



The invisible hand and EKC hypothesis: what are the drivers of environmental degradation and pollution in Africa?

Samuel Asumadu Sarkodie¹

Received: 25 March 2018 / Accepted: 16 May 2018 / Published online: 24 May 2018
© Springer-Verlag GmbH Germany, part of Springer Nature 2018

Abstract

This study examined the drivers of environmental degradation and pollution in 17 countries in Africa from 1971 to 2013. The empirical study was analyzed with Westerlund error-correction model and panel cointegration tests with 1000 bootstrapping samples, U-shape test, fixed and random effect estimators, and panel causality test. The investigation of the nexus between environmental pollution economic growth in Africa confirms the validity of the EKC hypothesis in Africa at a turning point of US\$ 5702 GDP per capita. However, the nexus between environmental degradation and economic growth reveals a U shape at a lower bound GDP of US\$ 101/capita and upper bound GDP of US\$ 8050/capita, at a turning point of US\$ 7958 GDP per capita, confirming the scale effect hypothesis. The empirical findings revealed that energy consumption, food production, economic growth, permanent crop, agricultural land, birth rate, and fertility rate play a major role in environmental degradation and pollution in Africa, thus supporting the global indicators for achieving the sustainable development goals by 2030.

Keywords Cross-sectional dependence · Panel cointegration test · Panel Granger causality · Africa · Econometrics

Introduction

Advancement in sustainable development has become critical in economic development at the global level. As accentuated in the sustainable development goals, improving education, human and institutional capacity, and raising awareness on climate change mitigation, increasing adaptation options, providing early warning signs, and reducing the impact of climate change will help achieve the global temperature threshold of below 2 °C (United Nations 2015). However, due to lack of progressive research in the scope of the study, least developing and developing countries seem to be left behind in readiness and adaptation to climate change and its impact. The Intergovernmental Panel on Climate Change (IPCC) argues that the immediate effect of climate change in developing

countries is a 2–4% per annum reduction in economic growth by 2040 and extends to 10% per annum by 2100 (IPCC 2007).

Even though Africa contributes less to environment pollution compared to other continents like Asia, North and South America, Antarctica, Europe, and Australia, however, Africa is the most vulnerable continent to climate change and its related impacts. According to the 2015 Climate Change Vulnerability Index, seven out of the ten countries (Sierra Leone, South Sudan, Nigeria, Chad, Ethiopia, Central African Republic, and Eritrea) at the highest risk of climate change impact are from Africa (Maplecroft 2015). Majority of African countries are agrarian economy and depend heavily on the agricultural sector for almost 28% of its economic revenue, while 65% of the working population are dependent on the agricultural sector for their daily livelihoods. Due to low adaptive capacity, high financial and technological constraints, changes in weather patterns such as rainfall variability and higher temperatures affect food production leading to extreme poverty, hunger, rural-urban migration, and social instability (i.e., conflicts, destabilization of regional security, and political violence), which are already happening (Maplecroft 2015).

The adverse effect of climate change has propelled a lot of scientific research on the environmental Kuznets curve (EKC) hypothesis evident in energy, environmental, and resources

Responsible editor: Nicholas Apergis

Electronic supplementary material The online version of this article (<https://doi.org/10.1007/s11356-018-2347-x>) contains supplementary material, which is available to authorized users.

✉ Samuel Asumadu Sarkodie
asumadusarkodiesamuel@yahoo.com

¹ Department of Environmental Science, Faculty of Science and Technology, Macquarie University, Sydney, NSW 2109, Australia

economics literature. The conceptual framework of the EKC hypothesis encompasses the causal nexus between economic growth and environmental degradation emanating from the work of Grossman and Krueger (1995). Their work found an inverted U-shape curve based on the long-run equilibrium relationship between economic growth and environmental degradation. This means that there is a nexus between a country's economic development and high echelons of environmental degradation at the initial stages (i.e. pre-industrial economy). However, as the country attains a threshold in economic development, the population becomes aware of the essence of environmental quality and is willing to pay more to improve their quality of life, cleaner energy, and a cleaner environment. The aftermath of their seminal work has been accentuated in different studies; however, few studies on the EKC hypothesis using panel data in Africa provide heterogeneous results which offer the reason to revisit this interesting theme. For example, recent studies (Effiong and Iriabije 2018; Twerefou et al. 2017) confirm the validity of the EKC hypothesis in sub-Saharan Africa (SSA), while Zerbo (2017) and Zoundi (2017) reject the validity of the EKC hypothesis in sub-Saharan Africa. Twerefou et al. (2017) argue that economic growth improves environmental quality and globalization; thus, foreign direct investment in Africa hampers environmental sustainability and its quality. However, the study proposes the participation in globalization in terms of technological advancement in clean and renewable energy technologies employed in Africa. On the contrary, Effiong and Iriabije (2018) argue that economic growth has no significant impact on environmental quality in SSA. Zoundi (2017) argues that environmental pollution improves economic growth in Africa, while energy consumption is identified as the main driver for poor environmental quality.

After accentuating the strengths of previous studies in Africa, two main weaknesses are identified.

1. Majority of the study that examines the EKC hypothesis in Africa only considers the negative sign and the significance of the second derivative to make statistical inferences of the presence of an inverted U shape. However, Lind and Mehlum (2010) argue that using only the aforementioned conditions may be misleading. In reality, sound judgment can only be made if the following conditions are met; first, the second derivative should have a negative sign and be significant, and second, the extremum point of the regression must be within the data range.
2. Majority of the studies in Africa do not employ the so-called cross-sectional dependence test. A progressive body of literature on panel data has identified cross-sectional dependence as a crucial test in panel data analysis. Cross-sectional dependence may occur in panel data due to the presence of common shocks and unobserved

factors that affects the error term leading to bias and inconsistent results (De Hoyos and Sarafidis 2006).

Considering the above, the current study employs robust panel data analysis methods that provide an opportunity for solving the weaknesses outlined.

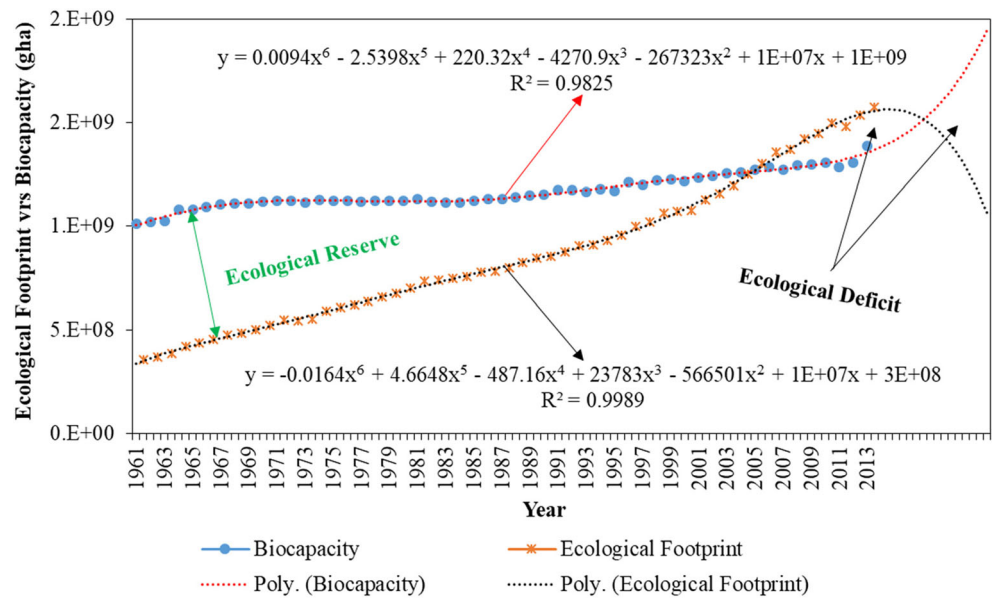
Why is it plausible to investigate the EKC hypothesis and employ ecological footprint as an indicator of environmental degradation in Africa? Ecological footprint is defined as, “a measure of how much area of biologically productive land and water an individual, population, or activity requires to produce all the resources it consumes and to absorb the waste it generates, using prevailing technology and resource management practices”(Global Footprint Network 2017a). On the contrary, biocapacity is defined as, “the ecosystems' capacity to produce biological materials used by people and to absorb waste material generated by humans, under current management schemes and extraction technologies”(Global Footprint Network 2017a). Within the past decades, Africa's biocapacity was higher than its population footprint; as a result, there was a vast ecological reserve as depicted in Fig. 1. Nonetheless, in recent years, Africa's ecological footprint has exceeded its ability to regenerate what the population demands because of climate change vulnerability and poor management of the natural resources, thus liquidating the ecological assets thereby leading to ecological deficit (see Fig. 1). To better understand the future implications, a simple linear regression with polynomial terms was used to predict the future state of Africa's ecological footprint and biocapacity, which shows a high level of ecological deficit.

Against the backdrop, the study examines the current state of environmental degradation and pollution in 17 countries in Africa by testing the validity of the EKC hypothesis. We present a comparative study by employing ecological footprint as a benchmark for environmental degradation while carbon dioxide emission is used as an indicator for environmental pollution.

To meet the objectives, the study employs the Westerlund error-correction model (WECM), U-shape relationship test, fixed and random effect estimators, and panel causality test. To account for cross-sectional dependence in the WECM-based panel cointegration tests, the study employs the bootstrapping approach for 1000 samples.

The study contributes to existing literature by, first, exploring a research topic that is topical and provides scientific significance, which has the tendency to provoke future research interest in the scope of the study. Second, the concept of sustainable development has been integrated into the research hypothesis which is of relevance to development cooperation. Third, the research brings novel perspectives, methodologies, and new evidence that provides knowledge that will accelerate the transformation of least developing and developing countries toward a sustainable development. Lastly, the study

Fig. 1 Ecological footprint versus biocapacity (gha). [Source: Author's construction with data from Global Footprint Network]



combines an interdisciplinary approach that considers related local, national, and international debates and policies.

Literature review

There are a lot of studies that assess the factors that affect environmental degradation or environmental pollution. Many of these studies either examine the validity of the EKC hypothesis, emissions emancipated human index (eHDI), population-related emissions (IPAT, STIRPAT, and ImPACT), or the pollution haven hypothesis (PHH). However, the EKC hypothesis stands tall among them. A few of the tons of research on environmental pollution/degradation that employs the panel data analysis have been listed in Table 1. The literature presented either examines the EKC hypothesis (i.e., supports or rejects the validity of the EKC hypothesis) or does not examine the EKC hypothesis but the long-run equilibrium relationships existing between the variables of interest.

