel cointegration test of long-run relationship for the entire model. H_0: Model is not cointegrated in the long run. H_0 is rejected if the *p*-value of the estimate is less than 0.01, thus indicating the presence of cointegration.

human development, may become outstretched in such situations due to the poor living conditions of the populace.

5.3 Results of the heterogeneous panel causality test

In table 8, we present the results of the heterogeneous panel causality test based on Dumitrescu and Hurlin (2012). Our results at the aggregate level denote the existence of a unidirectional causality between both climate change variables and quality of life. Specifically, we find that HDI has a one-way causal relationship with EFP and CO_2, with no reverse causality. This suggests that an increase in human development index causes a depletion in the atmospheric condition in Africa. Similar unidirectional causality results are also shown for the SSA region. At first, the results for this region reveal that human development does not homogenously cause ecological footprint, implying that climate change in the region is not due to an increase in human development. Surprisingly, this finding is dampened by the next result, which shows that HDI does have a one-way causality on carbon emissions, thus reaffirming the earlier position for the whole region.

Table 8: Pairwise panel causality test using Dumitrescu-Hurlin (2012) method

Null hypothesis	W-stat	Zbar-stat	p-value
Model 1: $\text{HDI}_{i,t} = f(\text{EFP}_{i,t}, \text{CO}_{2i,t})$			
HDI does not homogenously cause EFP	1.94	3.38	0.08
EFP does not homogenously cause HDI	3.25	1.07	0.20
HDI does not homogenously cause CO_2	2.89	2.44	0.04
CO_2 does not homogenously cause HDI	1.65	1.73	0.19
Model 2: $\text{HDINA}_{i,t} = f(\text{EFPNA}_{i,t}, \text{CO}_2\text{NA}_{i,t})$			
HDINA does not homogenously cause EFPNA	2.40	2.19	0.00
EFPNA does not homogenously cause HDINA	1.37	1.36	0.02
HDINA does not homogenously cause CO_2NA	1.60	2.45	0.07
CO_2NA does not homogenously cause HDINA	1.49	1.97	0.00
Model 3: $\text{HDISSA}_{i,t} = f(\text{EFPSSA}_{i,t}, \text{CO}_2\text{SSA}_{i,t})$			
HDISSA does not homogenously cause EFPSSA	2.44	2.85	0.11
EFPSSA does not homogenously cause HDISSA	1.90	2.27	0.00
HDISSA does not homogenously cause CO_2NA	1.87	1.99	0.05
CO_2SSA does not homogenously cause HDISSA	2.65	2.07	0.13

Notes: This table shows the Dumitrescu-Hurlin (2012) for the pairwise panel causality test. H_0 is no causality in the direction, and this is rejected if the p-value is less than 0.01, suggesting the presence of causality.

Interestingly, in the North African region, there is a bi-directional causality between the climate change variables and HDI. The direction of causality implies that an increase in climate crisis affects human development, while an increase in human development can also stimulate climate-related problems. The findings of the causality substantiate our earlier result that the sampled regions show cross-sectional dependence due to spill-over effects from common factors, such as macroeconomic conditions, geographical location, and political climate.

5.4 Results of PVAR and IRFs

In this section, we discuss the output of the Bayesian panel VAR using the graph of the impulse response functions (IRFs). The IRF for the whole panel follows a Monte Carlo simulations with 1000 repetitions and its 95% confidence level, which is denoted by the dashed lines, is shown in figure 1 for the three endogenous variables: HDI, EFP and

CO_2. The impact of a one standard deviation shock of one variable (e.g., EFP) on HDI is denoted by the solid line which represents the impulse function.

The graph shows that a one standard deviation shock to carbon emissions leads to (i) a significant and negative response of human development index and (ii) a significantly positive response of ecological footprint. This implies that industrial activities, causing the release of carbon monoxide generates huge ecological footprint, which together reduces the quality of life in Africa. We infer from this finding that deterioration in HDI of African countries could be due to increased manufacturing and exploration activities in the region. Indeed, on the one hand, when production activities are unregulated, jobs are created but there may be no restraints on the emission levels, which invariably would cause health hazards. On the other hand, strains on production activities will help improve the ecosystem but may lead to job losses which would also affect HDI.

The output shows that a standard deviation shock in carbon emissions will cause an immediate decline of HDI of about 5%. This deficit increases with time, peaking around 7% before reaching equilibrium. Regarding the ecological footprint, a shock to this variable significantly impacts HDI, but not carbon emissions. These findings confirm that an increase in the use of productive surface area of the earth would exacerbate the living conditions of humans. Conversely, a low usage of ecological factors are consistent with better quality of life. Indeed, the output shows that a shock in ecological footprint causes a huge decline in HDI by about 11%. Our results also reveal evidence of reverse causality between HDI and the climate change proxies, thus complementing prior studies that document a similar bidirectional relationship.

