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ARTICLE

Moderating Effect of Institutional Quality on the Population Growth-Environmental Sustainability Nexus in Sub-Saharan Africa

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Abstract

This study examines the moderating effect of institutional quality on the population growth-environmental sustainability nexus in Sub-Saharan Africa (SSA) over the period 2000 – 2020. Applying the Generalized Method of Moments (GMM) estimation technique and a Granger causality test to check if there exists any causality between population growth and emission levels, the findings indicate that population growth positively impacts on emission level in Sub-Saharan Africa, thus, affecting the environment negatively. However, its observed effect was statistically insignificant due to the interaction of institutions with population growth which proved significant. The results further indicate that other macroeconomic variables impacting positively and significantly on emission level in SSA are economic complexity index and per capita GDP. The study also establishes that there is no causal relationship between population growth and emission level in SSA. Lastly, the study finds that institutions play a vital role in reducing emission levels in the zone. It is therefore recommended that the government should vigorously pursue population and environmental policies directed at promoting environmental sustainability by controlling population, and promoting sustainable environmental practices.

Key words: Institutions; Population; Environmental sustainability; Difference GMM; SSA

JEL Classification: O43; 044; J130; J180

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1. Introduction

Population is a minefield in the global environmental movement. Many environmental groups and leaders have stopped trying to cross this minefield, because negotiating it is risky. However, concealing the reality of the situation is focusing on other important environmental issues such as global warming, sprawl, water and air pollution, the loss of agricultural land, biodiversity, and animal habitat while neglecting the main issue of population. The struggle for survival, to make use of nature's plentiful resources, and to care for the expanding human population has always been crucial to human evolution. However, using environmental resources for human use is nothing new (**Wolman, 1993**). The human species has faced environmental issues in one way or another throughout the majority of its tenure on this planet. The initial issue was the lack of local resources including food, housing, and other necessities that were at least partially given by nature (**Fisher & Peterson, 1976**). **Hunter (2000)**, however, asserts that what is novel is the degree of resource consumption required by a "larger-than-ever" global population, which is currently growing by roughly 80 million people each year (**World Bank, 2022**).

Life does not exist in a vacuum; it follows that human existence will have some relationship with the system supporting it (i.e. the environment). Where the human struggle for survival involves burning energies to harness resources from such system, it follows again that human economic processes generate wastes that are ejected into the environment which serves also as resource base, and a life support system. The apparently obvious implications are that more people on earth would require greater productive and consumption processes. On the one hand, it is anticipated that as the human population grows, more resources will need to be exploited for survival, and the objects of labour—primarily represented by the natural environment—will be subjected to additional stress and pressure. Two significant factors raise and exacerbate a sustainability dilemma. First, the fact that so many of the resources currently being used are finite and unreplaceable shows that we are getting close to the point where our planet's natural resources can no longer be used indefinitely. Second, the generation of wastes by these human economic processes as well as increased use of facilities and services of the environment, risk the danger of deteriorating the quality of the environment; human existence is threatened by a process that in many ways pollutes its life support system.

From the viewpoint of one person, the size of the earth seems immense. The natural resources of the world have no apparent boundaries. But the world does not consist of just one person; there are currently over eight billion of us, and we are growing by a million people every 4.8 days on average (**US Census Bureau, 2011**). In contrast to 1950, when the world's population doubled, today some people have seen the population triple during their lifetimes (**Cohen, 2003**). Unfortunately, this is not without implications, as it adds to the uncertainties about human survival in the future, especially in an era where global human population needed only the second half of 20th century and early 21st century to more than triple what it had been for the whole of preceding years of human evolution. According to **Hotelling (1931)**, concerns over the world's diminishing mineral resources, forested areas, and other exhaustible resources have prompted calls for restrictions on their utilisation. The conservation movement has its roots in the belief that these products are currently too inexpensive for the benefit of future generations, that they are being exploited selfishly at an excessive rate, and that as a result of their excessive affordability, they are being produced and consumed wastefully.

The environment was being harmed by modern industrialization and population increase as early as the middle of the nineteenth century, according to writers. Unchecked population growth would exceed the capacity of the planet to provide enough food, according to Robert Malthus, whose' "Essay on the Principle of Population" has either been extensively praised or ridiculed. Malthus started a discussion on carrying capacity, and his influence can still be felt today. However, this perspective has come under fire for its too simplistic focus on population size as the only factor influencing resource change. To some other researchers and theorists, however, the Malthusian ideology about the impact of human population and activities on the earth is rather defective and implausible. In fact, Thomas Malthus is cited by **Zhou (2009)** as an example of a scholar who had negative views on how population expansion will affect industrialisation and ultimately the environment.

The sustainability of the planet's life support systems and human well-being are both impacted by socioeconomic and environmental effects of population growth (**Engelman, 1997**). Farmland can get degraded, which can lower or even completely eliminate its productivity. According to **Coffin (1993)**, this is due to the fact that satisfying the resource needs of a growing population ultimately necessitates some type of land-use change, whether to increase food production by clearing forests, to intensify production on already-cultivated land, or to build the infrastructure required to support increased population. **Clarke (1996)** stated that fast population expansion and global environmental change are two themes that have attracted major public attention during the past several decades. Population rise became a global public policy challenge during the mid-twentieth century as mortality drops in many developing nations were not matched by reductions in fertility, resulting in record growth rates. The public's awareness of environmental change has increased significantly since 1970, when observable levels of environmental degradation and the development of satellite photography to support environmental study fuel popular concern.

The discussion of "sustainable development," which aims to fulfil the needs and aspirations of the current population without sacrificing the welfare of future generations, frequently includes both population and environmental concerns today (**WCED, 1988**). Without environmental sustainability, there can be no sustainable development. The fact that "safeguarding the environment" through a set of specified practises is one of the main objectives of both the current Sustainable Development Goals (SDGs) and the previous Millennium Development Goals (MDGs) of the United Nations comes as no surprise. The concept of sustainability is inextricably linked to the prudent management of the planet's natural resources.

Population stabilisation may minimise the influence of people on the environment, with the idea being that less population means less strain on the land, air, and water environments (**Hunter, 2000**).

The precise interaction between population dynamics and the environment is therefore complicated and poorly understood. The multiplicity of "mediating" factors that eventually shape this linkage make things more difficult. These include technological aspects (such as ways of producing energy), institutional and political aspects (such as environmental control), and cultural aspects. These complexities, notwithstanding, it is becoming increasingly clear that population growth has a powerful effect on the natural environment. Consequently, investigations have continued at local, regional and global levels.

With the sustainability problem being most dreadful alongside its incriminating consequences, it is imperative to carry out this investigation, to examine the population-environment interactions in the most populous region in Africa - Sub-Saharan Africa. As much as the increase in population undoubtedly has its unavoidable impact on the environmental sustainability problem, it is imperative to consider the role of institutions in minimizing or controlling to some extent, the impacts of the increasing population on the environment via sound and consistent policies. Therefore, this study is conducted to investigate what is known about the association between population dynamics and the natural environment, and the role of institutions in this association. That is, to determine the impact of population changes on the environment and examine the moderating role of institutional quality on the population growth- environmental sustainability nexus in Sub-Saharan Africa, drawing from existing demographic and environmental literature.