There are extensive empirical studies on cointegration and long-run equilibrium relationships between environmental pollution and macroeconomic variables. For example, Behera and Dash (2017) examine the nexus between CO₂ emissions, GDP, foreign direct investment, energy consumption, and urbanization in 17 South and Southeast Asian countries from 1980 to 2012 using panel cointegration analysis. Both Pedroni and Westerlund tests show a long-run equilibrium relationship for the entire panel countries. The Westerlund cointegration shows evidence of a long-run relationship in the middle- and low-income South and Southeast Asian countries in contrast to high-income South and Southeast Asian countries. Zaman and Abd-el Moemen (2017) investigated the nexus between CO₂ emissions from transport, permanent cropland, energy production from renewable energy source, high-

technology exports, and government expenditure on health in Latin America and the Caribbean Countries from 1980 to 2013. The study employed panel ordinary least squares (OLS), FE, RE, two-stage least squares (2SLS), 2SLS FE, and 2SLS RE. Evidence from the study shows that increasing levels of electricity production from renewable energy increase CO₂ emissions, while high levels of health expenditure, high-technology exports, and permanent crop decrease CO₂ emissions. Wolde-Rufael and Idowu (2017) investigated the effect of real GDP per capita, energy consumption, and trade openness on environmental pollution in China and India from 1974 to 2010 using the autoregressive distributed lag (ARDL), fully modified ordinary least squares (FMOLS), and dynamic ordinary least squares (DOLS) regression analysis. Their study showed that economic growth has no impact on environmental pollution. Income inequality was revealed to have the least impact on CO₂ emissions; however, economic growth and energy consumption are the determinants of environmental pollution in China and India. Redistribution of wealth has no impact on pollution in India in contrast to China where income inequality affects environmental pollution. Dogan and Aslan (2017) examined the relationship between CO₂ emissions, real GDP per capita, tourism, and energy consumption in 25 EU countries from 1995 to 2011 using the OLS-FE, FMOLS, DOLS, and GM estimator. Their study revealed that, while economic growth and tourism reduces environmental pollution, energy consumption increases environmental pollution in the long run. There was evidence of a bidirectional causality from energy consumption and economic growth to environmental pollution. Sweidan and Alwaked (2016) examined the relationship between ecological intensity of well-being, real GDP per capita, health expenditure, exports, and democratization from 1995 to 2012 in 6 gulf cooperation council (GCC) countries using

Table 1 Literature survey on environmental Kuznets curve hypothesis

Author(s)	Time frame	Case study	Variables	Methodology	Inferences
Abdallah and Abugamos (2017)	1980–2014	20 MENA countries	CO ₂ emissions, population, GDP, energy intensity, urbanization	STIRPAT model	Their study tested and supported the validity of the EKC hypothesis. They found an inverted U-shaped relationship between environmental pollution and urbanization. In other words, increasing the role of urbanization decreases CO ₂ emissions contrary to energy intensity and growth in GDP.
Al-Mulali and Ozturk (2016)	1990–2012	27 developed countries	CO ₂ emissions, GDP, trade openness, renewable and nonrenewable energy consumption, energy prices, urbanization	FMOLS	Their study tested for the presence of the EKC hypothesis. They found an inverted U-shaped relationship between economic growth and environmental pollution.
Amri (2016)	1990–2010	75 countries	Real GDP per capita, foreign direct investments, labor, capital input, and renewable and nonrenewable energy consumption	Dynamic panel estimation	The study found a bidirectional causality between renewable energy consumption and foreign direct investment.
Azam (2016)	1990–2011	11 Asian countries	CO ₂ emissions, GDP, foreign direct investment, energy consumption, gross savings, and life expectancy	Fixed and random effects	The study found a negative impact of environmental pollution on economic growth through the study did not test the validity of the EKC hypothesis.
Azam and Khan (2016)	1975–2014	Tanzania, Guatemala, China, and USA	CO ₂ emissions, GDP, energy consumption, trade openness, and urbanization	Regression and cointegration	The study tested and supported the validity of the EKC hypothesis in low-income countries (Tanzania and Guatemala), while the hypothesis was invalid in middle-income and upper-income countries (China and USA).
Behera and Dash (2017)	1980–2012	17 South and Southeast Asian countries	CO ₂ emissions, GDP, foreign direct investment, energy consumption, and urbanization	Panel cointegration (Pedroni and Westerlund tests)	Both Pedroni and Westerlund tests show a long-run equilibrium relationship for the entire panel countries. The Westerlund cointegration shows evidence of a long-run relationship in middle- and low-income South and Southeast Asian countries in contrast to high-income South and Southeast Asian countries.
Bilgili et al. (2016)	1977–2010	17 OECD countries	CO ₂ emissions, real GDP per capita, and renewable energy consumption	FMOLS and DOLS	The study confirmed the validity of the EKC hypothesis by exhibiting an inverted U-shaped relationship between environmental pollution and income per capita. The study found a negative impact of renewable energy consumption on environmental pollution.
Charfeddine and Mrabet (2017)	1972–2007	15 MENA countries	Ecological footprint, real GDP, energy consumption, urbanization, fertility rate, life expectancy, political institution index	Pedroni panel cointegration, DOLS, and FMOLS	The study confirms the U-shaped EKC hypothesis and there exists a long-run equilibrium relationship between ecological footprint, real GDP, energy consumption, and urbanization. In addition, there was evidence of a negative impact of urbanization and energy consumption on environmental pollution in oil-exporting countries. Life expectancy and fertility rate decreases ecological footprint, while strong political institutions increase ecological footprint.
Dogan and Aslan (2017)	1995–2011	25 EU countries	CO ₂ emissions, real GDP per capita, tourism, and energy consumption		While economic growth and tourism reduce environmental pollution, energy consumption increases environmental

Table 1 (continued)

Author(s)	Time frame	Case study	Variables	Methodology	Inferences
Dutta and Das (2016)	1960–2010	30 countries	Total CO ₂ emissions, GDP, CO ₂ emissions from coal and solid fuel consumption, CO ₂ emissions from gasoline fuel consumption, and CO ₂ emissions from oil and liquid fuel consumption	OLS-FE, FMOLS, DOLS, and GM estimator VAR and Granger causality	pollution in the long run. There was evidence of a bidirectional causality from energy consumption and economic growth to environmental pollution. The study found a bidirectional causality between environmental pollution and economic growth. Economic growth was revealed as the main driver of coal-related carbon dioxide emissions.
Hakimi and Hamdi (2016)	1971–2013	Morocco and Tunisia	CO ₂ emissions, real GDP per capita, foreign direct investment, capital, and trade openness	VECM and panel cointegration	The study found a long-run equilibrium relationship between the variables. There was a bidirectional causality between environmental pollution and foreign direct investment inflows, thus supporting the notion that trade liberalization hampers clean environment.
Kais and Sami (2016)	1990–2012	58 countries	CO ₂ emissions, real GDP per capita, energy consumption, urbanization, and trade openness	GMM	The study reveals a positive impact of energy consumption on environmental pollution. The study further confirmed the validity of the U-shaped EKC hypothesis, consistent with existing literature. Urbanization and trade openness have a negative impact on environmental pollution. However, the latter is valid for North Asia and European countries.
Khan et al. (2016)	2000–2013	9 developed countries	CO ₂ emissions, real GDP per capita, natural resources depletion, PFC gas emissions, SF ₆ gas emissions, PM _{2.5} pollution, number of infant deaths, health expenditure, PPP, fossil fuel energy consumption, and energy consumption	GMM	The study confirms the EKC hypothesis by exhibiting a U-shape relationship between energy depletion, net forest depletion, and natural resource depletion. A U-shaped EKC hypothesis was further confirmed between the individual effect of PFC gas emissions, SF ₆ gas emissions, PM _{2.5} pollution, and economic growth. However, a combined effect of PFC gas emissions, SF ₆ gas emissions, and PM _{2.5} pollution rejects the U-shaped EKC hypothesis.
Menegaki and Tsagarakis (2015)	1990–2010	33 European countries	GDP, coal, crude oil, natural gas, and renewable energy sources	Random effect and Arelano-Bond-Bover dynamic model	The study confirms the validity of the EKC hypothesis in the nexus between economic development and crude oil production.
Özoku and Özdemir (2017)	1980–2010	26 OECD and 52 emerging countries	CO ₂ emissions, real GDP per capita, and energy consumption	Polynomial regression analysis	The study rejected the validity of the EKC hypothesis in both the 26 OECD countries and the 52 emerging countries. Thus, environmental pollution does not decrease in high-income countries which is the basis for the EKC hypothesis.
Rahman (2017)	1960–2014	11 Asian countries	CO ₂ emissions, real GDP per capita, energy consumption, exports, and population	FMOLS and DOLS	The study confirms the validity of the U-shaped EKC hypothesis between economic growth and environmental pollution. Population density, exports of goods and services, and energy consumption hamper environmental quality in the long term. The study finds a bidirectional causality between population and economic growth.
Sencer Atasoy (2017)	1960–2010	50 US states	CO ₂ emissions, real GDP per capita, energy consumption, and population	AMG and CCEMG	Both methods reveal a mixed result in the EKC hypothesis testing. The validity of the EKC hypothesis was affirmed

Table 1 (continued)

Author(s)	Time frame	Case study	Variables	Methodology	Inferences
Swaidan and Alwaked (2016)	1995–2012	6 GCC countries	Ecological intensity of well-being, real GDP per capita, health expenditure, exports, and democratization	PCSE	in 30 of the 50 states via the AMG estimator; however, the CCEMG estimator reveals a weak EKC hypothesis. There is a positive relationship between the ecological intensity of well-being and economic development. Thus, there is a continual stress on the environment due to economic development through the overexploitation of natural resources.
Wolde-Rufael and Idowu (2017)	1974–2010	China and India	CO ₂ emissions, real GDP per capita, energy consumption, and trade openness	ARDL, FMOLS, and DOLS	Economic growth has no impact on environmental pollution. Income inequality was revealed to have the least impact on CO ₂ emissions; however, economic growth and energy consumption are the determinants of environmental pollution in China and India. Redistribution of wealth has no impact on pollution in India in contrast to China where income inequality affects environmental pollution.
Zaman and Abd-el Moemen (2017)	1980–2013	Latin America and the Caribbean countries	CO ₂ emissions from transport, permanent cropland, energy production from renewable energy source, high-technology exports, and government expenditure on health	Panel OLS, FE, RE, 2SLS, 2SLS FE, and 2SLS RE	Increasing levels of electricity production from renewable energy increase CO ₂ emissions, while high levels of health expenditure, high-technology exports, and permanent crop decrease CO ₂ emissions.
Zaman and Moemen (2017)	1975–2015	90 countries	CO ₂ emissions, GDP, foreign direct investment, trade openness, agricultural, services and industrial value added, energy consumption, and government expenditure on health and education	FE and GMM	Their study showed no evidence of emissions emancipated human development index and pollution haven hypothesis from the 90 countries. Growth in the sectors and, thus, industrialization seem to increase CO ₂ emissions, while value addition to agricultural production tends to reduce CO ₂ emissions. The pollution-based emissions hypothesis shows that as population increases, CO ₂ emissions escalate in high-income countries. High levels of energy consumption in the countries tend to impact CO ₂ emissions positively. The study confirmed the validity of the EKC hypothesis. They found an inverted U-shaped relationship between economic growth and environmental pollution in low- and middle-income countries in contrast to high-income countries.
Zoundi (2017)	1980–2012	25 African countries	CO ₂ emissions per capita, real GDP per capita, renewable energy per capita, energy consumption per capita, and population	Panel cointegration, DOLS, DFE, MG, PMG, and GMM	The study found no evidence of the validity of the EKC hypothesis in Africa. Thus, CO ₂ emissions increase with increasing economic growth, while renewable energy has a negative impact on environmental pollution.

Source: Author's construction

the panel-corrected standard errors (PCSE). There was a positive relationship between the ecological intensity of wellbeing and economic development. Thus, there is a continual stress on the environment due to economic development through the overexploitation of natural resources. Hakimi and Hamdi (2016) examined the relationship between CO₂ emissions, real GDP per capita, foreign direct investment, capital, and trade openness from 1971 to 2013 in Morocco and Tunisia using the vector error-correction model (VECM) and panel cointegration analysis. The study found a long-run equilibrium relationship between the variables. There was a bidirectional causality between environmental pollution and foreign direct investment inflows, thus supporting the notion that trade liberalization hampers clean environment. Dutta and Das (2016) examined the nexus between total CO₂ emissions, GDP, CO₂ emissions from coal and solid fuel consumption, CO₂ emissions from gasoline fuel consumption, and CO₂ emissions from oil and liquid fuel consumption from 1960 to 2010 in 30 countries using the vector autoregressive (VAR) and the Granger causality analysis. The study found a bidirectional causality between environmental pollution and economic growth. Economic growth was revealed as the main driver of coal-related carbon dioxide emissions. Amri (2016) examined the dynamic effect of real GDP per capita, foreign direct investments, labor, and capital input on renewable and nonrenewable energy consumption from 1990 to 2010 in 75 countries using the dynamic panel estimation. The study found a bidirectional causality between renewable energy consumption and foreign direct investment.