Turning to the output in figure 2 for the North African region, the results are similar to the above findings. Although there is a slight difference in the response of HDI to the shocks, we find that standard deviation shocks in both carbon emissions and ecological

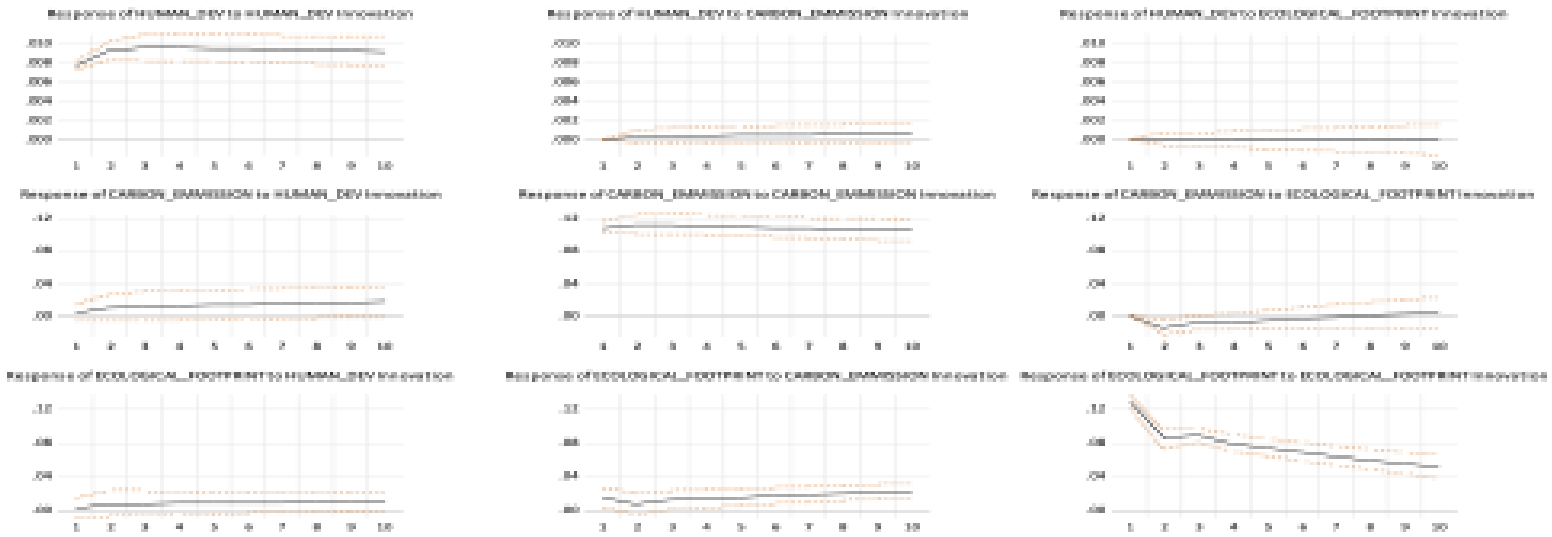


Figure 2: Impulse response functions for the whole of Africa

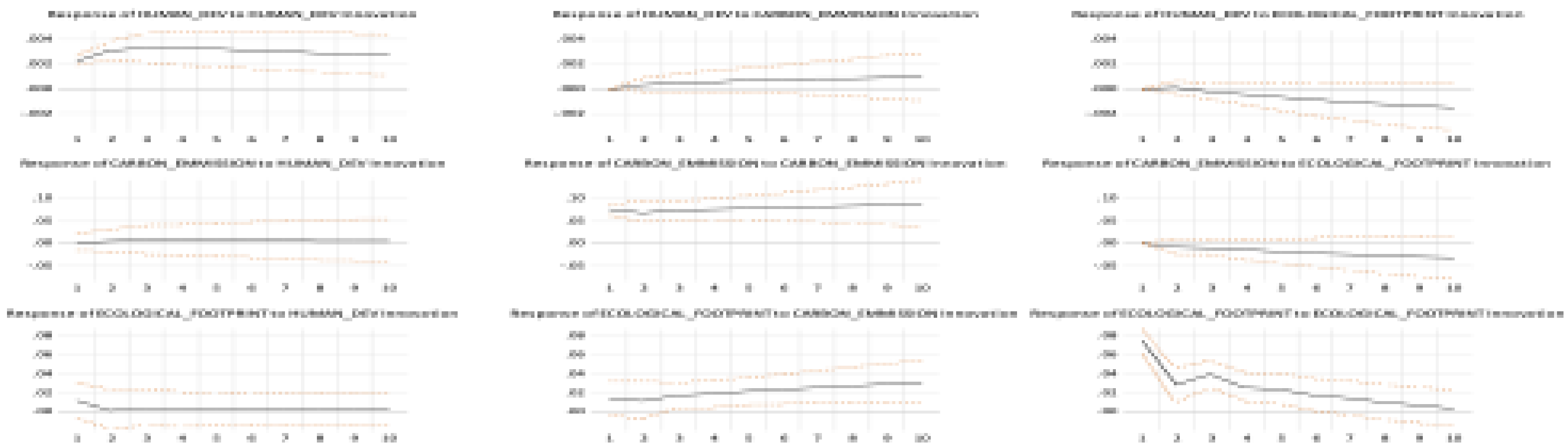


Figure 3: Impulse response functions for the North Africa region

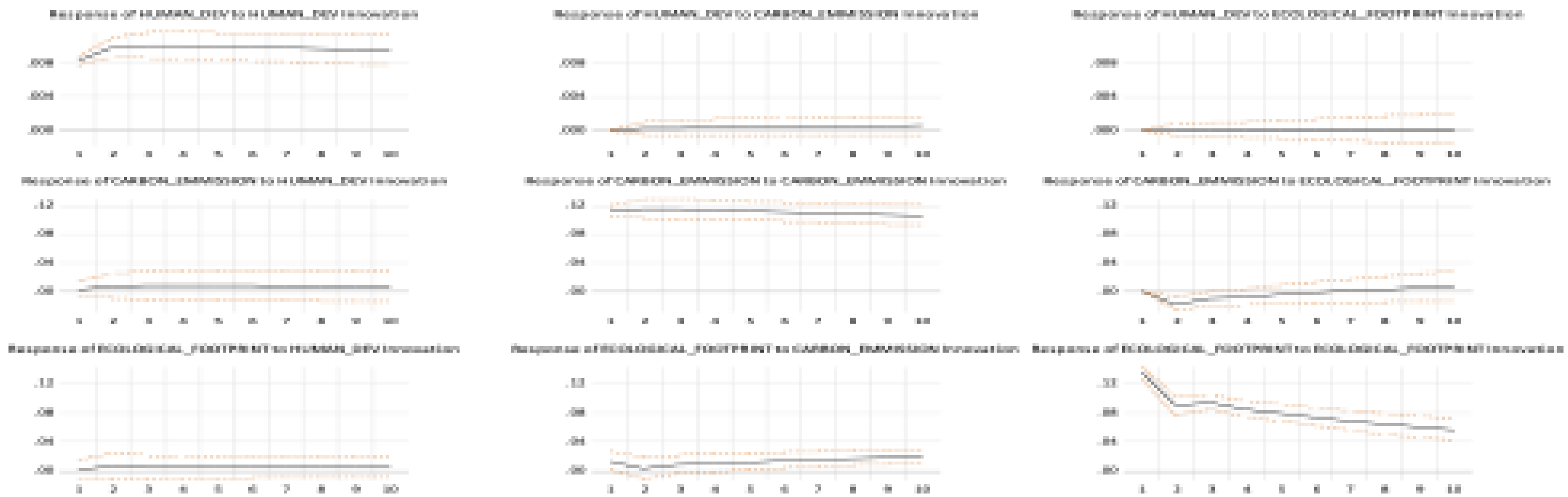


Figure 4: Impulse response functions for the SSA region

footprint have significant impact on HDI. By contrast, the output in figure 3 for the SSA region shows massive impact of the shocks in both carbon emissions and ecological footprint on HDI, though with a weak persistence, thus rapidly reaching equilibrium.

Summarily, the output of the IRFs reveal that climate change and quality of life interact with each other. Essentially, an increasing shock from climate change proxies results in a downward move in HDI for Africa, North Africa, and SSA, with a massive persistent effect for the latter. In addition, the HDI impact that arises from the climate change shock has a long-term impact for the whole of Africa and the Northern African region before returning to equilibrium. The persistence of the impact is, however, not pronounced for the SSA region.

To wrap up our discussion of the Bayesian PVAR, we turn attention to the output of the variance-decomposition (see the Appendix), with a view to explaining the percentage of variation in HDI captured by climate change proxies. The output shows how a change in a variable (in the row) is explained by itself and other variables (in the column). For the full sample, the results reveal an increasing impact of both carbon emissions and ecological footprint on the variations in HDI. The output shows that carbon emissions explain about 33% while ecological footprint explains 1% of the variation in the imbalances of HDI. Turning to the SSA region, the two climate change proxies respectively have about 22% and 3% explanation for the variations in HDI. Lastly, and for the Northern region, HDI appears to be largely self-explaining as the impact of the external factors are insignificant. We therefore surmise that variations in the quality of life in Africa are profoundly due to the effects of climate change.