Man's activities are driven mainly by his needs, desires and interest (**Smith, 1776**). His primary needs are food, shelter and clothing which are all gotten from the environment's resources. Today, a variety of human activities and the sheer weight of human population are waging unprecedented war on the natural environment that we share with all life forms on this planet (**Engelman, 1997; Engelman, Cincotta, Dye, Gardner & Wisenwski, 2000**). Our demands on the world are beyond its natural boundaries due to the extraordinary increase in population. While a lot of positive efforts are being made to ensure the sustainability of humans on earth, the problem of having too many people has made the lasting remedies hard to discover. In 2020, the changes in population status of the Sub-Saharan Africa regions were recorded as shown in Table.

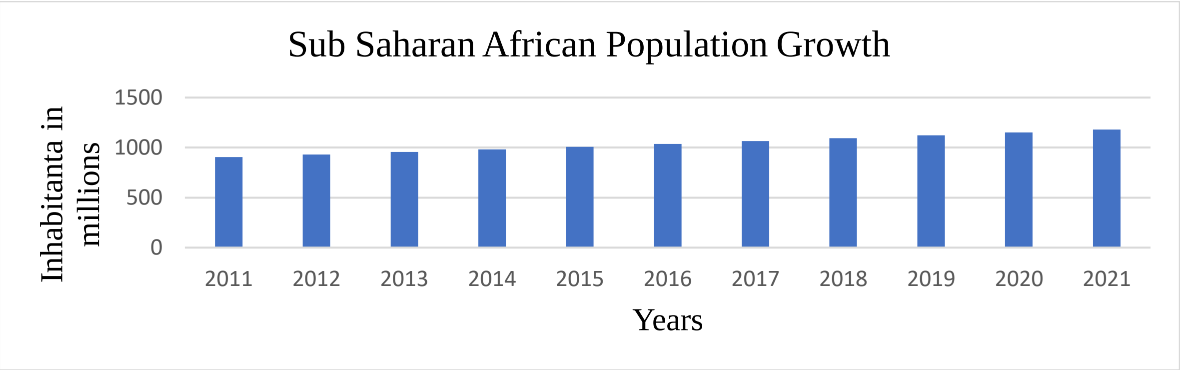
The Sub-Saharan African population has more than doubled since its discovery in the fifteenth century. With the data obtained from past censuses, the Sub-Saharan African population increased steadily from 904.28 million in 2011 to 1,181.16 billion in 2021. The region has one of the fastest growing populations in the world with estimated growth rate of about 2.6%. The trend of population growth in Sub-Saharan Africa from 2011 till 2021 is shown in the Figure 1.

Table 1: Changes in population status of the Sub-Saharan Africa regions

Region	Population (2019)	Population (2020)	Yearly Change (%)	Net Change	Fertility Rate (%)
Eastern Africa	433,904,943	445,405,606	2.65	11,500,663	4.434965689
Western Africa	391,440,157	401,861,254	2.66	10,421,097	5.183416088
Middle Africa	174,308,432	179,595,134	3.03	5,286,702	5.531989159
Southern Africa	66,629,895	67,503,635	1.31	873,740	2.499612524

Source: Statista, 2020

Figure 1: Trend of population growth in Sub-Saharan Africa from 2011-2021



Source: Authors' Excel Computation Using Data from World Bank

By the middle of the century, Sub-Saharan Africa's population is expected to nearly quadruple to more than two billion people if current trends continue. The region's population is expanding three times faster than the worldwide average, and by 2070, it will surpass Asia as the world's most populous region, based on UN projections. Of course, the issue is not that the population is increasing; rather, it is that throughout time, this increase has been accompanied by some environmental problems, the majority of which are getting worse. Most times, the evidence indicates that anthropogenic activities including trade, agriculture, forestry, deforestation, the use of fossil fuels, and other activities linked to economic growth are to blame for the production of greenhouse gases, such as CO2. However, anthropogenic activities increase as the human population grows, which results in an increase in CO2 emissions. For instance, **Liddle (2015)** argues that rising population over the coming decades may result in higher energy demand and higher CO2 emissions. The world ranks of some Sub-Saharan African countries by emission levels in 2016 is given in the Table 2.

Table 2: World rank of Sub-Saharan African countries by emission levels in 2016

Country	Region	Rank	CO2 Emission (Tons)	Population Change (%)
Nigeria	Western Africa	43rd	82,634,214	0.70
Angola	Middle Africa	75th	30,566,933	3.13
Kenya	Eastern Africa	91st	16,334,919	3.60
Ghana	Western Africa	94th	14,469,986	3.54
Sudan	Eastern Africa	96th	13,294,106	4.18
Ethiopia	Eastern Africa	98th	10,438,855	4.03
Zimbabwe	Southern Africa	100th	10,062,628	-4.17
Cote d'Ivoire	Western Africa	101st	10,056,492	1.16
Tanzania	Eastern Africa	103rd	9,731,560	2.50
Cameroon	Western Africa	104th	9,454,331	2.21
Benin	Western Africa	120th	6,563,709	4.13

Source: Worldometer, 2016

Concern over the rate at which CO2 emissions are increasing along with the zone's population growth develops at the same time. As a result, it is expected that the rapid population expansion will cause the zone's per capita emissions to increase. Expectedly, this will lead to a large increase in overall CO2 emissions. The National Aeronautics and Space Administration (NASA) recently assessed that methane, a chemically reactive GHG, has far greater impacts than previously thought. The acid rain that sulphur dioxide causes has a negative impact on both terrestrial and aquatic ecosystems (**National Pollutant Inventory, 2006**; **Joseph, 2019**). Evidence from the literature has demonstrated that human activities are the primary cause of the production of greenhouse gases (GHG) such CO2 (carbon dioxide) and SO2 (sulphur dioxide), which are the two main causes of climate change.

Although the African continent contributes a very small amount of GHGs to global emissions (**Intergovernmental Panel on Climate Change, 2001**), the primary reasons of GHG emission in Africa have not yet been thoroughly identified in the literature. Researchers have found that the agricultural industry has recently faced environmental pollution issues that can be attributed to new production practises and expanded production structures imbibed to meet the growing population and the demand for new energy globally (**Narayan et al., 2008**; **Agbonlahor & Phillip, 2015**; **Siyan & Adegoriola, 2017**). The **Environmental Health Committee (2004)** and **Wood (2004)** reports state that these gaseous contaminants have reached alarming levels. The health of the population is negatively impacted by exhaust from all combustion engines that contain these pollutants, which in turn has a negative impact on their productivity. When applied to the larger environment, engine combustion causes the build-up of carbon dioxide in the atmosphere and is to blame for climatic shifts (**Gislason, 2006**). Due to their ability to trap heat without releasing it as infrared or thermal radiation, GHGs like carbon dioxide and methane are among the air pollutants that contribute significantly to global warming (**Oguntoke & Adeyemi, 2017**).

From the foregoing, it suffices to say the obvious that an investigation into the sustainability problem is both imperative and urgently called for. However, only few studies have been done on Sub-Saharan Africa, despite the fact that many have been done on other regions of the world. It is on these premises that this study is developed to empirically address the following research questions: (i) what is the impact of population growth on environmental sustainability in Sub-Saharan Africa?; (ii) is there any causal relationship between population growth and emission level in Sub-Saharan Africa?; and (iii) what is the moderating role of institutional quality on the population growth-environmental sustainability nexus in Sub-Saharan Africa?