The second strand of studies (thus, the EKC hypothesis) has received much attention in the literature, due to its effectiveness in understanding the environmental pollution and economic growth interactions. Al-Mulali and Ozturk (2016) tested for the presence of the EKC hypothesis in 27 developed countries using the FMOLS. They found an inverted U-shaped relationship between economic growth and environmental pollution. In addition, an increase in economic growth, nonrenewable energy consumption, and urbanization increases environmental pollution, while an increase in trade openness and renewable and energy prices decreases environmental pollution. Azam and Khan (2016) examined the validity of the EKC hypothesis in Tanzania, Guatemala, China, and USA from 1975 to 2014 using linear regression and cointegration analysis. The study supported the validity of the EKC hypothesis in low-income countries (Tanzania and Guatemala), while the hypothesis was invalid in middle-income and upper-income countries (China and USA). Zoundi (2017) examined the relationship between CO₂ emissions per capita, real GDP per capita, renewable energy per capita, energy consumption per capita, and population in 25 African countries from 1980 to 2012. The study employed the panel cointegration, DOLS, dynamic fixed effect (DFE), mean group (MG), pooled mean group (PMG),

and generalized method of moments (GMM) estimation. The study found no evidence of the validity of the EKC hypothesis in Africa. Thus, CO₂ emissions increase with increasing economic growth, while renewable energy has a negative impact on environmental pollution. Zaman and Moemen (2017) examined the relationship between CO₂ emissions, GDP, foreign direct investment, trade openness, agricultural, services and industrial value added, energy consumption, and government expenditure on health and education from 1975 to 2015 in 90 countries using the FE and GMM estimation. Their study showed no evidence of emissions emancipated human development index and pollution haven hypothesis from the 90 countries. Growth in the sectors and, thus, industrialization seem to increase CO₂ emissions, while value addition to agricultural production tends to reduce CO₂ emissions. The pollution-based emissions hypothesis shows that as population increases, CO₂ emissions escalate in high-income countries. High levels of energy consumption in the countries tend to impact CO₂ emissions positively. The study confirmed the validity of the EKC hypothesis. They found an inverted U-shaped relationship between economic growth and environmental pollution in low- and middle-income countries in contrast to high-income countries. Sencer Atasoy (2017) examined the relationship between CO₂ emissions, real GDP per capita, energy consumption, and population in 50 states of the USA from 1960 to 2010 using the augmented mean group (AMG) and the common correlated effects mean group (CCEMG). The results of the study show that both methods reveal a mixed result in the EKC hypothesis testing. The validity of the EKC hypothesis was affirmed in 30 of the 50 states via the AMG estimator; however, the CCEMG estimator reveals a weak EKC hypothesis. Rahman (2017) analyzed the effect of real GDP per capita, energy consumption, exports, and population on CO₂ emissions in 11 densely populated Asian countries from 1960 to 2014 using the FMOLS and DOLS. The study confirms the validity of the U-shaped EKC hypothesis between economic growth and environmental pollution. Population density, exports of goods and services, and energy consumption hamper environmental quality in the long term. The study finds a bidirectional causality between population and economic growth. Özokcu and Özdemir (2017) examined the effect of real GDP per capita and energy consumption on CO₂ emissions in 26 OECD and 52 emerging countries from 1980 to 2010 using the polynomial regression. The study rejected the validity of the EKC hypothesis in both the 26 OECD countries and the 52 emerging countries. Thus, environmental pollution does not decrease in high-income countries, which is the basis for the EKC hypothesis. Charfeddine and Mrabet (2017) examined the relationship between ecological footprint, real GDP, energy consumption, urbanization, fertility rate, life expectancy, and political institution index in 15 Middle East and North African (MENA) countries from 1972 to 2007 using the

Pedroni panel cointegration, DOLS, and FMOLS. The study confirms the U-shaped EKC hypothesis and there exists a long-run equilibrium relationship between ecological footprint, real GDP, energy consumption, and urbanization. In addition, there was evidence of a negative impact of urbanization and energy consumption on environmental pollution in oil-exporting countries. Life expectancy and fertility rate decreases ecological footprint, while strong political institutions increase ecological footprint. Khan et al. (2016) examined the relationship between CO₂ emissions, real GDP per capita, natural resources depletion, PFC gas emissions, SF₆ gas emissions, PM_{2.5} pollution, number of infant deaths, health expenditure, purchasing power parity (PPP), fossil fuel energy consumption, and energy consumption from 2000 to 2013 in 6 developed countries using the GMM method. The study confirms the EKC hypothesis by exhibiting a U-shape relationship between energy depletion, net forest depletion, and natural resource depletion. A U-shaped EKC hypothesis was further confirmed between the individual effect of PFC gas emissions, SF₆ gas emissions, PM_{2.5} pollution, and economic growth. However, a combined effect of PFC gas emissions, SF₆ gas emissions, and PM_{2.5} pollution rejects the U-shaped EKC hypothesis. Kais and Sami (2016) examined the validity of the EKC hypothesis between CO₂ emissions, real GDP per capita, energy consumption, urbanization, and trade openness from 1990 to 2012 in 58 countries using the GMM method. The study reveals a positive impact of energy consumption on environmental pollution. The study further confirmed the validity of the U-shaped EKC hypothesis, consistent with existing literature. Urbanization and trade openness have a negative impact on environmental pollution. However, the latter is valid for North Asia and European countries. Bilgili et al. (2016) examined the causal effect between CO₂ emissions, real GDP per capita, and renewable energy consumption from 1977 to 2010 in 17 OECD countries using the FMOLS and DOLS cointegration method. The study confirmed the validity of the EKC hypothesis by exhibiting an inverted U-shaped relationship between environmental pollution and income per capita. The study found a negative impact of renewable energy consumption on environmental pollution. Abdallah and Abugamos (2017) employed the stochastic impacts by regression on population, affluence and technology (STIRPAT) model to examine the validity of the environmental Kuznets curve hypothesis in 20 MENA countries from 1980 to 2014. They found an inverted U-shaped relationship between environmental pollution and urbanization. In other words, increasing the role of urbanization decreases CO₂ emissions contrary to energy intensity and growth in GDP. Even though accounting and stochastic models like environmental impact of different variables including population, affluence and technology (IPAT), ImPACT, and STIRPAT may have advantage in terms of addressing the functional misspecification problems related with

some econometric models (fixed effect, random, etc.) and provide a clear line of action for decision makers, however, they are disadvantaged in the choice of variables and the problem of scale in relation to the quantitative analysis. Azam (2016) examined the impact of environmental pollution on economic growth in 11 Asian countries from 1990 to 2011 using the fixed and random effect estimators. The study found a negative impact of environmental pollution on economic growth though they did not test the validity of the EKC hypothesis. The study confirmed the popular notion that increasing environmental degradation hampers economic growth especially in developing countries; however, fixed and random effects are weak estimators in the presence of cross-sectional dependence. In other words, generalizing the outcome of the study to the entire Asian countries might be misleading due to the latter.

The following weaknesses or research gaps are identified from existing literature:

1. A critical appraisal of the above literature shows that there is no consensus on the EKC hypothesis due to the mixed results depending on the length of data (period), locations/countries selected, and the econometric method employed.
2. Majority of these studies employ carbon dioxide emission as the dependent variable to examine environmental degradation or environmental pollution. However, using ecological footprint as an indicator for environmental degradation provides more discussions on sustainability. Studies that employ ecological footprint as an indicator for environmental degradation are limited. To the best of our knowledge, this is the first time such a study is executed in Africa.
3. Majority of the studies that examine the EKC hypothesis only consider the negative sign and the significance of the second derivative to make statistical inferences of the presence of an inverted U shape. However, Lind and Mehlum (2010) argue that using only the aforementioned conditions may be misleading. In reality, sound judgment can only be made if the following conditions are met. First, the second derivative should have a negative sign and be significant, and second, the extremum point of the regression must be within the data range. Against the backdrop, our study improves on the limitations of the previous studies.

Vulnerability and readiness to climate change

We analyze the Vulnerability and Readiness to Climate Change using the Notre Dame Global Adaptation Index (ND-GAIN). ND-GAIN is a free and open source measurement tool that covers over 20 years of data and 45 indicators useful to analyze the vulnerability and readiness of countries

to climate change. Thus, it provides first-hand information of the risk, trend, and scenarios of climate change and its impacts. The ND-GAIN examines the vulnerability (i.e., vulnerability in water, food, health, ecosystem service, human habitat, and infrastructure) and the readiness to develop resilience to climate change. Vulnerability, thus, “measures a country’s exposure, sensitivity and ability to adapt to the negative impact of climate change”(ND-GAIN 2014). Readiness encompasses social, economic, and governance, which “measures a country’s ability to leverage investments and convert them to adaptation actions”(ND-GAIN 2014).

Figure 2 shows the 17 countries in Africa selected for the study. With regard to geographical subregion, Algeria, Egypt, Morocco, and Tunisia are in the Northern Africa geographical subregion. Benin, Côte d’Ivoire, Ghana, Nigeria, Senegal, and Togo are in the Western Africa geographical subregion. Cameroon, Congo, and Congo Democratic Republic are in

the Central Africa geographical subregion. Kenya is in the Eastern Africa geographical subregion and South Africa, Zambia, and Zimbabwe are in the Southern Africa geographical subregion. The selection of the countries was due to the availability of data; however, the geographical makeup (subregions) of the countries makes it representative enough for the entire Africa.

Democratic Republic of the Congo, Congo, Zimbabwe, Togo, Kenya, Benin, Nigeria, Côte d’Ivoire, Cameroon, Zambia, and Senegal are all in the red zone/upper-left quadrant countries based on the ND-GAIN matrix presented in Table 2. This means that the aforementioned countries require huge investment and innovations to improve their readiness for climate change mitigation and great urgency for action toward reducing climate change and its impact (ND-GAIN 2014).

A critical examination of the Human Development Index (HDI) report reveals that Democratic Republic

Fig. 2 Seventeen countries in Africa selected for the study [Source: Author’s construction with Google map]



Table 2 Vulnerability and readiness to climate change

Country	ND-GAIN matrix ^a	HDI	Rank	Env. sus (tons of CO ₂ /capita)	forest area (%)	ΔForest (%)	NR dep (%)	RE con (%)	Pop
Algeria	Yellow zone	0.745	83rd	3.5	0.8	17.3	14.7	0.2	39.7 million
Benin	Red zone	0.485	167th	0.6	38.2	−25.2	1.4	50.6	10.9 million
Côte d'Ivoire	Red zone	0.472	171st	0.4	32.7	1.8	4	74.4	22.7 million
Cameroon	Red zone	0.518	153rd	0.3	39.8	−22.6	5.6	78.1	23.3 million
Democratic Republic of Congo	Red zone	0.435	176th	0	67.3	−4.9	31.8	96	77.3 million
Congo	Red zone	0.592	135th	0.6	65.4	−1.7	39.2	48.2	4.6 million
Egypt	Green zone	0.691	111st	2.4	0.1	65.9	6.4	5.5	91.5 million
Ghana	Blue zone	0.579	139th	0.6	41	8.2	17.5	49.5	27.4 million
Kenya	Red zone	0.555	146th	0.3	7.8	−6.6	2.8	78.5	46 million
Morocco	Green zone	0.647	123rd	1.8	12.6	13.7	1	11.3	34.4 million
Nigeria	Red zone	0.527	152nd	0.6	7.7	−59.4	6.6	86.5	182.2 million
Senegal	Red zone	0.494	162nd	0.6	43	−11.5	1.1	51.4	15.1 million
South Africa	Green zone	0.666	119th	8.9	7.6	0	3.1	16.9	54.5 million
Togo	Red zone	0.487	166th	0.3	3.5	−72.6	7.8	72.7	7.3 million
Tunisia	Green zone	0.725	97th	2.5	6.7	61.9	3.8	13	11.3 million
Zambia	Red zone	0.579	139th	0.3	65.4	−7.9	8.9	88.2	16.2 million
Zimbabwe	Red zone	0.516	154th	0.9	36.4	−36.6	3.8	75.6	15.6 million

Source: Author's construction

Env. sus environmental sustainability, *ΔForest* change in the total forest area, *NR dep* natural resource depletion, *RE con* renewable energy consumption, *Pop* population

^a For pictorial view, see ESM [Appendix A](#)

of Congo ranks 176th with 0.435 HDI, 0.0 tons of carbon dioxide emissions per capita, 67.3% of total land area as forest area, −4.9% change in the total forest area, natural resource depletion of 31.8% of GNI, a renewable energy consumption of 96% of total final energy consumption, and a population of 77.3 million (UNDP 2016).