5.5 Results of regression analyses: robustness checks

In this study, we explore the relationship between climate change and quality of life in Africa and its regions. Having conducted the foregone estimations, we now turn our attention to further empirical investigations based on regression models. To this end, we generate regression results on the direct impact of climate change proxies and other explanatory variables on the quality of life in Africa by applying the IV-Lewbel 2SLS estimator and Prais-Winstein regression. Notably, we find similar pattern of results for the two regression methods; for this reason, and purpose of brevity, we discuss only the findings from using the IV-Lewbel 2SLS estimator.[1]

In table 9, we show the IV-Lewbel 2SLS regression output and find that climate change affects quality of life in Africa. This finding is supported by the negative and statistically significant coefficients (at the 5% level) of both the ecological footprint and carbon emissions on HDI. Essentially, an increase in carbon emissions leads to a reduction in HDI by 18%. Similarly, a rise in ecological footprint reduces quality of life by 12%. Our results are in tandem with prior studies (Costanza et al., 2007; Ambrey and Daniels, 2017), who also find that the implications of environmental degradation are critical for human existence.

In terms of other explanatory variables, the coefficients of economic and development indicators, as well as those of political, governance and institutional factors, are positively signed, except for inflation and population growth. For instance, renewable energy has a positive and statistically significant coefficient at the 1% level, thus suggesting that increases in access to clean cooking fuels and energy-efficient technologies will improve quality of life of the populace because there will be less health-related challenges occurring due to exposure to environmental hazards. In recent studies, Acheampong et al. (2019) and Aluko et al. (2021) also confirm that the use of modern clean technologies can drastically reduce the health-related consequences of climate change.

Furthermore, the coefficient of GDP per capita is positive and significant, indicating that a rise in output production of a country, per head, will enhance their living standards as there will be more income in the hands of households. Similar positive and significant

[1]The results for the Prais-Winstein regressions are documented in the Appendix.

signs are shown for the coefficients of economic freedom, FDI, and trade openness. We opine from these results that improving the quality of life would require significant amount of both local and foreign investments in a country. Moreover, the ability of countries to attract these investments through its trade and economic policies is also a vital factor in improving human development. More importantly, the quality of institutions embedded in a country has a direct impact on the rate of investments a country would experience, which in turn can serve as a viable medium to significantly improve quality of life.

Our findings do not differ from prior studies that have also shown how economic and governance indicators improve human development (Aluko and Opoku, 2022; Opoku et al., 2022). Meanwhile, the results of inflation and population growth appear to have negative coefficients. We deduce from the output of the regression that increases in population and cost of living will trigger a reduction in human development. This does not come as a shock as we opine that inflation affects the purchasing power of money due to erosion of disposable income. Thus, an increase in inflation will ultimately have a devastating effect on the quality of life of the populace, particularly for large households, where there is a high number of people jostling to spend the meagre income.

Does the effect of climate change on quality of life differ materially by region? We now turn attention to answering this question by considering the results obtained for the regions of Africa. The outputs are shown in tables 10 and 11 for the SSA and North African regions, respectively. In table 10, we find that carbon emissions and ecological footprint have negative and statistically significant effect on the quality of life in the SSA region. This finding suggests that higher levels of environmental degradation restrict human development in the region. A further implication of this finding is evident in the level of malnutrition, poverty, and forced migration prevalent among the citizens of countries within this region. The coefficients of other explanatory variables such as GDP

Table 9: Climate change and quality of life in Africa using IV-Lewbel 2SLS

DV = HDI	Model 1	Model 2	Model 3	Model 4	Model 5
EFP	-0.120**	-0.330*		-0.235***	-0.334*
	(0.211)	(0.013)		(0.011)	(0.005)
CO_2	-0.181**		-0.225**	-0.040***	-0.229**
	(0.003)		(0.011)	(0.129)	(0.104)
Renewable	0.341***	0.503*	0.331*	0.336*	
	(0.101)	(0.012)	(0.040)	(0.013)	
GDP per capita	0.476***	0.396**	1.153**	1.337**	
	(0.003)	(0.019)	(0.110)	(0.022)	
Economic freedom	0.224**	0.337**	0.322	0.331*	
	(0.019)	(0.055)	(0.004)	(0.053)	
FDI	0.326*	1.301*	0.445**	1.657*	
	(0.101)	(0.211)	(0.013)	(0.322)	
Trade openness	0.232	0.336***	0.224*	0.995**	
	(0.105)	(0.048)	(0.115)	(0.104)	
Inflation	-0.033*	-0.503	-1.320***	-0.221	
	(0.014)	(0.211)	(0.120)	(0.113)	
Population growth	-0.410***	-1.098***	-0.009	-1.215*	
	(0.161)	(0.220)	(0.103)	(0.101)	
Control of corruption	0.221***	1.335*	0.336**		0.775*
	(0.152)	(0.012)	(0.104)		(0.341)
Political stability	0.390*	0.300***	0.330		0.631**
	(0.216)	(0.220)	(0.008)		(0.011)
Regulatory quality	0.334**	0.501	0.214**		0.440*
	(0.001)	(0.093)	(0.002)		(0.129)
Rule of law	0.226*	0.201**	0.331		0.562**
	(0.005)	(0.103)	(0.023)		(0.008)
Government effectiveness	0.873***	0.401	1.331***		0.102
	(0.224)	(0.113)	(0.016)		(0.015)
Constant	33.902**	12.151**	22.360***	24.654***	19.265***
	(1.335)	(0.310)	(0.295)	(1.005)	(0.143)
R^2	0.402	0.351	0.286	0.341	0.297