2. Review of related literature

Some theorists contend that rapid population expansion is a direct source of environmental deterioration, meaning that other factors influence the ecosystem indirectly through population growth. Rapid population expansion serves to amplify the environmental effects of the root causes, as opposed to eventually generating environmental degradation. These factors, which differ from place to region, include resource demand from wealthy countries, poverty, conflict, polluting technologies, and distorting policies. **Shaw (1989)** contends that it is possible to reconcile the two competing ideas, which both exonerate population expansion from any environmental harm and the other blames it for it. Population serves to amplify the effects of the root causes, but because it is a secondary factor, it does not directly contribute to environmental deterioration. By affecting the root causes, population growth might make things worse. Population growth would not matter much if the underlying factors were not active. Consider how the environment would not be impacted by the number of users if all polluting technologies were made pure. However, population expansion makes the issue worse because the root causes have not been addressed (**Shaw, 1989**). If a polluting technology is utilized by many individuals, the deterioration it causes will be greater than if it is only used by a few.

Numerous research investigations have been carried out in this field as a result of the population-environmental sustainability nexus having sparked discussions throughout the years. The first study to look into the connection between energy use and income was conducted by Kraft and Kraft in 1978. Utilising data from the United States from 1947 to 1974, the study was carried out. Since the publication of this study, a number of empirical studies have been conducted using various methodologies and sample sizes to investigate the causality and/or relationship between energy use, trade openness, economic growth, population density, and CO2 emissions in various nations and regions of the world. In California, **Cramer (1998)** identified county-level correlations between emissions, population density, regulatory initiatives, and other relevant variables. Though population expansion affects different types of pollutants differently, results point to a 7.5–8% rise in emissions for every 10% increase in population. This is also consistent with information from **Khan et al. (2013)**, who reported that Pakistan's energy use from 1975 to 2011 dramatically increased CO2 emissions.

Begum et al. (2015) looked at how population growth, energy use, and GDP growth affected CO2 emissions. The ARDL bound testing method is used in the study for the 1970–2009 time frame. The findings showed that while population growth rate did not significantly affect per capita CO2 emissions, per capita energy consumption and GDP did have a long-term favourable impact. **Ohlan (2015)** examined the effects of India's population density, energy use, trade openness, and economic growth on CO2 emissions between 1970 and 2013. The study found that, in both the long- and short-term, population density, economic growth, and energy consumption have a considerable beneficial impact on CO2 emissions. However, it has been shown that India's population is the biggest cause of CO2 emissions. **Mamudul et al. (2016)** used time series data for the years 1970–2012 for China, Brazil, India, and Indonesia to assess the effects of energy use and population growth on CO2 emissions. For related time series data for the top emerging CO2 emitter countries in both the short run and the long run, the study applied the ARDL bound test approach while taking into account both the linear and non-linear assumptions. The findings showed that as wealth and energy consumption rose in the four countries, CO2 emissions also rose dramatically. In Brazil and India, the link between CO2 emissions and population increase was shown to be considerable, whereas in China and Indonesia, it was both short- and long-term inconsequential.

The impact of population growth on carbon emissions in Nigeria is estimated by **Casey and Galor (2016)** using the STIRPAT model on an unbalanced annual panel of cross-country data from 1950 to 2010. Before taking into account the feedback from environmental damages to economic damages, the results demonstrate that population policies have a favourable impact on economic outcomes. Population measures would undoubtedly continue to produce these feedback benefits, but they are not required to produce favourable economic results. Similar to this, **Goodness and Prosper (2017)** used the dynamic panel threshold approach to examine how population growth and economic growth affect CO2 emissions. Data from a panel of 31 developing nations form the basis of the study. According to the findings, economic expansion has a negative impact on CO2 emissions under low growth conditions, but a positive impact under high growth conditions, with the marginal impact being greater under high growth conditions. The result establishes a U-shaped association rather than supporting the EKC theory. Population increase and energy use were both found to have a positive and considerable impact on CO2 emissions.

Azam (2018) also looked at the relationship between population growth and the environment for Iran and other MENA nations from 2014 to 2020. According to the study's findings, air pollution and population growth rates are positively and significantly correlated in the MENA region. Additionally, it supports the existence of the kuznets environmental curves for the MENA region's nations. From 2013 to 2017, **Yuan, Hongyuan, and Zeng (2022)** looked at how green innovation affected CO2 emissions in China and how institutional quality had a moderating effect. Green innovation dramatically decreased CO2 emissions, according to the findings. The association between CO2 emissions and green innovation is negatively moderated by institutional quality, which results in a higher CO2 emission decrease when institutional quality is high.

In 39 developing countries (mostly in the Sub-Saharan African region), **Haldar and Sethi (2022)** looked at the role of institutions in reducing the effect of energy consumption on CO2 emissions while controlling for other factors like trade, capital formation, FDI, financial development, and population from 1995 to 2017. The panel grouped-mean and panel quantile regression, mean group (MG), augmented mean group (AMG), common correlated effect mean group (CCEMG) estimator, dynamic system GMM, and were used for the empirical results. The results demonstrated that institutional quality controls energy use and improves its efficiency in reducing CO2 emissions. Energy use by industry and institutional quality have a large and detrimental combined effect on emissions. Long-term CO2 emissions are found to be greatly reduced by using renewable energy. The ARDL approach was used by **Edmund and Tosun (2022)** to look at potential international best practises for achieving sustainable environmental development in China. For this analysis, they used data from China from 1996Q1 to 2018Q4 and appropriate tools including institutions, technical innovation, and renewable energy. The environmental kuznet curve's inverted U-shaped idea is shown to be invalid for the instance of China by the findings. It also said that there was a proven inverse association between the chosen factors and the CO2.

2.1 Limitations of Previous Studies and Value Added

There is no agreement on how to examine people and the environment, as is seen from the examination of the main theoretical frameworks. The discussion has mostly focused on the two opposing ideologies of the classical and neoclassical schools of economics. It has been challenging to obtain consensus since it is difficult to generalise policy from the varied experiences of different locations. Further research is required because the connection is not evident.

It is clear from the foregoing studies that most studies that have been done in this area have focused on the direct impact of population on the environment. No study, to the best of our knowledge, has examined the moderating role of institutions in this relationship. The role of institutions is lacking, yet necessary for any meaningful debate on population and the environment. To fill this gap, this study adopts institutional quality as a moderating variable and examine its role in moderating the population-environmental sustainability nexus in Sub-Saharan Africa.

3. Methodology

3.1 Theoretical Framework

To examine the interaction effect of institutions on the population-environment relationship in Sub-Saharan Africa, this study will draw from the STIRPAT model. The basic STIRPAT model as offered by **Ehrlich and Holdren (1971)**, specified that environmental impact is a function of population, affluence, and technology, that is:

$$I = P \times A \times T \quad (1)$$

Where;

I = Environmental Impact

P = Population

A = Affluence

T = Technology

I = PCT, where C stands for consumption, was the original formula, but IPAT is a better acronym than IPCT since income per capita, not consumption, is what matters and is the easiest to assess. According to **Perman et al. (2003)**, the identity reflects the amount of technical advancement required to maintain the same impact for any given change in population or wealth. The model is critiqued, nonetheless, due to some alleged flaws. It is a deterministic model, for instance, in that it emphasises population increase, prosperity, and technology as the only factors that can precisely account for environmental changes. In reality, events in the actual world don't always happen precisely; instead, they sometimes involve unpredictability and other complications that are not represented in deterministic models like the IPAT identity.