Congo ranks 135th with 0.592 HDI, 0.6 tons of carbon dioxide emissions per capita, 65.4% of total land area as forest area, −1.7% change in the total forest area, natural resource depletion of 39.2% of GNI, a renewable energy consumption of 48.2% of total final energy consumption, and a population of 4.6 million (UNDP 2016).

Zimbabwe ranks 154th with 0.516 HDI, 0.9 tons of carbon dioxide emissions per capita, 36.4% of total land area as forest area, −36.6% change in the total forest area, natural resource depletion of 3.8% of GNI, a renewable energy consumption of 75.6% of total final energy consumption, and a population of 15.6 million (UNDP 2016).

Togo ranks 166th with 0.487 HDI, 0.3 tons of carbon dioxide emissions per capita, 3.5% of total land area as forest area, −72.6% change in the total forest area, natural resource depletion of 7.8% of GNI, a renewable energy consumption of 72.7% of total final energy consumption, and a population of 7.3 million (UNDP 2016).

Kenya ranks 146th with 0.555 HDI, 0.3 tons of carbon dioxide emissions per capita, 7.8% of total land area as forest area, −6.6% change in the total forest area, natural resource depletion of 2.8% of GNI, a renewable energy consumption of 78.5% of total final energy consumption, and a population of 46 million (UNDP 2016).

Benin ranks 167th with 0.485 HDI, 0.6 tons of carbon dioxide emissions per capita, 38.2% of total land area as forest area, −25.2% change in the total forest area, natural resource depletion of 1.4% of GNI, a renewable energy consumption of 50.6% of total final energy consumption, and a population of 10.9 million (UNDP 2016).

Nigeria ranks 152nd with 0.527 HDI, 0.6 tons of carbon dioxide emissions per capita, 7.7% of total land area as forest area, −59.4% change in the total forest area, natural resource depletion of 6.6% of GNI, a renewable energy consumption of 86.5% of total final energy consumption, and a population of 182.2 million (UNDP 2016).

Côte d'Ivoire ranks 171st with 0.472 HDI, 0.4 tons of carbon dioxide emissions per capita, 32.7% of total land area as forest area, 1.8% change in the total forest area, natural resource depletion of 4% of GNI, a renewable energy consumption of 74.4% of total final energy consumption, and a population of 22.7 million (UNDP 2016).

Cameroon ranks 153rd with 0.518 HDI, 0.3 tons of carbon dioxide emissions per capita, 39.8% of total land area as forest area, – 22.6% change in the total forest area, natural resource depletion of 5.6% of GNI, a renewable energy consumption of 78.1% of total final energy consumption, and a population of 23.3 million (UNDP 2016).

Zambia ranks 139th with 0.579 HDI, 0.3 tons of carbon dioxide emissions per capita, 65.4% of total land area as forest area, – 7.9% change in the total forest area, natural resource depletion of 8.9% of GNI, a renewable energy consumption of 88.2% of total final energy consumption, and a population of 16.2 million (UNDP 2016).

Senegal ranks 162nd with 0.494 HDI, 0.6 tons of carbon dioxide emissions per capita, 43% of total land area as forest area, – 11.5% change in the total forest area, natural resource depletion of 1.1% of GNI, a renewable energy consumption of 51.4% of total final energy consumption, and a population of 15.1 million (UNDP 2016).

Ghana is the only country among the 17 in the blue zone/upper-right quadrant countries based on the ND-GAIN matrix, meaning that Ghana is in the process of responding effectively toward climate change mitigation but requires great adaptation strategies and urgency for action (ND-GAIN 2014). Ghana ranks 139th with 0.579 HDI, 0.6 tons of carbon dioxide emissions per capita, 41% of total land area as forest area, 8.2% change in the total forest area, natural resource depletion of 17.5% of GNI, a renewable energy consumption of 49.5% of total final energy consumption, and a population of 27.4 million (UNDP 2016).

In the same vein, Algeria is in the yellow zone/lower-left quadrant countries based on the ND-GAIN matrix. This means that Algeria is managing climate change vulnerabilities; however, improving their readiness to climate change mitigation will boost their future adaptation to climate stress and challenges (ND-GAIN 2014). Algeria ranks 83rd with 0.745 HDI, 3.5 tons of carbon dioxide emissions per capita, 0.8% of total land area as forest area, 17.3% change in the total forest area, natural resource depletion of 14.7% of GNI, a renewable energy consumption of 0.2% of total final energy consumption, and a population of 39.7 million (UNDP 2016).

Egypt, Morocco, South Africa, and Tunisia are in the green zone/lower-right quadrant countries based on the ND-GAIN matrix. This means these countries are well invested and innovative to readily adapt to climate change challenges even though adaptation challenges still exist (ND-GAIN 2014).

Egypt ranks 111st with 0.691 HDI, 2.4 tons of carbon dioxide emissions per capita, 0.1% of total land area as forest area, 65.9% change in the total forest area, natural resource depletion of 6.4% of GNI, a renewable energy consumption of 5.5% of total final energy consumption, and a population of 91.5 million (UNDP 2016).

Morocco ranks 123rd with 0.647 HDI, 1.8 tons of carbon dioxide emissions per capita, 12.6% of total land area as forest

area, 13.7% change in the total forest area, natural resource depletion of 1% of GNI, a renewable energy consumption of 11.3% of total final energy consumption, and a population of 34.4 million (UNDP 2016).

South Africa ranks 119th with 0.666 HDI, 8.9 tons of carbon dioxide emissions per capita, 7.6% of total land area as forest area, 0.0% change in the total forest area, natural resource depletion of 3.1% of GNI, a renewable energy consumption of 16.9% of total final energy consumption, and a population of 54.5 million (UNDP 2016).

Tunisia ranks 97th with 0.725 HDI, 2.5 tons of carbon dioxide emissions per capita, 6.7% of total land area as forest area, 61.9% change in the total forest area, natural resource depletion of 3.8% of GNI, a renewable energy consumption of 13% of total final energy consumption, and a population of 11.3 million (UNDP 2016).

As stated, Africa emits less carbon dioxide emissions; however, its impact on the continent is very significant. Analysis of the international disaster database (Guha-Sapir et al. 2016) shows that Africa has experienced climate stress-related disasters ranging from storm (includes tropical cyclone and convective storm), volcanic activity (ashfall), flood (flash flood, coastal flood, riverine flood and others), earthquake (ground movement and tsunami), extreme temperatures (heatwave and coldwave), and mass movement (dry) (landslide, subsidence, and rockfall), presented in Table 3. Table 3 reveals the social and economic impact of climate stress-related outcomes in the 17 countries in Africa. For example, Algeria has experienced 77 total disasters, 11,721 disaster-related deaths and 2,184,422 people have been affected with an economic damage of US\$ 11,814,846,000 within the past decades. The above information provides a direction for the selection of variables and the motivation for the study.

Methodology

Data

The empirical estimation of the study employs ten study variables presented in Table 4. The variables from 1971 to 2013 include agricultural land, crude birth rate, CO₂ emissions, energy use, total fertility rate, food production index, GDP per capita, square of GDP per capita, permanent cropland from the World Development Indicators,¹ and ecological footprint from the Global Footprint Network² for 17 selected countries in sub-Saharan Africa, namely, Algeria, Egypt, Morocco, Tunisia, Benin, Côte d'Ivoire, Ghana, Nigeria, Senegal, Togo, Cameroon, Congo, Congo Democratic Republic, Kenya, South Africa, Zambia, and Zimbabwe, respectively.

¹ <https://data.worldbank.org/data-catalog/world-development-indicators>

² <http://data.footprintnetwork.org>

Table 3 Climate stress-related outcomes

Country	Extreme temperature	Earthquake	Volcanic activity	Mass movement (dry)	Floods	Drought	Storm	Total disasters	Deaths	Total affected	Economic damage (US\$)
ALG	1	20	0	1	55	0	0	77	11,721	2,184,422	11,814,846,000
BEN	0	0	0	0	21	2	1	24	193	5,405,347	8,315,000
CIV	0	0	0	1	10	0	0	11	161	25,881	0
CMR	0	0	3	1	12	5	0	21	1895	946,527	1,500,000
COD	0	5	3	5	32	2	4	51	1354	1,572,268	31,200,000
COG	0	0	0	1	9	0	0	10	182	173,782	59,000
EGY	4	5	0	2	14	0	6	31	1779	376,522	1,481,000,000
GHA	0	1	0	0	20	3	0	24	467	16,402,695	120,300,000
KEN	0	1	0	4	55	15	1	76	3030	53,305,136	259,888,000
MOR	3	3	0	2	32	5	3	48	14,492	1,975,636	2,051,159,000
NGA	2	0	0	3	34	1	30	70	2767	13,428,048	718,525,000
SEN	0	0	0	0	22	10	2	34	274	10,346,412	429,235,000
SOA	3	9	0	1	25	9	38	85	1727	21,403,066	4,020,070,000
TGO	0	0	0	0	11	3	1	15	72	1,141,615	700,000
TUN	0	1	0	0	15	2	0	18	975	586,667	440,800,000
ZMB	0	0	0	1	20	5	0	26	473	9,364,712	20,900,000
ZWE	0	0	0	0	10	8	9	27	664	21,679,345	948,700,000

Source: Author's construction with data from Guha-Sapir et al. (2016)

The presented plot in ESM Appendix B reveals all the prominent trend of all the variables in the selected countries. The selection of the variables was founded on the sustainable development goals and existing literature on the scope of the study.

The ecological footprint is employed as an indicator of environmental degradation, while carbon dioxide emission is used as an indicator for environmental pollution. Ecological footprint goes beyond carbon footprint but quantifies the area of biologically productive land and water required to produce all the resources consumed and how the system absorbs its generated waste using resource management practices and predominant technologies. In this way, the global debate will

not be limited to climate change but sustainable development. ESM Appendix B shows that Tunisia has the highest ecological footprint compared to the other countries. The ecological footprint is a useful indicator for environmental and resources accounting because it accounts for the population demand on nature, such as cropland, fishing grounds, carbon footprint, forest products, and grazing land (Global Footprint Network 2017b).

Economic growth is basically the main driver of environmental degradation and pollution. However, economic growth is reliant on other factors, namely, the scale and technique effects that engineer its impact on environmental quality and deterioration. The scale effect (Stern 1998) suggests that an increase in a country's economic growth has a monotonic effect on environmental degradation, meaning that the more a country increases its economic productivity, the more the environment deteriorates due to the increasing demand for natural resources to meet the required supply. The technique effect (Islam et al. 1999) suggests that an increase in economic productivity is engineered through diversification, technological advancement such as value addition, clean and renewable energy technologies, and innovations while reducing environmental degradation. ESM Appendix B shows that South Africa has the highest economic growth compared to the other countries.