Notes: This table presents the main regression results for the nexus between climate change and quality of life in Africa. Estimation is performed by IV-Lewbel 2SLS regression, with coefficients computed using standard errors robust to heteroskedasticity and clustered at the firm level. Standard errors are shown in parentheses. The outcome variable is HDI which is a proxy for quality of life. The key explanatory variables are climate change proxied with carbon emission and ecological footprint. Other explanatory variables are grouped into two: (i) economic and development (E&D) indicators and (ii) political, governance and institutional (PGI) factors. Model 1 includes all variables in the estimation. Model 2 includes all variables except carbon emission (CO_2). Model 3 includes all variables except ecological footprint (EFP). Model 4 includes all variables except PGI factors and model 5 captures all variables except E&D factors. All regressions control for country fixed effects, and year fixed effects as well as an intercept term. *, **, and *** denote significance at 10%, 5% and 1%, respectively. Definitions of variables and data sources are provided in table 1.

Table 10: Climate change and quality of life in SSA using IV-Lewbel 2SLS

DV = HDI	Model 1	Model 2	Model 3	Model 4	Model 5
EFP	-0.770*	-0.097***		-0.591**	-0.516
	(0.034)	(0.146)		(0.200)	(0.153)
CO_2	-0.562***		-0.687***	-0.120***	-0.698*
	(0.220)		(0.090)	(0.223)	(0.071)
Renewable	0.214*	0.409	0.453*	0.138*	
	(0.005)	(0.213)	(0.007)	(0.003)	
GDP per capita	0.337**	0.043*	0.424	1.253	
	(0.101)	(0.007)	(0.061)	(0.100)	
Economic freedom	0.409	0.363*	0.766***	0.460**	
	(0.022)	(0.105)	(0.020)	(0.109)	
FDI	-0.551***	-0.463	-0.531	-0.976*	
	(0.101)	(0.300)	(0.013)	(0.113)	
Trade openness	0.413	0.566*	0.378*	0.879**	
	(0.290)	(0.102)	(0.150)	(0.221)	
Inflation	-0.047*	-0.150***	-1.277*	-0.034	
	(0.108)	(0.002)	(0.041)	(0.001)	
Population growth	-0.500**	-0.320*	-0.359	-0.762*	
	(0.009)	(0.012)	(0.045)	(0.055)	
Control of corruption	0.302	0.536*	0.612*		0.518
	(0.031)	(0.130)	(0.080)		(0.216)
Political stability	0.278*	0.043**	0.463		0.333*
	(0.003)	(0.009)	(0.101)		(0.011)
Regulatory quality	0.417*	0.365	0.332*		0.752***
	(0.036)	(0.102)	(0.140)		(0.013)
Rule of law	0.680	0.432*	0.409***		0.495*
	(0.005)	(0.001)	(0.055)		(0.201)
Government effectiveness	0.437**	0.264	0.573*		0.361
	(0.092)	(0.109)	(0.022)		(0.219)
Constant	27.30*	32.25	19.00***	22.685**	24.39*
	(0.578)	(0.420)	(0.157)	(0.990)	(0.201)
R^2	0.504	0.435	0.442	0.501	0.453

Notes: This table presents the main regression results for the nexus between climate change and quality of life in sub-Saharan Africa. Estimation is performed by IV-Lewbel 2SLS regression, with coefficients computed using standard errors robust to heteroskedasticity and clustered at the firm level. Standard errors are shown in parentheses. The outcome variable is HDI which is a proxy for quality of life. The key explanatory variables are climate change proxied with carbon emission and ecological footprint. Other explanatory variables are grouped into two: (i) economic and development (E&D) indicators and (ii) political, governance and institutional (PGI) factors. Model 1 includes all variables in the estimation. Model 2 includes all variables except carbon emission (CO_2). Model 3 includes all variables except ecological footprint (EFP). Model 4 includes all variables except PGI factors and model 5 captures all variables except E&D factors. All regressions control for country fixed effects, and year fixed effects as well as an intercept term. *, **, and *** denote significance at 10%, 5% and 1%, respectively. Definitions of variables and data sources are provided in table 1.