As a result, there has been discussion among environmentalists over the validity of presenting environmental impact as a simple product of independent elements as well as the factors that should be included and their relative importance. Some have highlighted potential interactions between the three factors in particular, while others have wished to draw attention to other elements that were left out of the equation, such as societal and political structures and the potential for both advantageous and detrimental environmental actions (**Alcott, 2010**).

Dietz and Rosa (1994) created the Stochastic Impact by Regression on Population, Affluence, and Technology (STIRPAT) model in an effort to address the shortcomings of the IPAT model. By including additional variables that can have an impact on the environment and utilising the stochastic term, ε, the STIRPAT model represents the randomness and complexity in the real world. Again, the model allows for great flexibility by taking into consideration the non-linearity in environmental impact from one region to another. The non-linear form of the STIRPAT model can be mathematically specified as follows:

$$I = \alpha P\beta\ A\gamma\ T\phi\ \varepsilon \qquad (2)$$

Where;

I = Environmental impact variable

P = Population

A = Affluence

T = Technology

ε = Stochastic term

A natural logarithmic transformation will yield a linearized form of the model as follows:

$$\ln I = \ln\alpha + \beta\ln P + \gamma\ln A + \phi\ln T + \varepsilon \qquad (3)$$

Where the prefix 'ln' represents the natural logarithm of the variables in the STIRPAT model, and α, β, γ, and ϕ represent coefficient parameters

3.2 Model Specification

The model for this investigation will be estimated using the system Generalized Method of Moment (GMM) technique, as described by **Arellano and Bover (1995)**; and **Blundel and Bond (1998)**.

Functional Form:

EML = f (POPG, RQ, POPG*RQ, ECI, EMP, PCGDP, GFCF) (4)

Specifying eq. (3.4) in a panel data and econometric form, gives:

$$\ln EML_{it} = \alpha_i + \lambda_{i1}\ln EML_{it-1} + \beta_{i1}\ln POPG_{it} + \beta_{i2}RQ_{it} + \beta_{i3}(\ln POPG_{it}{*}RQ_{it}) + \beta_{i4}\ ECI_{it} + \beta_{i5}\ln EMP_{it} + \beta_{i6}\ln PCGDP_{it} + \beta_{i7}GFCF_{it} + \Upsilon_{it} + \epsilon_{it} \qquad (5)$$

The above model will be used to answer the objectives of the study. That is, to examine the impact of population growth on emission levels in Sub-Saharan Africa; to determine if there exists any causal relationship between population growth and emissions levels in Sub-Saharan Africa; and examining the moderating effect of institutional quality on the population growth- environmental sustainability nexus in the zone.

Where;

EML = Emission Levels

POPG = Population Growth (annual %)

RQ = Regulatory Quality

ECI = Economic Complexity Index

UNEMP = Unemployment (% of total labour force)

PCGDP = Per Capita Gross Domestic Product

GFCF = Gross Fixed Capital Formation

α = Constant term

ϒ = Unobserved country-specific effect

ϵ = Stochastic error term

EML_{it-1} = Lagged level of EML

$\lambda_{i1}, \beta_{i1}, \beta_{i2,\ldots}\beta_{i8,}$ are the parameters to be estimated

i = Cross-sectional index (i = 1, 2, … 26)

t = The time period (t = 2000, 2001, … 2020)

All variables except economic complexity index and regulatory quality will be transformed into their natural logarithms.

The interaction term ($\ln POPG_{it}{*}RQ_{it}$) is included to ascertain the moderating role of institutional quality on the relationship between population growth and environmental sustainability in Sub-Saharan African countries.

3.3 Method of Estimation

This study employs the Generalized Method of Moments (GMM) estimation technique. In a dynamic panel model, the GMM is a dynamic panel data estimator that is especially designed to compensate for endogeneity of the lagged dependent variable (**Tonuchi & Ariolu, 2021**). When the explanatory variable and the error term have a correlation, this is known as endogeneity. **Hansen (1982)** was the one who first introduced GMM. It employs orthogonality criteria to allow for effective estimate in the presence of unknown form heteroscedasticity.

The general form of the GMM estimation is stated as follows:

$$\ln Y_{it} = \phi\ln Y_{it-1} + \beta X'_{it} + \alpha Z'_{it} + (\Upsilon_i + \epsilon_{it}) \qquad (6)$$

Incorporating our model into this, we have that:

$\ln Y_{it} = \ln EML_{it}$ - represents (N x 1) vector of regress and

$\phi\ln Y_{it-1} = \lambda_{i1}\ln EML_{it-1}$ – represents the lagged value of the regressand

X'_{it} = represents (2 x K) vector of regressors (i.e $lnPOPG_{it}$ RQ_{it})

Z'_{it} = is a 4 x K vector of control variables i.e, ECI_{it}, $lnEMP_{it}$, $lnPCGDP_{it}$, $lnGFCF_{it}$

β = is a K x 1 vector of parameters to be estimated

Υ_i = Unobserved country-specific effect

ϵ_{it} = Stochastic error term

Following this, our STIRPAT model can be specified as follows:

$$I_{it} = f(X'_{it}, Z'_{it}) \quad (7)$$

From equation (3.6), we take the natural logarithm, and introduce unobserved country-specific effects Υ_i, and the interactive terms $lnPOPG_{it}*RQ_{it}$. Measurement error is represented by ϵ_{it}.

Therefore, we have:

$$lnY_{it} = \phi lnY_{it-1} + \beta lnX_{it} + \alpha lnZ_{it} + \pi lnPOPG_{it}*RQ_{it} + (\Upsilon_i + \epsilon_{it}) \quad (8)$$

The main goal is getting consistent estimate of β when N < T, holding that cov(X_{it}, Υ_i, ϵ_{it}) ≠ 0, implying that all the regressors are respectively correlated with country-specific effects and measurement errors.

To remove the country-specific effects in equation (3.8), first difference is applied thus:

$$lnY_{it} - lnY_{it-1} = \phi lnY_{it-1} - \phi lnY_{it-2} + \beta lnX_{it} - \beta lnX_{it-1} + \alpha lnZ_{it} - \alpha lnZ_{it-1} + \pi\ lnPOPG_{it}*RQ_{it-1} + \Upsilon_i - \Upsilon_i + \epsilon_{it} - \epsilon_{it-1} \quad (9)$$

So that Cov(X'_{it}, ϵ_{it}) = 0

However, notwithstanding the first differencing, the problem of endogeneity remains because Cov(Y_{it-1}, ϵ_{it-1}) ≠ 0, that is, Y_{it} is correlated with the past errors in Δ ϵ_{it} and probably present Cov(Y_{it}, ϵ_{it}) ≠ 0. Additionally, E(Υ_i) = E(ϵ_{it}) = E(Υ_i, ϵ_{it}) = 0; E(ϵ_{it}, ϵ_{js}) = 0.