Energy consumption plays a critical role in the EKC hypothesis after economic growth. Energy consumption thus, electricity and heat production, contributes 25% (12.25 Gt CO₂-eq) of the direct global greenhouse gas emissions by economic sectors (IPCC 2016). As a result, the sustainable

Table 4 Variable description

Indicator name	Indicator code
Agricultural land (% of land area)	AGLND
Birth rate, crude (per 1000 people)	CBRT
CO ₂ emissions (kt)	CO2
Ecological footprint (gha per person)	ECF
Energy use (kg of oil equivalent per capita)	ENC
Fertility rate, total (births per woman)	TFRT
Food production index (2004–2006 = 100)	FOOD
GDP per capita (current US\$)	GDPC
Square of GDP per capita (current US\$)	GDPC ²
Permanent cropland (% of land area)	PCROP

Source: Author's construction

development goal (SDG) 7 seeks to increase the penetration of clean, renewable, and sustainable energy technologies to the global energy mix while increasing universal access to affordable energy (United Nations 2015). The inclusion of energy consumption is essential in climate change mitigation and its impact. ESM Appendix B shows that South Africa has the highest energy consumption levels compared to the other countries.

Carbon dioxide emissions have received global attention due to its effect on climate change. Sub-Saharan Africa produces less emissions compared to other developing and developed countries but more susceptible to the impact of climate change. Recent studies reveal the negative effect of carbon dioxide emissions on food production and economic growth in Africa (Asumadu and Owusu 2017b; Samuel and Owusu 2017). The inclusion of this variable is to examine the role of Africa in climate change while satisfying SDG 13, which seeks to incorporate climate change measures into national policy planning and improve education and early warning signs of climate change and adaptation options to reduce its impact in Africa (United Nations 2015). ESM Appendix B shows that South Africa is a major contributor of carbon dioxide emissions compared to the other countries due to their dependence on fossil-fuel energy sources.

Agriculture, forestry, and land use (AFOLU) is critical to global climate change and life sustenance. AFOLU contributes 24% (11.76 Gt CO₂-eq) of the direct global greenhouse gas emissions by economic sectors (IPCC 2016). As a result, the inclusion of food production, permanent crops, and agricultural lands is essential in examining the role of AFOLU in environmental degradation and pollution in Africa since Africa is an agrarian continent from which its major economic output depends on. The agricultural sector contributes 70% of employment to the population and 30% of the economic sector in Africa (UNDP 2014). Issues of deforestation, poverty, and hunger are eminent in the subregion; therefore, a systematic study of these issues meets SDGs 2 and 12 which seeks to end hunger and achieve food security and sustainable agricultural practices while ensuring sustainable production and consumption patterns (United Nations 2015). A lot of studies (Asumadu and Owusu 2016a; Sarkodie and Owusu 2017b) reveal the role played by poor agricultural practices such as manure management, fertilizer application, cropping pattern, etc. in environmental degradation in Africa. While agricultural sector contributes to climate change, it is the most vulnerable economic sector to climate change stress due to the intermittency of rainfall patterns, climate change-induced temperatures, crop failure, land and water resources depletion, and the outbreak of pest and diseases (UNDP 2014). ESM Appendix B shows that Zambia makes the highest contribution to Africa’s food basket, Nigeria has the largest land designated for agricultural activities, while Tunisia has the largest land designated for permanent crops.

Finally, women ensure food security, namely, food access, food availability and food utilization, and agricultural productivity in Africa; thus, gender plays a critical role in climate change mitigation and its impact (UNDP 2014). In developing countries, it is estimated that 20–50% of the labor force in the agricultural sector is women. In Africa, 50% of women occupy the agricultural labor force, while in the least developed countries, agriculture is the primary occupation of 79% of the economically active women. However, the role of women in agriculture is dependent on their age, ethnicity, region, and social status (UNDP 2014). Therefore, the inclusion of fertility rate is essential to understanding the role of gender in climate change. It is important to note that the underlying cause of population growth is fertility and birth rates. Increasing population growth increases the demand on the natural resources (ecological footprint) which reduces the biocapacity of nature leading to an ecological deficit. Against the background, the determinants of environmental degradation and pollution cannot omit the sociodemographic role played by fertility and birth rates especially in Africa. ESM Appendix B shows that almost the 17 countries have the same fertility rates; however, Côte d’Ivoire and Kenya have the highest fertility rate, while Côte d’Ivoire has the highest crude birth rates.

Westerlund error-correction model

Different panel cointegration and error-correction methods, including the popular Pedroni test, have been reported in the literature. However, our study employs the Westerlund (Persyn and Westerlund 2008) cointegration test due to its enormous advantages required in this study. Westerlund is based on four structural cointegration tests which are normally distributed, contrary to the residual dynamics; hence, no common factor restriction is imposed. Two of these cointegration tests exam the presence of error correction in individual units, while the other two tests exam the presence of error correction in the whole panel. The null hypothesis of the test infers whether the conditional error-correction term is zero, thus no cointegration across cross-sectional units and the panel in totality. Contrary to other tests, Westerlund test accommodates unit-specific trends, unit-specific short-run dynamics, parameters of the slope, and cross-sectional dependence, a major problem with panel data (Persyn and Westerlund 2008). Alternatively, Westerlund test can compute for robust values using a bootstrapping method when serial correlation is suspected in cross-sectional units. To examine the cointegration among the variables in the panel, the study employs the WECM-based panel cointegration tests by Persyn and Westerlund (2008) expressed as:

$$\Delta y_{it} = \delta'_i d_t + a_i y_{i, t-1} + \lambda'_i x_{i, t-1} + \sum_{j=1}^{p_i} a_{ij} \Delta y_{i, t-j} + \sum_{j=-q_i}^{p_i} \gamma_{ij} \Delta x_{i, t-j} + \varepsilon_{it} \tag{1}$$

Where y and x are the dependent (lnECF | lnCO2) and independent (lnENC, lnGDPC, and lnGDPC2) observations for cross-sectional units ($i = 1, \dots, N$) in period ($t = 1, \dots, T$), d_t has a deterministic element, ε is the error term, $\lambda'_i = -a_i\beta'_i$, and the speed of adjustment toward equilibrium ($y_{i,t-1} - \beta'_i x_{i,t-1}$) is executed by parameter a_i after an immediate shock. Thus, y_{it} and x_{it} are cointegrated if $a_i < 0$, fulfilling the condition of the error correction, while $a_i = 0$ shows no cointegration and no error correction across the individuals in the panel.

We progress to estimate the group mean tests expressed as:

$$\Delta y_{it} = \hat{\delta}'_i d_t + \hat{a}_i y_{i,t-1} + \hat{\lambda}'_i x_{i,t-1} + \sum_{j=1}^{p_i} \hat{a}_{ij} \Delta y_{i,t-j} + \sum_{j=-q_i}^{p_i} \hat{\gamma}_{ij} \Delta x_{i,t-j} + \hat{\varepsilon}_{it} \tag{2}$$

Where p_i and q_i are the lag and lead orders allowed to differ across the individuals in the panel. For brevity, the detailed algorithm and explanations are available in Persyn and Westerlund (2008).

U-shape relationship test

A lot of studies on the EKC hypothesis employ the nonlinear term mostly a quadratic term of economic growth, the negative sign and the significance of the quadratic term to arrive at a conclusion of a U-shape curve using the standard regression method. However, the test is weak and produces an error when a de facto relationship is “convex but monotone over relevant data values” (Lind and Mehlum 2010). The Utest provides a solution to the outlined weaknesses of the existing method. The Utest command is used in Stata after the estimation method to corroborate the EKC hypothesis using the quadratic term. Three types of curves are reported by the Utest, namely, a U shape, an inverted U shape, and a monotone, respectively. In order to test for a U-shape relationship, the Utest begins with a simplified regression formula expressed as (Lind and Mehlum 2010):

$$y_i = \alpha + \beta x_i + \gamma f(x_i) + \varphi z_i + \varepsilon_i, i = 1, 2, \dots, n. \tag{3}$$

Where y is the dependent variable; x is the independent variable of interest; β , γ , and φ are the parameters of the model; f is a known function that provides a curvature to the equation; z denotes a “vector for control variables”; and ε represents the error term.

The known function (f) is assumed to have one extreme point within the data range of x values [x_l, x_h]. A U-shape relationship means that the model fulfills the condition:

$$\beta + \gamma f'(x_l) < 0 < \beta + \gamma f'(x_h) \tag{4}$$

The violation of the conditions leads to an inverse U shape or a monotone. Thus, under the null hypothesis [$H_0: \beta +$

$\gamma f'(x_l) \geq 0$ and/or $\beta + \gamma f'(x_h) \leq 0$] against the alternative hypothesis [$H_1: \beta + \gamma f'(x_l) < 0$ and $\beta + \gamma f'(x_h) > 0$]. The most comprehensive algorithm of the Utest is available at Lind and Mehlum (2010).

Fixed and random effect estimators

The study employs the fixed and random effect estimators by following the standard panel data model expressed as:

$$\ln ECF_{i,t} = \alpha + \beta_1 \ln ENC_{i,t} + \beta_2 \ln GDPC_{i,t} + \beta_3 \ln GDPC^2_{i,t} + \beta_4 \ln FOOD_{i,t} + \beta_5 \ln PCROP_{i,t} + \beta_6 \ln AGLND_{i,t} + \beta_7 \ln CO2_{i,t} + \beta_8 \ln CBRT_{i,t} + \beta_9 \ln TFRT_{i,t} + u_{i,t} \tag{5}$$

$$\ln CO2_{i,t} = \alpha + \beta_1 \ln ECF_{i,t} + \beta_2 \ln ENC_{i,t} + \beta_3 \ln GDPC_{i,t} + \beta_4 \ln GDPC^2_{i,t} + \beta_5 \ln FOOD_{i,t} + \beta_6 \ln PCROP_{i,t} + \beta_7 \ln AGLND_{i,t} + \beta_8 \ln CBRT_{i,t} + \beta_9 \ln TFRT_{i,t} + u_{i,t} \tag{6}$$

Where lnECF | lnCO2 are the logarithmic transformation of the dependent variables; α denotes the time-invariant nuisance parameter in individual i and time t ; lnENC, lnGDPC, lnGDPC2, lnFOOD, lnPCROP, lnAGLND, lnCBRT, and lnTFRT are the log of the independent variables (regressors); and u is assumed to be independent and identically distributed across the cross-sectional units over a time period. Thus, the null hypothesis [$H_0: \rho_{i,j} = \rho_j, i = \text{cor}(u_{i,t}, u_{j,t}) = 0$ for $i \neq j$] versus the alternative hypothesis [$H_1: \rho_{i,j} = \rho_j, i \neq 0$ for $i \neq j$] where $\rho_{i,j}$ is the “product moment of correlation coefficient of the disturbances.”

The study employs the Hausman (1978) specification test to compare the estimators of the fixed and random effect models expressed as:

$$H = (\beta_a - \beta_b)' (V_a - V_b)^{-1} (\beta_a - \beta_b) \tag{7}$$

Where the Hausman’s test statistic (H) is a distributed chi-squared (χ^2) under H_0 : difference in coefficients not systematic, β_a denotes the consistent estimator’s coefficient vector, β_b denotes the efficient estimator’s coefficient vector, V_a represents the consistent estimator’s covariance matrix, and V_b represents the efficient estimator’s covariance matrix.

Panel causality test

We examine the causality in the heterogeneous panel data using the Dumitrescu and Hurlin (2012) Granger noncausality test, an augmented version of Granger (1969) expressed as:

$$y_{i,t} = \alpha_i \sum_{k=1}^K \gamma_i^{(k)} y_{i,t-k} + \sum_{k=1}^K \beta_i^{(k)} x_{i,t-k} + \varepsilon_{i,t} \tag{8}$$

Where lag order $K \in N^*$ is the same for all the individuals in the panel and $\beta_i = (\beta_i^{(1)}, \beta_i^{(2)}, \dots, \beta_i^{(k)})'$ represents the

coefficients that are time constant and can vary across the individuals in the panel, under the null hypothesis ($H_0 : \beta_i = 0, \forall i = 1, 2, \dots, N$) of noncausality versus the alternative hypothesis [$H_a : \{ \beta_i = 0, \forall i = 1, 2, \dots, N_1 \} \beta_i \neq 0, \forall i = N_1 + 1, N_1 + 2, \dots, N$] where the unknown N_1 follows the condition $0 \leq N_1/N < 1$] of causality among at least one panel var. The causality test includes an average Wald statistic across the individuals in the panel and reports the P value of the Z -bar (\bar{Z}) statistic used in the study.