Table 11: Climate change and quality of life in Northern Africa using IV-Lewbel 2SLS

DV = HDI	Model 1	Model 2	Model 3	Model 4	Model 5
EFP	0.168***	-0.273		0.093*	0.660***
	(0.320)	(0.051)		(0.004)	(0.012)
CO_2	0.189***		0.729*	0.250**	0.721*
	(0.207)		(0.103)	(0.002)	(0.342)
Renewable	0.355	0.429*	0.450	0.044*	
	(0.110)	(0.003)	(0.102)	(0.052)	
GDP per capita	0.013**	0.346**	0.975*	0.865**	
	(1.441)	(0.230)	(0.021)	(0.014)	
Economic freedom	0.046**	0.572	0.463	0.277	
	(1.990)	(0.008)	(0.011)	(0.005)	
FDI	0.012	0.590*	0.394*	0.448***	
	(0.370)	(0.012)	(0.210)	(0.103)	
Trade openness	0.048*	0.205**	0.042*	0.679*	
	(1.079)	(0.116)	(0.001)	(0.024)	
Inflation	-0.125	-0.338	-0.943**	-0.543	
	(0.030)	(0.032)	(0.003)	(0.022)	
Population growth	-0.011	-0.725*	-0.651	-0.504*	
	(0.034)	(0.103)	(0.023)	(0.229)	
Control of corruption	0.126	0.672**	0.506*		0.450*
	(0.204)	(0.021)	(0.024)		(0.003)
Political stability	0.376***	0.463*	0.473		0.583
	(3.008)	(0.016)	(0.012)		(0.220)
Regulatory quality	0.254*	0.923	0.519**		0.674*
	(0.101)	(0.014)	(0.331)		(0.315)
Rule of law	0.099**	0.617*	0.537		0.287**
	(0.038)	(0.034)	(0.002)		(0.011)
Government effectiveness	0.449***	0.268	0.450*		0.340***
	(0.026)	(0.011)	(0.031)		(0.103)
Constant	25.63**	20.11*	19.66***	18.35**	25.31*
	(0.220)	(0.042)	(0.302)	(0.510)	(0.204)
R^2	0.327	0.376	0.351	0.470	0.399

Notes: This table presents the main regression results for the nexus between climate change and quality of life in Northern Africa. Estimation is performed by IV-Lewbel 2SLS regression, with coefficients computed using standard errors robust to heteroskedasticity and clustered at the firm level. Standard errors are shown in parentheses. The outcome variable is HDI which is a proxy for quality of life. The key explanatory variables are climate change proxied with carbon emission and ecological footprint. Other explanatory variables are grouped into two: (i) economic and development (E&D) indicators and (ii) political, governance and institutional (PGI) factors. Model 1 includes all variables in the estimation. Model 2 includes all variables except carbon emission (CO_2). Model 3 includes all variables except ecological footprint (EFP). Model 4 includes all variables except PGI factors and model 5 captures all variables except E&D factors. All regressions control for country fixed effects, and year fixed effects as well as an intercept term. *, **, and *** denote significance at 10%, 5% and 1%, respectively. Definitions of variables and data sources are provided in table 1.

per capita, economic freedom, and renewable energy are found to be largely positive and statistically significant, confirming earlier results that living standards in the face of environmental degradation, can only be improved if there are strong institutional qualities. On the contrary, we find that population growth, inflation and FDI hinder quality of life in sub-Saharan Africa because their coefficients are found to be negative, indicating that an increase in any of these measures does not necessarily translate to improved quality of life in the SSA region.

With respect to the results for the North African region, it is interesting to see strong positive support for the role of environmental degradation on the quality of life in the region. This stems from the positive and statistically significant coefficients (at 1% level) exhibited by the proxies of carbon emissions and ecological footprint in the model. Our result shows that a percentage increase in carbon emission cause a rise in HDI by about 19% while ecological footprint causes HDI to rise by about 17%. This connotes that environmental degradation in the Northern region of Africa is, perhaps, a blessing to the citizens as it has significantly improved their living standards over the years. Another interesting angle to this might be due to the institutional qualities. Hence, we take a look at the coefficients of these indicators. Similar finding is observed as the coefficients of regulatory quality are positive and statistically significant at 1% level. This indicates that better institutional qualities in the face of environmental degradation could improve the quality of life (Asongu and Nwachukwu, 2017). Meanwhile, just like the preceding results, we also find negative and statistically significant coefficients for population growth and inflation, thus affirming previous stance that these variables cause a reduction in HDI.