Arellano and Bond (1991) propose a Generalized Method of Moments estimator that uses all available delays in levels to instrument differenced variables that are not strictly exogenous. They also devised a test for autocorrelation, which can render some lags useless as instruments if it exists. Lagged levels are poor instruments for first differences if the variables are close to a random walk, which is a problem with the original Arellano-Bond estimator.

In view of the foregoing, forward orthogonal deviations transformation will be applied instead of first differencing. The orthogonal deviations transform, proposed by **Arellano and Bover (1995)**, subtracts the average of all possible future data rather than the prior observation. It is computable for all observations except the last for each individual, regardless of how many gaps there are, minimizing data loss.

Therefore, equation (3.5) is specified thus:

$$\Delta lnEML_{it} = \lambda_{i1}\Delta lnEML_{it-1} + \beta_{i1}\Delta lnPOPG_{it} + \beta_{i2}\Delta RQ_{it} + \beta_{i3}(lnPOPG_{it}*RQ_{it}) + \beta_{i4}\ \Delta ECI_{it} + \beta_{i5}\Delta lnEMP_{it} + \beta_{i6}\Delta lnPCGDP_{it} + \beta_{i7}\Delta lnGFCF_{it} + \Delta\epsilon_{it} \quad (10)$$

Where;

$lnEML_{it-1}$ is the lag of the dependent variable emission levels

$lnPOPG_{it}*RQ_{it}$ is the interactive term

ϵ_{it} is the error term

Levels

Assuming that E[Δ X_{it}, Υ_i] = E[Δ Z_{it}, Υ_i] = 0 and that E[ΔY_{i2}, Υ_i] = 0 satisfies initial conditions, then the additional moment conditions can be obtained as follows:

E[Δ X_{it-s},(Υ_i + Z_{it})] = 0, since s = 1 when Z_{it}~MA(0), and for s = 2 when Z_{it}~MA(0) (Arellano and Bover, 1995). This allows for the use of appropriately lagged initial differences of variables as instruments for level equations. In a system with both first-differences and level equations, both sets of moment conditions can be used as a linear GMM estimator. A system GMM estimator is created by combining both sets of moment conditions.

Moreover, because the autoregressive parameters will be too large given the nature of the data (relatively large panels over a short period), the Arellano and Bond estimator is likely to perform poorly. Therefore, building on further development of Arellano and **Bover's (1995)** work by **Blundell and Bond (1998)**, the system GMM is introduced which uses additional moment conditions. And as **Roodman (2009)** clearly stated it, the two-step system GMM is more efficient and robust to treat heteroscedasticity and autocorrelation.

Using the system GMM, there are some basic diagnostic tests to be carried out in order to check for the suitability of the instrument sets used. These include the test for instrument validity developed by **Hansen (1982)** and **Sargan (1985)** known as the J-test. Secondly, test for autocorrelation/serial correlation of the second order (AR(2)) of the error term by **Arellano and Bond (1991)**. These tests will be carried out accordingly.

3.4 Data source and software

This study sampled 26 Sub-Saharan African countries between 2000 and 2020. The countries sampled were based on availability of data. The data was sourced from the World Development Indicators (WDI), Climate Change Data, and Economic Complexity Index (ECI). The definition and measurement of the variables used in the analysis are presented in Table 3.1 below. For the a priori expectations from both theoretical and empirical point of view, population growth has been found to have negative impact on environmental sustainability. Therefore, in this study, it will be expected that an increase in population growth will increase the emission levels. Stata 17 econometric software shall be employed in the analyses.

Table 3: Description of variables, measurement and sources

Variable	Unit of measurement	A priori sign	Source
EML	Environment conditions (total greenhouse gases emissions)		Climate Change Data
POPG	Population growth (annual %). An increase in population will increase emission levels, ceteris paribus	Positive	World Development Indicator
RQ	Regulatory quality estimate. An increase in the quality of regulations will decrease emission levels, ceteris paribus	Negative	World Development Indicator
ECI	Economic complexity index. An increase in ECI will increase emission levels, ceteris paribus	Positive	Economic Complexity Index
EMP	Employment rate (% of total labour force). An increase in EMP will decrease emission levels, ceteris paribus	Negative	World Development Indicator
PCGDP	GDP per capita. An increase in PCGDP will increase emission levels, ceteris paribus	Positive	World Development Indicator
GFCF	Gross Fixed Capital Formation. An increase in GFCF will decrease emission levels, ceteris paribus	Negative	World Development Indicator

Source: Authors

4. Presentation and analysis of results

4.1 Summary statistics

Table 4 shows the summary statistics of the data used in the analysis. It shows the mean, minimum, maximum, standard deviation, skewness and kurtosis. Variables whose skewness values are higher than 0 are long right tailed and skewed to the right, while those less than 0 are long left tailed and skewed to the left. Variables whose kurtosis values fall within 3 are mesokurtic, those which are less than 3 are platykurtic and those which are greater than 3 are leptokurtic.

4.2: Multicollinearity Test

The multicollinearity test is conducted to ascertain if any correlations exist among the independent variables. A high degree of correlation among the explanatory variables, whether positive or negative, depicts a problem of multicollinearity in the model. A correlation is regarded as high and hence, problematic, if its coefficient exceeds 0.8. It is not desirable because it makes it difficult to determine the individual impact of such correlated regressors on the dependent variables. This is achieved by generating a correlation matrix like the one in Table 5.

Table 4: Summary statistics

Variable	Mean	Minimum	Maximum	Std. Dev	Skewness	Kurtosis
LOGEML	68980.88	2568.665	555409.	112482.4	2.710662	9.951907
LOGPOPG	2.39301	0.0022907	4.155897	0.8169877	-0.9915666	3.580655
RQ	-0.4859042	-2.201544	1.19697	0.5879908	0.2565038	36.071
ECI	-0.8352068	-2.505675	0.894938	0.5780881	-0.0370576	2.84022
LOGEMP	59.259	36.071	85.866	13.99581	0.1571779	1.898115
LOGPCGDP	643249.4	2699.761	5359616	990368.3	2.231893	7.953559
LOGGFCF	22.98724	2.000441	81.02102	8.730262	1.713229	10.30447

Source: Authors

Table 5: Correlation Matrix

	EML	POPG	RQ	POPG*RQ	ECI	EMP	PCGDP	GFCF
EML	1.0000							
POPG	0.2660	1.0000						
RQ	-0.1382	-0.4256	1.0000					
POPG*RQ	-0.0591	0.1580	0.3159	1.0000				
ECI	-0.1273	-0.5097	0.5150	0.4066	1.0000			
EMP	0.2453	0.2987	-0.2654	-0.2372	0.2654	1.0000		
PCGDP	-0.0898	0.1118	-0.0216	-0.1735	-0.2314	0.0541	1.0000	
GFCF	-0.0289	0.2931	0.1025	-0.2113	-0.2617	0.0005	0.1253	1.0000

Source: Authors

Table 5 reports the degree of correlation among the variables of interest. It is observed that the correlation coefficients among these variables are healthy as none of these coefficients exceed 0.8, which could pose a problem of multicollinearity. Hence, there exist no problem of multicollinearity among the independent variables.