Results and discussion

Descriptive statistics

The study examines the descriptive statistical analysis to understand the characteristics exhibited by the study variables before any preprocessing prior to the selection of an estimation method, econometric modeling, and simulation.

ESM Appendix C reveals that the minimum, average, and maximum fertility rates in Africa are almost 2, 6, and 8 births per woman. However, Africa exhibits both negative skewness and negative kurtosis, meaning that there are frequent small gains in births per woman throughout the reproductive age and few extreme birth complications leading to child mortality. But, the fertility rate of a woman's reproductive age is propelled by internal decisions rather than external factors. The average crude birth rate in Africa is almost 39 births per 1000 people in a year but then again exhibits a negative skewness and a positive kurtosis. This means that the frequent small gains in annual births are due to external factors rather than internal decisions. The average permanent crops in Africa are almost 3% of the land area while exhibiting positive skewness and kurtosis, meaning that there are frequent small losses of the permanent crops because of poor agricultural practices and human-induced activities; nonetheless, there is a low tendency of converting land area for permanent cropping. The average agricultural land in Africa constitutes about 42% of the land area; however, the negative skewness shows a frequently small conversion of the land area into agricultural lands for agricultural purposes to boost the growing demand and economic productivity. The average food production index in Africa is almost 75%; however, there are frequent small losses in food production (positively skewed) due to preharvest, harvest, and postharvest losses.

The mean energy consumption in Africa is about 606 kg of oil equivalent per capita coupled with a positive skewness and leptokurtic distribution. This means that Africa has a high susceptibility to intermittent energy consumption patterns. The average carbon dioxide emissions in Africa is about 39,642 kt, while ecological footprint is 1.4 gha per person; however, the excess kurtosis and positive skewness show

the vulnerability of Africa to environmental degradation and pollution. In other words, there is a high risk of extreme outcome due to environmental pollution and degradation. The average economic growth is almost US\$ 1045 per capita with a positive skewness and positive excess kurtosis. The average US\$ 1045 per capita shows that each household can spend about US\$ 2.9 per day (i.e., US\$ 1045/365), which is above the poverty line of US\$ 1.90 per day (United Nations 2015). However, this is 17 countries of the recognized 54 nations in Africa, meaning that Africa has a high risk of extreme economic variability. The Jarque-Bera test shows that none of the variables are normally distributed. As a result, a logarithmic transformation is applied to the variables to have a constant variance prior to econometric analysis.

Panel unit root tests

The fundamental difference between time series and panel data is the issues of heterogeneity. The latter has low power to differentiate between stationary and nonstationary series in panel data with small sample sizes (Hurlin and Mignon 2007). As such, we employ the first-generation cross-sectional independence panel unit root tests, namely, Breitung, Fisher type, Im-Pesaran-Shin (IPS), Levin-Lin-Chu (LLC), and Harris-Tzavalis (HT) for the nonstationary test and the Hadri Lagrange multiplier (LM) for the stationary test. In order to provide a more accurate outcome, the study employs seven different panel unit root tests. Evidence from Table 5 shows that the null hypothesis that the variable is nonstationary cannot be rejected using the nonstationary tests; however, the null hypothesis is rejected at first difference. To corroborate the results, a further test is done using Hadri LM to test the null hypothesis of stationarity. The results confirm that the variables are integrated of order one.

Fixed and random effect

After the verification and confirmation of first-order integration of the variables, we use the within regression estimator to fit the fixed effect model while the generalized least squares (GLS) estimator is used to fit the random effect model. Table 6 presents the results of the fixed and random effects on ecological footprint, while Table 7 shows the effect on carbon dioxide emissions. Tables 6 and 7 show that both models are statistically significant for $\ln ECF$ and $\ln CO_2$.

We employ the Hausman's specification test to compare the estimates of the fixed and random effect models. The Hausman's test in Table 6 reveals that the chi-square is large and shows a significant difference, thus the null hypothesis that both fixed and random effects are not significantly different is rejected at 5% significance level. This means that the fixed effect model is selected over the random effect model in Table 6. On the contrary, the Hausman's test in Table 7 shows

Table 5 Panel unit root tests

Variable	Breitung		Fisher type		IPS		Hadri LM		LLC		HT		
	Level	1st diff	ADF χ^2	Level	1st diff	Z-t stats	Z stats	Level	1st diff	t stats	Level	Z stats	
ECF	1.9392	-12.1395	65.6237	791.1756	791.1756	-0.6385	-17.1213	80.8276	-1.9824	-0.7368	-14.6313	-2.0708	69.5621
Prob	0.9738	0.0000	0.0009	0.0000	0.0000	0.2616	0.0000	0.0000	0.9763	0.2306	0.0000	0.0192	0.0000
ENC	4.5294	-16.5497	13.6769	573.9169	573.9169	3.2073	-15.1665	85.7879	0.9739	-0.0691	-10.7325	1.2265	-52.6782
Prob	1.0000	0.0000	0.9993	0.0000	0.0000	0.9993	0.0000	0.0000	0.1650	0.4725	0.0000	0.8900	0.0000
GDPC	8.0158	-15.3114	7.6024	458.9845	458.9845	9.0423	-13.4439	77.6233	2.6248	6.1984	-10.0414	4.5370	-44.7681
Prob	1.0000	0.0000	1.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0043	1.0000	0.0000	1.0000	0.0000
GDPC2	8.4494	-14.8703	4.4315	432.9814	432.9814	12.9765	-12.8919	69.5800	2.5299	11.9906	-7.8119	4.6261	-40.7496
Prob	1.0000	0.0000	1.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0057	1.0000	0.0000	1.0000	0.0000
FOOD	11.0781	-13.4367	18.6352	753.8335	753.8335	10.9388	-16.2079	96.3252	-0.1305	9.8302	-12.3930	4.2661	-67.6376
Prob	1.0000	0.0000	0.9850	0.0000	0.0000	1.0000	0.0000	0.0000	0.5519	1.0000	0.0000	1.0000	0.0000
PCR0P	8.6936	-11.8656	10.2984	329.3797	329.3797	*	*	100.7910	4.9491	2.0865	-4.2250	3.3767	-36.1160
Prob	1.0000	0.0000	1.0000	0.0000	0.0000	*	*	0.0000	0.0000	0.9815	0.0000	0.9996	0.0000
AGLND	7.3362	-12.1562	23.3850	477.4768	477.4768	4.1781	-13.7632	99.1587	0.5611	0.3450	-7.4656	3.1941	-52.8914
Prob	1.0000	0.0000	0.9145	0.0000	0.0000	1.0000	0.0000	0.0000	0.2874	0.6350	0.0000	0.9993	0.0000
CBRT	14.9164	2.8600	64.5447	18.8626	18.8626	6.5164	3.0990	105.3985	35.2644	-11.8411	-19.5118	3.0258	-2.1638
Prob	1.0000	0.9979	0.0012	0.9833	0.0012	1.0000	0.9990	0.0000	0.0000	0.0000	0.0000	0.9988	0.0152
TFRIT	14.9930	3.8256	52.6391	63.6242	63.6242	6.3677	0.8193	108.3148	45.3498	-21.6220	-14.3351	3.2275	0.8181
Prob	1.0000	0.9999	0.0216	0.0015	0.0015	1.0000	0.7937	0.0000	0.0000	0.0000	0.0000	0.9994	0.0000
CO2	6.4461	-17.5294	20.5981	747.1428	747.1428	4.4298	-16.7552	101.9118	-2.5043	4.1434	-12.9565	2.6584	-58.9343
Prob	1.0000	0.0000	0.9659	0.0000	0.0000	1.0000	0.0000	0.0000	0.9939	1.0000	0.0000	0.9961	0.0000

Source: Author's construction

*Normality of Z-t-tilde-bar requires at least 7 observations per panel with balanced data and a time trend

Table 6 Fixed and random effects on lnECF

Variable	Fixed effects				Random effects			
	Coef.	Std. err.	<i>t</i>	<i>P</i> > <i>t</i>	Coef.	Std. err.	<i>Z</i>	<i>P</i> > <i>Z</i>
lnENC	0.4751	0.0313	15.1800	0.0000	0.4424	0.0302	14.6500	0.0000
lnGDPC	−0.5470	0.0959	−5.7100	0.0000	−0.5494	0.0960	−5.7200	0.0000
lnGDPC ²	0.0433	0.0072	6.0200	0.0000	0.0434	0.0072	6.0200	0.0000
lnFOOD	0.0666	0.0265	2.5200	0.0120	0.0374	0.0236	1.5900	0.1120
lnPCROP	−0.1625	0.0253	−6.4200	0.0000	−0.0896	0.0200	−4.4900	0.0000
lnAGLND	0.2063	0.0809	2.5500	0.0110	0.1106	0.0518	2.1300	0.0330
lnCO ₂	0.0587	0.0161	3.6500	0.0000	0.0507	0.0147	3.4500	0.0010
lnCBRT	−0.2048	0.1795	−1.1400	0.2540	−0.2637	0.1794	−1.4700	0.1420
lnTFRT	0.3577	0.1320	2.7100	0.0070	0.3700	0.1325	2.7900	0.0050
_cons	−2.4159	0.6674	−3.6200	0.0000	−1.4652	0.6367	−2.3000	0.0210
sigma _u	0.3713	<i>F</i> (9, 705)	67.0100	<i>R</i> -sq:	0.2083	Wald chi ² (9)	587.1400	<i>R</i> -sq:
sigma _e	0.1184	Prob > <i>F</i>	0.0000	0.3861	0.1184	Prob > chi ²	0.0000	0.4802
rho	0.9077	corr(<i>u_i</i> , <i>Xb</i>)	−0.7510		0.7557	corr(<i>u_i</i> , <i>X</i>)	0.0000	

Hausman test
 chi²(9) = 29.1300
 Prob > chi² = 0.0006

Source: Author’s construction

no significant difference between the two models; as such, the null hypothesis cannot be rejected at 5% significant level. In other words, both fixed and effect models can be used.

Interpretation of the results in Table 6 means that an increase in energy consumption increases environmental

degradation (lnECF) by 0.48%. Contrary to the EKC hypothesis, economic growth decreases environmental degradation 6% ($-\beta_2/2\beta_3$) and increases thereafter. This means that the EKC hypothesis is not valid for this model. An increase in food production, agricultural land, carbon dioxide emissions,

Table 7 Fixed and random effect lnCO₂

Variables	Fixed effects				Random effects			
	Coef.	Std. err.	<i>t</i>	<i>P</i> > <i>t</i>	Coef.	Std. err.	<i>Z</i>	<i>P</i> > <i>Z</i>
lnECF	0.3164	0.0866	3.6500	0.0000	0.3181	0.0870	3.6600	0.0000
lnENC	0.3512	0.0826	4.2500	0.0000	0.3534	0.0823	4.3000	0.0000
lnGDPC	2.1779	0.2124	10.2500	0.0000	2.2374	0.2136	10.4700	0.0000
lnGDPC ²	−0.1438	0.0163	−8.8400	0.0000	−0.1485	0.0163	−9.0800	0.0000
lnFOOD	0.0593	0.0617	0.9600	0.3370	0.0978	0.0603	1.6200	0.1050
lnPCROP	0.2470	0.0598	4.1300	0.0000	0.2409	0.0572	4.2100	0.0000
lnAGLND	0.8890	0.1857	4.7900	0.0000	0.7008	0.1693	4.1400	0.0000
lnCBRT	−0.0067	0.4172	−0.0200	0.9870	0.0346	0.4200	0.0800	0.9340
lnTFRT	−0.5326	0.3074	−1.7300	0.0840	−0.5641	0.3096	−1.8200	0.0690
_cons	−3.6293	1.5580	−2.3300	0.0200	−3.4305	1.5757	−2.1800	0.0290
sigma _u	1.7232	<i>F</i> (9, 705)	201.49	<i>R</i> -sq:	1.2318	Wald chi ² (9)	1781.34	<i>R</i> -sq:
sigma _e	0.2750	Prob > <i>F</i>	0.0000	0.1418	0.2750	Prob > chi ²	0.0000	0.1783
rho	0.9752	corr(<i>u_i</i> , <i>Xb</i>)	−0.3089		0.9525	corr(<i>u_i</i> , <i>X</i>)	0.0000	

Hausman test
 chi²(9) = 1.44
 Prob > chi² = 0.9975

Source: Author’s construction

and fertility rate increases environmental degradation by 0.07, 0.21, 0.06, and 0.36%, while permanent crop reduces environmental degradation by 0.16%, respectively.