6 Conclusion, policy implications, and future research

This study sheds light on the nexus between climate change and quality of life in Africa and its regions (North Africa and sub-Saharan Africa), by examining the impacts of environmental degradation, as measured by carbon emissions and ecological footprint, on human development. Specifically, our study covers 31 African countries over the period 2000 to 2018, offering interesting new insights to the existing literature, which yield important policy recommendations to both national and international stakeholders, as well as governmental and non-state agencies.

Using different estimation methods to capture cross-sectional dependence, endogeneity, and causality, we find long-term relationship between climate change and quality of life in Africa, especially in the SSA region. In addition, using heteroskedasticity-based instrumental variable regression analysis with robust standard errors, we establish the impact of climate change variables on human development in the continent. In general, we find that ecological footprint and carbon emissions negatively affect quality of life of African citizens. Burgeoning studies in the literature also provide evidence that climate change hampers living standards; see, for example, Ambrey and Daniels (2017) and Opoku et al. (2022). We conjecture that this evidence may be driven by increased mineral extraction, greenhouse gas emissions, and deforestation, amongst other factors. This situation connotes that environmental degradation in the continent has an increasingly deleterious effects on the well-being and survival of the populace. This finding emboldens us to prescribe that reducing the level of environmental degradation should be put at the forefront any SDG agenda for Africa, as we view this to a more sustainable mechanism for improving quality of life in that continent. Thus, implementing adaptive and mitigating strategies, such as access to clean and modern energy, providing environmental-friendly technological innovations, afforestation, and reduction in fossil fuel exploration, will not only help in the fight against climate crisis, but will also help to attain better quality of life for African citizens.

We further our analysis by investigating whether the baseline results may differ by region and find that in the SSA region, the effects of carbon emissions and ecological footprint on the quality of life is negative. Additionally, the quality of institutions, trade openness, and economic freedom are positive, suggesting that these indicators can foster living standards despite the negative effects of environmental degradation. Studies have shown that SSA suffers from poor governance (institutional) quality, as previously elaborated on in Section 2. Hence, we propose that improving the quality of governance should be adopted as a suitable mechanism for improving quality of life in Africa, especially in SSA, even in the face of climate change. Our results also show that population growth and inflation have damaging effects on HDI. Our finding is in tandem with prior studies that have argued that an increase in the cost of living and population, without a commensurate increase in disposable income, is a dangerous path to economic downturn. Consequently, we submit that national governments in Africa should introduce family planning initiatives to deal with ensuing population crisis and sound monetary policies to abate rising inflation. As policy recommendations, both strategies have the potential to improve living standards in the SSA region, despite the climate crisis ravaging the region.

Further, we illuminate the effect of climate change on quality of life in the Northern region. Although our earlier findings suggest negative effects for the whole of Africa and the SSA region, it is interesting to find strong positive evidence that carbon emissions and ecological footprint improve human development in North Africa. We argue that the positive impact is perhaps due to strong governance mechanism in the region compared to the SSA region. Our result confirms this by showing that an increase in governance quality of a region can further aid human development. As already discussed, several studies have shown that the effects of climate change can be less harmful if a country has sound governance environment. Hence, institutional quality plays a crucial role in conditioning the impact of climate change on human development in NA.

Our results render important policy implications to international organisations, national and sub-national governments in Africa. A crucial implication of our findings is that the nexus between climate change and quality of life in Africa is heterogeneous and time-varying. Therefore, policy initiatives toward mitigating the effects of climate crises should consider regional dynamics of the continent. Given our results, we recommend that policymakers focus on tailor-made sustainable climate strategies that would, on one hand, alleviate the deleterious consequences of environmental degradation and, on the other, improve the quality of life of African citizens.

Lastly, we contend that our study opens a pathway for future research. Our paper has examined the relationship between climate change variables and quality of life, using human development index. A potential avenue for further studies is considering other dimensions of human development. On the climate change variables, future research may also consider micro-level data such as greenhouse gas emission and nitrogen oxide. Furthermore, upcoming research can examine the differential consequences of climate change on men versus women using Gender Development Index (GDI).

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Appendix A Additional tables and figures

Table A.1: African countries included in the analysis.

Algeria, Angola, Botswana, Burkina Faso, Cameroon, Congo, Cote d'Ivoire, Democratic Republic of Congo, Egypt, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Madagascar, Malawi, Mali, Morocco, Mozambique, Namibia, Niger, Nigeria, Senegal, Sierra Leone, South Africa, Togo, Tunisia, Uganda, Zambia, and Zimbabwe.