4.3: Bond Test

It is essential to do the bond test in order to decide whether to use the system GMM style or the difference GMM style. In his second piece of advice, **Bond (2001)** advises that the autoregressive model be initially estimated using a pooled OLS and fixed effects technique. The corresponding fixed effects estimate should be regarded as a lower bound estimate, whereas the pooled OLS estimate should be regarded as an upper bound estimate. The system GMM estimator should be favoured over the difference GMM estimator if the obtained difference GMM estimate is near to or lower than the fixed effect estimates, indicating that the difference GMM is downward due to inadequate instrumentation.

Table 6 shows the results of the pooled OLS, fixed effect and two step difference GMM. The result shows the coefficients of the lagged dependent variable (logeml). L.logeml has a coefficient of 0.8811381 in the difference GMM estimation, which is no way close to or less than the fixed effect estimates (0.6874917). This then suggests that the difference GMM style will be the best estimator for this analysis instead of the system GMM.

Table 6: Bond test result

Test	Coefficient of Lagged Dependent Variable
Pooled OLS	0.9960364
Fixed Effect	0.6874917
Difference GMM	0.8811381
Decision	**Use Difference GMM**

Source: Authors

4.4. System GMM results

Table 7: Two step difference GMM results

VARIABLES	DIFFERENCE GMM
L.LOGEML	0.8811381*** (0.3415)
LOGPOPG	0.1295233 (0.1475)
RQ	-0.057007 (0.0998)
POPG*RQ	-0.2255209** (0.1285)

ECI	0.1551789** (0.0740)
LOGEMP	-0.7454399 (0.5394)
LOGPCGDP	0.8777867* (0.2797)
LOGGFCF	-0.0366819 (0.0668)
OBSERVATIONS	494
INSTRUMENTS	12
GROUPS	26
AR (2)	0.412
HANSEN STATISTICS	0.313

Source: Authors. **Note**: *, ** and *** represent 10%, 5% and 1% levels of significance respectively. The corrected standard errors are in parentheses.

From the results presented in Table 7, it can be observed that the coefficient of population growth is 0.1295, suggesting that population growth has a positive relationship with emission levels. Therefore, holding other variables constant, a 1 per cent increase in the population growth leads to about 12.95% increase in emission level, and reduces environmental sustainability by the same amount. This result conforms to a priori expectation, and in fact supports the argument of the Classical theory. Although this conforms (at face value) to a priori expectation, the observed effect of population growth is not statistically significant. The non-significance of the result could be interpreted to mean that, if African population growth is effectively harnessed, it could spur growth that will be emission-free. All that is needed is the necessary technology that is supported by sound government policies. This research output agrees with the works of some researchers in the likes of **Goodness and Prosper (2017)** who found that population growth has a positive relationship with emission levels, such that the higher the population growth, the higher the emission levels. **Wang et al. (2017)** also found that the population size has strong explanatory power on CO_2 emissions in the three regions of China.

The coefficient of regulatory quality is -0.0570, implying a negative relationship between regulatory quality and emission levels. So that on the average, and holding other variables constant, a percentage increase in regulatory quality leads to about 5.70% decrease in emission level. This result conforms to a priori expectation, but the observed effect of regulatory quality is not statistically significant. This output agrees with **Casey and Galor (2016)**, who found out that population policies have a positive effect on environmental performance, such that higher implementation of policies will lead to better environmental performance. There is no doubt that sound environmental protection policy world-over could go a long way towards reducing greenhouse gas emissions. One of such regulation could be in the form of emission-tax. If industries, and of course individuals, are taxed based on their level of emission, they will do everything possible to reduce their emission level so as to be liable for a minimal tax rate. This is in line with the work of **Aziz et al. (2024)** who demonstrate that a significant negative relationship exists between environmental protection policies and GHG emissions. More so, the British Columbia carbon tax, implemented in 2008, has been found to be effective in reducing emissions (**Lawley &Thivierge, 2018**; **Pretis, 2022**).

The interaction of population growth and regulatory quality resulted in a negative coefficient of -0.2255. This explains that institution indeed moderates the population growth-environmental sustainability nexus in Sub-Saharan Africa. The implication of this result is that a percentage increase in institutional quality would lead to a decrease in population growth by 22.55%, which will in turn lead to a decrease in emission levels by the same amount, thus sustaining the environment. The observed effect of the interaction between population growth and institutions is statistically significant at 5% level of significance. This further explains the weak regulatory framework in Sub-Saharan Africa. To achieve a clean environment that is devoid of pollution, strong institutions are necessary so as to put the required environmental policies in place towards securing a clean environment. **Han (2020)** confirm that environmental regulation policies play a significant role in promoting the environmental regulation level.

Regarding the control variables employed in the study, the coefficient of economic complexity is 0.1551, which indicates a positive relationship between the economic complexity index (ECI) and emission levels in SSA. The observed effect of ECI is statistically significant at 5% level of significance. So that holding other variables constant, a percentage increase in ECI leads to 15.51% increase in emission level. Every increase in emission level is certainly a decrease in environmental quality. This relationship conforms to a prior expectation because increasing economic complexity index is a result of increased economic activities, and hence, the generation of wastes, including gases. This output also agrees with **Ogbuabor et al. (2023)** who both found out that economic complexity index has a positive relationship with emission levels. The coefficient of employment is **-**0.7454, which indicates a negative relationship between the level of employment and emission levels. The observed effect of employment is statistically insignificant at 5% level of significance. Holding other variables constant, a percentage increase in employment leads to 74.54% decrease in emission level. This relationship conforms to a prior expectation because increasing employment is expected to decrease the tendency of moving towards a linear economy, and hence, sustaining the environment.

Furthermore, the coefficient of per capita GDP is 0.8777, implying a positive relationship between per capita GDP and emission levels. So that on the average, and holding other variables constant, a percentage increase in per capita GDP leads to about 87.77% increase in emission level. The observed effect of per capita GDP is statistically significant at 5% level of significance and conforms to the a priori expectation. This finding agrees with the finding of **Alam and Kabir (2013)**. They found that GDP per capita has a significant positive impact on emission levels. Again, though it is somewhat in line with the argument of the environmental Kuznets curve (EKC), that as countries develop economically, moving from lower to higher levels of per capita income, overall levels of environmental degradation will eventually decrease. However, this cannot necessarily imply a proof of Kuznets' ideation since Sub-Saharan Africa has not yet acquired the level of technology that can be used to control the level of emission, so that it can fall with every increase in per capita income. Finally, the coefficient of gross fixed capital formation (GFCF) is -0.0366, implying a negative relationship between GFCF and emission levels. So that on the average, and holding other variables constant, a percentage increase in GFCF leads to about 3.66% decrease in emission level. The observed effect of GFCF is statistically insignificant at 5% level of significance but conforms to the a priori expectation.

4.5. Long Run Coefficients

From the above results, the interaction term, ECI and PCGDP were the only variables whose observed effects proved to be statistically significant. It is important to note that GMM estimates here apply only to the short run. To this effect, long run coefficients were generated to determine if these 3 variables also have statistical significance in the long run.

Interaction Term

Table 8: Long Run Coefficient of Interaction Term

Logeml	Coefficient	Std. err	. z	P>|z|	[95% conf. interval]	
_nl_1	-.1869271	.1142464	-1.64	0.102	-.4108459	.0369918

Source: Authors

The long run coefficient explains that this interactive term will not be significant in the long run.