On environmental pollution ($\ln\text{CO}_2$), an increase in ecological footprint, energy consumption, permanent crop, and agricultural land increases environmental pollution by 0.32, 0.35, 0.25, and 0.89%, respectively. Economic growth increases environmental pollution by 7.6% ($-\beta_2/2\beta_3$) and decreases thereafter, thus validating the EKC hypothesis in 17 African countries contrary to the study of Zoundi (2017) that found no evidence of EKC in Africa.

WECM analysis

Due to the weaknesses of both the fixed and random effect models, we adopt a more robust model that examines the cointegration of the panel data. In addition, error correction, long-run and short-run equilibrium relationships, mean-group estimates, country-specific outputs, and four additional test statistics are reported based on 1000 bootstrapped samples. Table 8 presents the results of Westerlund error-correction-based panel cointegration tests. The P value of the Gt and $G\alpha$ test statistics, which employ the individually weighted averages of the estimated α_i 's and t ratios and the P value of the Pt and $P\alpha$, which pool information over the entire cross-sectional units are significant at 1% level thus, rejects the null hypothesis of no cointegration. Meaning that at least one cross-sectional unit (Gt and $G\alpha$) is cointegrated and evidence of cointegration in the entire panel (Pt and $P\alpha$). As a sensitivity analysis, the study examines a possible effect of cross-sectional dependencies in the panel data by employing the bootstrapping method for 1000 samples presented as robust probability values in Table 8. Evidence from the bootstrapping method validates the previous results; thus, the null hypothesis of no cointegration is rejected.

After validating the existence of cointegration, we examine the error correction of the entire panel. Table 8 reveals that the error correction ($ec = -0.58$ for ECF and -0.55 for CO_2) is negative and significant at 1% level, meaning the speed of adjustment in correcting the previous disturbances in environmental degradation and environmental pollution is 58 and 55%, respectively. We use the MG model to evaluate the whole panel on environmental degradation/pollution-energy-economic growth nexus. The results of the MG model reveal that an increase in energy consumption increases environmental degradation by 0.22% and environmental pollution by 0.42%. On the contrary, an increase in economic growth increases environmental degradation by 13% and increases thereafter, thus confirming the scale effect. The scale effect (Stern 1998) suggests a monotonic increase between environmental degradation and a country's economic growth. However, an increase in economic growth increases environmental pollution by 7.9% and decreases thereafter, thus

corroborating the validity of the EKC hypothesis by the random effect model, meaning that environmental degradation is problematic in Africa compared to environmental pollution. Our results are in line with Effiong and Iriabije (2018) and Twerefou et al. (2017) that confirmed the validity of the EKC hypothesis in SSA contrary to Zerbo (2017) and Zoundi (2017) which reject the validity of the EKC hypothesis in SSA.

The next step is to examine the long-run and the short-run equilibrium relationship of the whole panel data. Table 8 reveals that the long-run equilibrium relationship for both models is not significant; however, the short-run relationship reveals that energy consumption increases environmental degradation by 0.30% and environmental pollution by 1% in the short run. As expected, energy consumption appears to be the greatest driver of environmental degradation and environmental pollution in the short term. Energy demand in Africa has increased by half since 2000, with Nigeria and South Africa accounting for 40% of the demand (International Energy Agency 2014). Bioenergy accounts for 60% of Africa's total energy driven by the famous firewood and charcoal for cooking and heating purposes. Apart from Namibia and South Africa, bioenergy dominates the total energy mix of each country in Africa (International Energy Agency 2014). The dominance of bioenergy comes with illegal felling of trees for firewood and timber and burning of firewood for charcoal production, which results in the deterioration of the environment while reducing air quality.

Away from the MG estimation and generalization of the results, we examine the detailed output (long run, short run, and error correction) of the individual countries presented in Table 8. On Algeria (ALG), the error correction ($ec = -0.81, -0.72$) is negative and significant. This means that the speed of adjusting the disturbance in environmental degradation and pollution in Algeria is 81 and 72%; however, both long-run and short-run relationships are not significant in both models.

On Benin (BEN), the error correction ($ec = -0.74, -0.64$) is negative and significant, meaning the speed of correcting the disturbances in environmental degradation and pollution to equilibrium in Benin is 74 and 64%; however, the short-run relationship is not significant. The long-run equilibrium relationship shows that energy consumption increases environmental degradation while economic growth decreases environmental degradation and increases thereafter, confirming a recent study in Benin (Owusu and Samuel 2016a). Moreover, economic growth decreases environmental pollution in Benin and increases thereafter.

On Côte d'Ivoire (CIV), the error correction ($ec = -0.72, -0.52$) is negative and significant. This means that it takes 72 and 52% speed to adjust the disturbances in previous environmental degradation and pollution in Côte d'Ivoire. The long-run equilibrium relationship shows that energy consumption increases environmental degradation in the long-run; thus,

Table 8 Environmental degradation/pollution-energy-economic growth nexus

Country	Variable	ECF				CO ₂			
		Coef.	Std. err.	Z	P>Z	Coef.	Std. err.	Z	P>Z
ALG	lnENC L1.	-0.1529	0.1196	-1.2800	0.2010	0.3675	0.2339	1.5700	0.1160
	lnGDPC L1.	1.0314	0.5346	1.9300	0.0540	-0.6943	1.1305	-0.6100	0.5390
	lnGDPC ² L1.	-0.0483	0.0343	-1.4100	0.1590	0.0434	0.0716	0.6100	0.5440
	_cons	-21.9809	5.8854	-3.7300	0.0000	-11.9086	13.0765	-0.9100	0.3620
	trend	0.0092	0.0025	3.6100	0.0000	0.0102	0.0058	1.7600	0.0780
	ec	-0.8127	0.1894	-4.2900	0.0000	-0.7185	0.1501	-4.7900	0.0000
	lnENC D1.	-0.1762	0.2250	-0.7800	0.4340	-0.3794	0.4262	-0.8900	0.3730
BEN	lnGDPC D1.	2.2187	1.6087	1.3800	0.1680	-1.3221	3.1546	-0.4200	0.6750
	lnGDPC ² D1.	-0.1330	0.1042	-1.2800	0.2020	0.0811	0.2032	0.4000	0.6900
	lnENC L1.	0.2425	0.1233	1.9700	0.0490	-0.4108	0.5035	-0.8200	0.4150
	lnGDPC L1.	-1.3563	0.4140	-3.2800	0.0010	-4.7382	1.7807	-2.6600	0.0080
	lnGDPC ² L1.	0.1116	0.0361	3.0900	0.0020	0.4102	0.1558	2.6300	0.0080
	_cons	-2.1424	4.1205	-0.5200	0.6030	-66.2716	23.8648	-2.7800	0.0050
	trend	0.0025	0.0015	1.6100	0.1080	0.0435	0.0117	3.7100	0.0000
CIV	ec	-0.7392	0.1446	-5.1100	0.0000	-0.6355	0.1403	-4.5300	0.0000
	lnENC D1.	0.1504	0.1273	1.1800	0.2380	1.0093	0.5499	1.8400	0.0660
	lnGDPC D1.	-1.7883	0.9689	-1.8500	0.0650	-0.9222	4.2348	-0.2200	0.8280
	lnGDPC ² D1.	0.1581	0.0825	1.9200	0.0550	0.0897	0.3610	0.2500	0.8040
	lnENC L1.	0.3296	0.1174	2.8100	0.0050	-0.1828	0.3169	-0.5800	0.5640
	lnGDPC L1.	-0.9317	1.1935	-0.7800	0.4350	0.6356	3.2993	0.1900	0.8470
	lnGDPC ² L1.	0.0780	0.0915	0.8500	0.3940	-0.0436	0.2507	-0.1700	0.8620
CMR	_cons	21.1193	7.3699	2.8700	0.0040	-6.1881	13.4249	-0.4600	0.6450
	trend	-0.0102	0.0028	-3.6800	0.0000	0.0048	0.0039	1.2400	0.2170
	ec	-0.7202	0.1618	-4.4500	0.0000	-0.5187	0.1616	-3.2100	0.0010
	lnENC D1.	0.0382	0.1405	0.2700	0.7860	0.4018	0.4175	0.9600	0.3360
	lnGDPC D1.	0.0765	2.4639	0.0300	0.9750	-6.2462	7.0314	-0.8900	0.3740
	lnGDPC ² D1.	0.0102	0.1842	0.0600	0.9560	0.4749	0.5256	0.9000	0.3660
	lnENC L1.	-0.2221	0.1866	-1.1900	0.2340	-1.9257	1.4811	-1.3000	0.1940
COD	lnGDPC L1.	0.3612	0.3839	0.9400	0.3470	6.7166	4.2827	1.5700	0.1170
	lnGDPC ² L1.	-0.0299	0.0299	-1.0000	0.3180	-0.4868	0.3308	-1.4700	0.1410
	_cons	0.6813	5.0190	0.1400	0.8920	-2.8816	27.9272	-0.1000	0.9180
	trend	-0.0002	0.0020	-0.1100	0.9130	-0.0020	0.0116	-0.1700	0.8610
	ec	-0.0465	0.1167	-0.4000	0.6900	-0.5645	0.1427	-3.9600	0.0000
	lnENC D1.	-0.1498	0.2469	-0.6100	0.5440	1.2555	2.7665	0.4500	0.6500
	lnGDPC D1.	-0.4010	1.2953	-0.3100	0.7570	10.4872	14.8837	0.7000	0.4810
COG	lnGDPC ² D1.	0.0271	0.0972	0.2800	0.7800	-0.8519	1.1148	-0.7600	0.4450
	lnENC L1.	0.0243	0.0643	0.3800	0.7060	0.4807	0.8426	0.5700	0.5680
	lnGDPC L1.	0.0789	0.1362	0.5800	0.5620	2.4291	1.3430	1.8100	0.0700
	lnGDPC ² L1.	-0.0064	0.0122	-0.5200	0.6010	-0.2099	0.1199	-1.7500	0.0800
	_cons	-0.0751	1.2763	-0.0600	0.9530	1.3206	6.8901	0.1900	0.8480
	trend	-0.0002	0.0007	-0.2300	0.8160	-0.0046	0.0031	-1.5100	0.1300
	ec	0.0163	0.1015	0.1600	0.8720	-0.2397	0.1136	-2.1100	0.0350
COG	lnENC D1.	0.0203	0.0836	0.2400	0.8080	2.0927	0.8145	2.5700	0.0100
	lnGDPC D1.	0.5273	0.1872	2.8200	0.0050	0.7248	1.7934	0.4000	0.6860
	lnGDPC ² D1.	-0.0487	0.0174	-2.8000	0.0050	-0.0667	0.1650	-0.4000	0.6860
COG	lnENC L1.	0.1605	0.1448	1.1100	0.2680	-0.2132	0.7621	-0.2800	0.7800
	lnGDPC L1.	0.6498	0.5316	1.2200	0.2220	-0.5687	2.7454	-0.2100	0.8360
	lnGDPC ² L1.	-0.0425	0.0413	-1.0300	0.3040	0.0704	0.2137	0.3300	0.7420