Table A.2: Climate change and quality of life in Africa using Prais-Winstein regression

DV = HDI	Model 1	Model 2	Model 3	Model 4	Model 5
EFP	-0.331*	-0.487*		-0.449**	-0.278***
	(0.029)	(0.120)		(0.233)	(0.521)
CO_2	-0.514**		-1.367*	-0.308*	-0.308*
	(0.120)		(0.448)	(0.019)	(0.221)
Renewable	0.229*	0.440	0.213*	0.247***	
	(0.004)	(0.001)	(0.024)	(0.093)	
GDP per capita	0.335*	0.291*	0.941*	1.478*	
	(0.022)	(0.022)	(0.033)	(0.236)	
Economic freedom	0.146**	0.476*	0.552**	0.999*	
	(0.110)	(0.005)	(0.100)	(0.004)	
FDI	0.065*	0.631	0.229*	0.875	
	(0.231)	(0.028)	(0.013)	(0.100)	
Trade openness	0.448	0.409**	0.239*	0.557**	
	(0.005)	(0.011)	(0.005)	(0.010)	
Inflation	-0.370	-0.335	-3.162**	-0.336**	
	(0.030)	(0.023)	(0.031)	(0.243)	
Population growth	-0.121*	-0.620**	-0.440	-1.362*	
	(0.006)	(0.194)	(0.016)	(0.001)	
Control of corruption	0.332*	1.690*	0.643**		0.578*
	(0.015)	(0.012)	(0.449)		(0.139)
Political stability	0.401*	0.562*	0.783		0.265**
	(0.020)	(0.138)	(0.022)		(0.033)
Regulatory quality	0.263	0.651**	0.740*		0.654**
	(0.010)	(0.013)	(0.009)		(0.026)
Rule of law	0.332	0.430**	0.418		0.568*
	(0.051)	(0.223)	(0.100)		(0.039)
Government effectiveness	0.344**	0.784**	0.563**		0.481
	(0.120)	(0.00)	(0.331)		(0.032)
Constant	11.47*	9.12*	12.64**	13.24**	10.96*
	(0.452)	(0.025)	(0.190)	(0.600)	(0.215)
R^2	0.328	0.285	0.332	0.429	0.340

Notes: This table presents the main regression results for the nexus between climate change and quality of life in Africa. Estimation is performed using Prais-Winstein regression, with coefficients computed using standard errors robust to heteroskedasticity and clustered at the firm level. Standard errors are shown in parentheses. The outcome variable is HDI which is a proxy for quality of life. The key explanatory variables are climate change proxied with carbon emission and ecological footprint. Other explanatory variables are grouped into two: (i) economic and development (E&D) indicators and (ii) political, governance and institutional (PGI) factors. Model 1 includes all variables in the estimation. Model 2 includes all variables except carbon emission (CO_2). Model 3 includes all variables except ecological footprint (EFP). Model 4 includes all variables except PGI factors and model 5 captures all variables except E&D factors. All regressions control for country fixed effects, and year fixed effects as well as an intercept term. *, **, and *** denote significance at 10%, 5% and 1%, respectively. Definitions of variables and data sources are provided in table 2.

Table A.3: Variance decomposition

Period	S.E.	Human development index	Ecological footprint	Carbon emissions
Africa				
1	0.0078	100.000	0.0000	0.0000
2	0.0122	99.9117	0.0181	0.0702
3	0.0155	99.8636	0.0159	0.1205
4	0.0183	99.8256	0.0155	0.1589
5	0.0206	99.7940	0.0149	0.1911
6	0.0227	99.7649	0.0145	0.2205
7	0.0246	99.7369	0.0143	0.2488
8	0.0264	99.7092	0.0141	0.2767
9	0.0280	99.6813	0.0140	0.3047
10	0.0295	99.6531	0.0140	0.3329
SSA				
1	0.0083	100.000	0.0000	0.0000
2	0.0129	99.9413	0.0112	0.0474
3	0.0163	99.9088	0.0113	0.0798
4	0.0192	99.8819	0.0136	0.1045
5	0.0216	99.8588	0.0160	0.1251
6	0.0238	99.8368	0.0190	0.1442
7	0.0257	99.8151	0.0223	0.1626
8	0.0275	99.7930	0.0260	0.1811
9	0.0291	99.7703	0.0299	0.1998
10	0.0307	99.7469	0.0341	0.2190
North Africa				
1	0.0023	100.000	0.0000	0.0000
2	0.0039	99.2197	0.1945	0.5858
3	0.0052	98.5528	0.1583	1.2888
4	0.0062	97.5947	0.3437	2.0616
5	0.0071	96.2610	0.8438	2.8952
6	0.0078	94.6989	1.5469	3.7543
7	0.0085	92.9535	2.4271	4.6194
8	0.0092	91.1149	3.4139	5.4712
9	0.0097	89.2342	4.4687	6.2971
10	0.0103	87.3595	5.5524	7.0881