Economic Complexity

Table 9: Long Run Coefficient of Economic Complexity Index

Logeml	Coefficient	Std. err	. z	P>|z|	[95% conf. interval]	
_nl_1	.1286229	.0564963	2.28	0.023	.0178922	.2393536

Source: Authors

The long run coefficient explains that economic complexity index will be significant in the long run.

Per Capita GDP

Table 10: Long Run Coefficient of Per Capita GDP

Logeml	Coefficient	Std. err	. z	P>|z|	[95% conf. interval]	
_nl_1	.7275694	.1002442	7.26	0.000	.5310943	.9240444

Source: Authors

The long run coefficient explains that per capita GDP will be significant in the long run.

4.6. Granger Causality Test

The Granger test explains the nature of causal relationship between population growth and emission levels in Sub-Saharan Africa as stated in objective 2. The result of this causality test as well as the computed f-Statistics, and their respective probabilities, with specific lag period is presented in Table 4.6.1 below. To assess whether the null hypothesis would be accepted or rejected, a significance level of 5 percent was chosen.

Table 4.6: Granger Causality Test

Null Hypothesis:	F-Statistic	Prob.
LOG_POPG_ does not Granger Cause LOG_EML_	0.55762	0.7325
LOG_EML_ does not Granger Cause LOG_POPG_	0.60314	0.6976

Note: The lag length of this test is 5. **Source**: Authors

If the probability value of the F-statistic is less than 0.05 threshold of significance, the null hypothesis must be rejected in the Granger causality test. Table 4.6's results show that none of the F-statistics' probability values are less than the 0.05 level of significance, thus we cannot rule out the null hypothesis and draw the conclusion that there is no connection between population increase and emission levels. This indicates that adjustments in the population growth five-year lag value have no effect on changes in emission levels. In a similar vein, the five-year lag value of emission levels has little bearing on changes in population growth. Thus, emission levels and population growth do not granger cause each other, implying that there is no causal relationship between them.

5. Conclusion and policy recommendations

This study has fully lent itself to an empirical investigation of the relationship between population growth and environmental sustainability (measured in terms of emission levels) in Sub-Saharan Africa, from the period 2000-2020. Following formal econometric methodology, some findings about the research objectives and their corresponding hypothesis have been made, using time series data from the World Bank's World Development Indicators, Economic Complexity Index and Climate Change Data. These findings, inter alia, principally include that population growth has an insignificant and positive impact on emission levels in Sub-Saharan Africa, and that no causal relationship exists between them. The implication of the former is that by positively impacting emission levels, population growth increases environmental pollution, thereby reducing environmental sustainability. Perhaps the absence of causal relationship between population growth and emission levels suggest that it is not necessarily population size that leads to generation of emissions, but the level of economic activities, for instance. However, the interaction between population growth and institutions shows a significant negative impact on emission level, indicating that strong institution is capable of moderating the impact of increasing population on the environment.

On the basis of these empirical findings, therefore, that the following policy recommendations are advanced.

- This study's key policy conclusion is that population screening policies may be an efficient way to cut CO2 and other petrol emissions. Therefore, Sub-Saharan Africa can reduce CO2 emissions by implementing a cautious population stabilisation programme. Fertility control techniques, for example, can be crucial to halting environmental deterioration and raising living standards.
- The government must also make family planning available everywhere. By spacing out births, family planning will lower infant mortality, drop birth rates, increase demand for its services (through raising awareness), and maybe lower fertility. However, family planning is insufficient to decrease fertility as soon as is required. Other fertility-reduction strategies that the government should implement include maternity benefit restrictions, financial incentives, and educational programmes.
- Sub-Saharan African governments should actively encourage and carry out green innovation ideas. The first step is for the federal, state, and local governments to actively foster an atmosphere that promotes green innovation. In order to promote green innovation, it is essential to strictly execute intellectual property protection mechanisms, concentrate on the pressing issues of CO2 emission reduction and environmental pollution control, and offer targeted fiscal and taxation policy support. Second, create an effective framework for conducting research on green innovation, boost funding for fundamental studies on the development of green technologies, and hasten the creation of scientific research partnerships between businesses, academic institutions, and governments.

References

Agbonlahor, M. U., & Phillip, D. O. A. (2015). Deciding to settle: Rural-rural migration and agricultural labour supply in Southwest Nigeria. *The Journal of Developing Areas*, 267-284.

Alam, S. & Kabir, N. (2013). Economic growth and environmental sustainability: Empirical evidence from East and South-East Asia. *International Journal of Economics and Finance*, *5*(2).

Alcott, B. (2010). Impact caps: Why population, affluence and technology strategies should be abandoned. *Journal of Cleaner Production*, *18*(6), 552 – 560.

Arellano, M., & Bond, S. (1991). Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations. *The review of economic studies*, *58*(2), 277-297.

Arellano, M., & Bover, O. (1995). Another look at the instrumental variable estimation of error-components models. *Journal of econometrics*, *68*(1), 29-51.

Azam, H. (2018). Relationship between population growth and the environment in Iran and other countries in the MENA region. *Quarterly Journal of the Macro and Strategic Policies*, *6*(21), 40-60.

Aziz, N., Hossain, B. & Lamb, L. (2024). The effectiveness of environmental protection policies on greenhouse gas emissions. *Journal of Cleaner Production*, *450*. https://doi.org/10.1016/j.jclepro.2024.141868

Begum, R., Sohag, K., Syed-Abdullah, M., & Jafar, M. (2015). Impact of GDP growth, energy consumption and population growth on CO2 emissions in Malaysia. *Renewable and Sustainable Energy Reviews*, *41*, 594-601.

Behera, S.R., & Dash, D.P. (2017). The effect of urbanization, energy consumption, and foreign direct investment on the carbon dioxide emission in the SSEA (South and Southeast Asian) region. *Renewable and Sustainable Energy Reviews*, 70, 96-106.

Blundell, R., & Bond, S. (1998). Initial conditions and moment restrictions in dynamic panel data models. *Journal of econometrics*, *87*(1), 115-143.

Bond, S. R., Hoeffler, A., & Temple, J. R. (2001). GMM estimation of empirical growth models. *Available at SSRN 290522*.

Botkin, D.B., Keller, E.A. (1997). Environmental Science: Earth as a Living Planet. 2nd ed. New York: John Wiley Press. p215.

Casey, G., & Galor, O. (2016). Population Growth and Carbon Emissions in Nigeria. National Bureau of Economic Research.

Clarke, J. I. (1996). The Impact of Population Change on Environment: An Overview, in Bernardo Colombo, Paul Demeny, and Max F. Perutz, eds., Resources and Population: Natural, Institutional, and Demographic Dimensions of Development, Oxford, U.K.: Clarendon Press, 254–268.

Cohen, J. E. (2003). Human population: the next half century. [Research Support, U.S. Gov't, Non-P.H.S.]. Science, 302(5648), 1172-1175. https://doi.org/10.1126/science.1088665

Cramer, J. C. (1998). Population growth and air quality in California. *Demography*, *35*(1), 45–56.

Crutzan, P.J. (2002) Geology of mankind. Nature 415:23.

Dietz, T., & Rosa, E. A. (1994). Rethinking the environmental impacts of population, affluence and technology. *Human ecology review*, *1*(2), 277-300.

Edmund, U and Tosun, M. (2022). Moderating effect of institutional policies on energy and technology towards a better environmental quality: A two dimensional approach to China"s sustainable development. *Technological Forecasting and Social Change*, 183, 121964.

Ehrlich, P. R. & Holdren, J. P. (1971). Impact of Population Growth. *Science*, 171(3977) 1212 – 1217.

Engelman, Cincotta, Dye, Gardner & Wisenwski. (2000). People in the Balance: Population and Natural Resources at the turn of the Millennium. Population Action International. Washington DC p 31.

Engelman, R. (1997). Human prospects: implications for environmental security. *Environmental Change and Security Project Report*, (3), 47-54.

Environmental Health Committee. (2004). Ambient Air Pollution: Health Hazards to Children. PEDIATRICS 114:6 PP 1699-1707.

Fisher, A., & Peterson, F. (1976). The exploitation of extractive resources. *The Economic Journal*, *87*(348), 681-721.

Gislason, S. (2006) Effects of air pollution. Accessed 12 September, 2023 at www.nutramed.com

Goodness, A., & Prosper, E. (2017). Effect of economic growth on Co2 emissions in developing countries. *Cogent Economics and Finance*, *5*(1), 1379239.

Haldar, A., & Sethi, N. (2022). Effect of institutional quality and renewable energy consumption on Co2 emissions- an empirical investigation of developing countries. *Environmental Science and Pollution Research*, *28*(12), 15485-15503.

Han, Y. (2020). Impact of environmental regulation policy on environmental regulation level: a quasi-natural experiment based on carbon emission trading pilot. *Environmental Science and Pollution Research*, *27*, 23602–23615.

Hansen, L. P. (1982). Large sample properties of generalized method of moments estimators. *Econometrica: Journal of the econometric society*, 1029-1054.

Hotelling, H. (1931). The economics of exhaustible resources. *Journal of Political Economy,* 39, 137–175. https://doi.org/10.1007/s11356-020-08658-8

Hunter, L. M. (2000). The environmental implications of population dynamics. RAND. Arlington.

Jolly, C. L. (1994). Four theories of population change and the environment. *Population and Environment*, *16*, 61-90.

Joseph, T. E. (2019). Investigating renewable energy potentials in solving energy crisis in Niger Delta riverine communities, Nigeria. *International Journal of Research in Electronics and Computer Engineering, 7(3), 905-915*

Khan, M. A., Khan, M. Z., Zaman, K., Khan, M. M., & Zahoor, H. (2013). Causal links between greenhouse gas emissions, economic growth and energy consumption in Pakistan: A fatal disorder of society." Retrieved from https://doi.org/10.1016/j.rser.2013.04.002

Kraft, J. & Kraft, A. (1978). On the relationship between energy and GNP. *Journal of Energy and Development*, 3, 401-403.

Lawley, C., & Thivierge, V. (2018). Refining the evidence: British Columbia's carbon tax and household gasoline consumption. *The Energy Journal*, *39*(2), 147-172.

Liddle, B. (2015). What are the carbon emissions elasticities for income and population? Bridging STIRPAT and EKC via robust heterogeneous panel estimates. *Global Environmental Change*, *31*, 62-73.

Mamudul, M. Murad, Hanifa, W., & Ozturk, I. (2016). Relationship among carbon emissions, economic growth, energy consumption and population growth: *Testing EKC Hypothesis for Brazil, China, India and Indonesia. Ecological Indicators*, 70, 466-479.

Narayan, P. K., Narayan, S., & Arti Prasad, A. (2008). Understanding the oil price-exchange rate nexus for the Fiji islands. *Energy Economics*, 30(5), 2686-2696. https://doi.org/10.1016/j.eneco.2008.03.003

National Pollutant Inventory summary report. (2006-07). Department of the Environment, Water, Heritage and the Arts. Accessed 12 September, 2023 at https://www.dcceew.gov.au/environment/protection/npi/publications/national-pollutant-inventory-summary-report-2006-07

Ogbuabor, J.E., Agu, C., & Mba, I.C. (2023). Do foreign direct investment inflow and trade openness influence international tourism demand in Africa? A study of the post-global financial crisis era. *Journal of Travel Research*. https://doi.org/10.1177/00472875231202171

Oguntoke, O., & Adeyemi, A. (2017). Degradation of urban environment and human health by emissions from fossil-fuel combusting electricity generators in Abeokuta metropolis, Nigeria. *Indoor and Built Environment*, *26*(4), 538-550.

Ohlan, R. (2015). The Impact of Population Density, Energy Consumption, Economic Growth and Trade Openness on CO2 Emissions in India. Natural Hazards, 79, 1409-1428.

Perman, R., Ma, Y., McGilvray, J., & Common, M. (2003). Natural resource and environmental economics. Harlow. *UK: Pearson Education*.

Pretis, F. (2022). Does a carbon tax reduce CO2 emissions? Evidence from British Columbia. *Environmental and Resource Economics*, *83*(1), 115-144.

Roodman, D. (2009). A note on the theme of too many instruments. *Oxford Bulletin of Economics and statistics*, *71*(1), 135-158.

Sargan, J. D. (1985). Estimating dynamic random effects from panel data covering short time periods. *Econometrica*

Shaw, R. P. (1989). Rapid population growth and environmental degradation: Ultimate versus proximate factors. *Environmental Conservation*, *16*(3), 199-208.

Siyan, P., & Adegoriola, A. E. (2017). An assessment of nexus between infrastructural development and Nigerian economic growth. *African Journal of Business Management*, *11*(18), 470-477.

Smith, A. (1776). *The wealth of nations [1776]* (Vol. 11937). na.

Tonuchi, E. J., & Ariolu, C. C. (2021). Renewable energy consumption, environmental sustainability, and economic growth in developing countries. *Asian Bulletin of Energy Economics and Technology, 6(1), 43-69.*

US Census Bureau (2011) U.S. Census Bureau, International Data Base Accessed July 19, 2023 at: http://www.census.gov/ipc/www/idb/worldpopinfo.php

Wang, Y., Kang, Y., Wang J., & Xu, L. (2017). Panel estimation for the impacts of population-related factors on CO2 emissions: A regional analysis in China. *Ecological Indicators*, *78*, 322-330. https://doi.org/10.1016/j.ecolind.2017.03.032

WCED. (1988). Intertemporal equillibra and exhaustible resources: An overlapping generation approach.

Wolman, M. G. (1993). Population, Land Use, and Environment: A Long History in Population and Land Use in Developing Countries. National Research Council, Washington, D.C.: National Academy Press.

Wood, J. (2004). Motor car emission, safety and alternatives. Available at Microsoft Encarta Premium Suite.

World Bank. (2022). Accessed 18 July, 2023 at https://databank.worldbank.org/source/world-development-indicators

Yuan, B. Hongyuan, L., & Zeng, M. (2022). Green innovation and China's Co2 emissions- the moderating effect of institutional quality. *Journal of Environmental Planning and Management*, 65(5), 877-906.

Zhou, H. (2009). Population growth and industrialization. *Economic Inquiry*, 47 (2), 249-265.