Table 8 (continued)

	_cons	-5.8474	7.5053	-0.7800	0.4360	20.7110	40.7248	0.5100	0.6110
	trend	0.0012	0.0028	0.4300	0.6640	-0.0086	0.0160	-0.5400	0.5910
	ec	-0.4966	0.1343	-3.7000	0.0000	-0.2607	0.1526	-1.7100	0.0880
	lnENC D1.	0.2400	0.1642	1.4600	0.1440	-0.3218	0.8458	-0.3800	0.7040
	lnGDPC D1.	3.0957	0.9626	3.2200	0.0010	3.4800	5.1086	0.6800	0.4960
	lnGDPC ² D1.	-0.2274	0.0687	-3.3100	0.0010	-0.2277	0.3601	-0.6300	0.5270
EGY	lnENC L1.	0.1000	0.1088	0.9200	0.3580	0.2907	0.1373	2.1200	0.0340
	lnGDPC L1.	0.2100	0.2321	0.9000	0.3660	1.0376	0.3893	2.6600	0.0080
	lnGDPC ² L1.	-0.0089	0.0160	-0.5600	0.5780	-0.0657	0.0258	-2.5500	0.0110
	_cons	0.1029	5.1376	0.0200	0.9840	-53.4103	11.8535	-4.5100	0.0000
	trend	-0.0008	0.0027	-0.2800	0.7770	0.0290	0.0063	4.5700	0.0000
	ec	-0.5227	0.1642	-3.1800	0.0010	-0.8922	0.1811	-4.9300	0.0000
	lnENC D1.	0.5370	0.1335	4.0200	0.0000	0.5037	0.1831	2.7500	0.0060
	lnGDPC D1.	-0.8540	0.6358	-1.3400	0.1790	0.4468	0.9210	0.4900	0.6280
	lnGDPC ² D1.	0.0741	0.0474	1.5600	0.1180	-0.0189	0.0689	-0.2700	0.7840
GHA	lnENC L1.	0.0267	0.0753	0.3500	0.7230	0.4423	0.1761	2.5100	0.0120
	lnGDPC L1.	-0.3211	0.4580	-0.7000	0.4830	-3.3973	0.9674	-3.5100	0.0000
	lnGDPC ² L1.	0.0238	0.0351	0.6800	0.4980	0.2629	0.0743	3.5400	0.0000
	_cons	-5.6283	1.9952	-2.8200	0.0050	-44.8869	9.4160	-4.7700	0.0000
	trend	0.0033	0.0012	2.7300	0.0060	0.0297	0.0058	5.1000	0.0000
	ec	-0.1078	0.0698	-1.5400	0.1230	-0.7073	0.1424	-4.9700	0.0000
	lnENC D1.	0.1321	0.1248	1.0600	0.2900	-0.0948	0.3092	-0.3100	0.7590
	lnGDPC D1.	0.9465	0.6883	1.3800	0.1690	-3.5771	1.5219	-2.3500	0.0190
	lnGDPC ² D1.	-0.0720	0.0551	-1.3100	0.1920	0.3120	0.1217	2.5600	0.0100
KEN	lnENC L1.	0.5070	0.3167	1.6000	0.1090	1.9164	1.2762	1.5000	0.1330
	lnGDPC L1.	0.1985	0.2521	0.7900	0.4310	0.4769	0.9983	0.4800	0.6330
	lnGDPC ² L1.	-0.0148	0.0210	-0.7000	0.4820	-0.0463	0.0842	-0.5500	0.5820
	_cons	10.3793	5.2907	1.9600	0.0500	-22.6489	12.6203	-1.7900	0.0730
	trend	-0.0070	0.0023	-3.0900	0.0020	0.0056	0.0039	1.4200	0.1560
	ec	-0.5160	0.1502	-3.4300	0.0010	-0.1579	0.1314	-1.2000	0.2290
	lnENC D1.	0.1172	0.3698	0.3200	0.7510	3.4966	1.6582	2.1100	0.0350
	lnGDPC D1.	0.1771	0.7492	0.2400	0.8130	0.5127	2.9115	0.1800	0.8600
	lnGDPC ² D1.	-0.0138	0.0631	-0.2200	0.8260	-0.0335	0.2443	-0.1400	0.8910
MOR	lnENC L1.	0.1601	0.2796	0.5700	0.5670	0.3632	0.1540	2.3600	0.0180
	lnGDPC L1.	-1.2589	0.4154	-3.0300	0.0020	1.1751	0.2604	4.5100	0.0000
	lnGDPC ² L1.	0.1038	0.0322	3.2200	0.0010	-0.0764	0.0183	-4.1900	0.0000
	_cons	-9.1789	8.5132	-1.0800	0.2810	-39.7102	13.9373	-2.8500	0.0040
	trend	0.0061	0.0049	1.2400	0.2150	0.0204	0.0077	2.6400	0.0080
	ec	-1.3497	0.1460	-9.2500	0.0000	-0.7420	0.2048	-3.6200	0.0000
	lnENC D1.	0.5376	0.3286	1.6400	0.1020	0.6581	0.2223	2.9600	0.0030
	lnGDPC D1.	-0.3481	1.7390	-0.2000	0.8410	2.0719	0.9971	2.0800	0.0380
	lnGDPC ² D1.	0.0524	0.1245	0.4200	0.6740	-0.1446	0.0717	-2.0200	0.0440
NGA	lnENC L1.	0.1979	0.2677	0.7400	0.4600	0.6530	1.3915	0.4700	0.6390
	lnGDPC L1.	0.5137	0.1699	3.0200	0.0020	0.9594	0.7260	1.3200	0.1860
	lnGDPC ² L1.	-0.0402	0.0129	-3.1100	0.0020	-0.0688	0.0555	-1.2400	0.2150
	_cons	-5.4574	2.4201	-2.2600	0.0240	-1.8163	9.2303	-0.2000	0.8440
	trend	0.0013	0.0017	0.7500	0.4540	-0.0007	0.0080	-0.0800	0.9350
	ec	-0.3773	0.1201	-3.1400	0.0020	-0.3996	0.1352	-2.9600	0.0030
	lnENC D1.	0.3111	0.3975	0.7800	0.4340	0.7741	1.9884	0.3900	0.6970
	lnGDPC D1.	0.2241	0.2222	1.0100	0.3130	-0.3338	1.1009	-0.3000	0.7620

Table 8 (continued)

SEN	lnGDPC ² D1.	-0.0129	0.0178	-0.7200	0.4700	0.0444	0.0886	0.5000	0.6160
	lnENC L1.	0.4206	0.1712	2.4600	0.0140	0.8466	0.2617	3.2400	0.0010
	lnGDPC L1.	1.7877	1.5794	1.1300	0.2580	5.9574	2.5281	2.3600	0.0180
	lnGDPC ² L1.	-0.1353	0.1237	-1.0900	0.2740	-0.4533	0.1974	-2.3000	0.0220
	_cons	12.5943	7.8080	1.6100	0.1070	-65.1193	15.3018	-4.2600	0.0000
	trend	-0.0103	0.0023	-4.4200	0.0000	0.0238	0.0050	4.7600	0.0000
	ec	-1.2717	0.1654	-7.6900	0.0000	-0.7842	0.1488	-5.2700	0.0000
	lnENC D1.	0.5785	0.3302	1.7500	0.0800	-0.5388	0.4905	-1.1000	0.2720
SOA	lnGDPC D1.	3.8126	3.7406	1.0200	0.3080	7.6169	5.6281	1.3500	0.1760
	lnGDPC ² D1.	-0.2916	0.2936	-0.9900	0.3210	-0.5952	0.4419	-1.3500	0.1780
	lnENC L1.	-0.0087	0.1272	-0.0700	0.9460	0.6460	0.2142	3.0200	0.0030
	lnGDPC L1.	-0.2688	0.3542	-0.7600	0.4480	0.6215	0.2553	2.4300	0.0150
	lnGDPC ² L1.	0.0178	0.0225	0.7900	0.4280	-0.0388	0.0161	-2.4100	0.0160
	_cons	3.0175	4.0377	0.7500	0.4550	-17.5866	5.8836	-2.9900	0.0030
	trend	-0.0008	0.0016	-0.5000	0.6170	0.0084	0.0028	2.9600	0.0030
	ec	-0.2530	0.1161	-2.1800	0.0290	-0.5224	0.1429	-3.6600	0.0000
TGO	lnENC D1.	0.3960	0.1863	2.1300	0.0340	0.9628	0.1396	6.9000	0.0000
	lnGDPC D1.	0.6348	0.8899	0.7100	0.4760	0.1732	0.6430	0.2700	0.7880
	lnGDPC ² D1.	-0.0349	0.0559	-0.6200	0.5330	-0.0117	0.0405	-0.2900	0.7730
	lnENC L1.	0.2559	0.1192	2.1500	0.0320	1.0313	0.5834	1.7700	0.0770
	lnGDPC L1.	-0.5917	0.5365	-1.1000	0.2700	-0.5196	3.1817	-0.1600	0.8700
	lnGDPC ² L1.	0.0515	0.0464	1.1100	0.2670	0.0798	0.2752	0.2900	0.7720
	_cons	10.8772	3.6443	2.9800	0.0030	-35.0899	16.9627	-2.0700	0.0390
	trend	-0.0054	0.0020	-2.6600	0.0080	0.0176	0.0091	1.9400	0.0520
TUN	ec	-0.5377	0.1538	-3.5000	0.0000	-0.8391	0.1698	-4.9400	0.0000
	lnENC D1.	0.5339	0.1393	3.8300	0.0000	2.2177	0.8440	2.6300	0.0090
	lnGDPC D1.	-1.2557	1.2508	-1.0000	0.3150	1.7929	7.4678	0.2400	0.8100
	lnGDPC ² D1.	0.1067	0.1082	0.9900	0.3240	-0.1459	0.6462	-0.2300	0.8210
	lnENC L1.	0.7997	0.3726	2.1500	0.0320	0.6362	0.2761	2.3000	0.0210
	lnGDPC L1.	-0.0053	0.6408	-0.0100	0.9930	1.2018	0.5000	2.4000	0.0160
	lnGDPC ² L1.	0.0112	0.0416	0.2700	0.7880	-0.0835	0.0340	-2.4500	0.0140
	_cons	12.8229	13.7943	0.9300	0.3530	-18.2068	11.0083	-1.6500	0.0980
ZMB	trend	-0.0090	0.0075	-1.2100	0.2270	0.0074	0.0056	1.3200	0.1850
	ec	-1.0862	0.1726	-6.2900	0.0000	-0.5058	0.1323	-3.8200	0.0000
	lnENC D1.	0.4848	0.3372	1.4400	0.1510	0.6501	0.2140	3.0400	0.0020
	lnGDPC D1.	-0.1104	2.5549	-0.0400	0.9660	2.4291	1.6013	1.5200	0.1290
	lnGDPC ² D1.	0.0280	0.1701	0.1600	0.8690	-0.1744	0.1068	-1.6300	0.1020
	lnENC L1.	0.6196	0.3527	1.7600	0.0790	1.9003	0.8602	2.2100	0.0270
	lnGDPC L1.	-0.1333	0.4203	-0.3200	0.7510	-1.9604	0.8543	-2.2900	0.0220
	lnGDPC ² L1.	0.0111	0.0334	0.3300	0.7400	0.1605	0.0679	2.3600	0.0180
ZWE	_cons	-9.4083	11.3095	-0.8300	0.4050	-11.9873	23.2807	-0.5100	0.6070
	trend	0.0029	0.0043	0.6700	0.5060	0.0056	0.0088	0.6300	0.5260
	ec	-0.3101	0.0990	-3.1300	0.0020	-0.7070	0.1667	-4.2400	0.0000
	lnENC D1.	0.6915	0.3305	2.0900	0.0360	2.3964	0.6664	3.6000	0.0000
	lnGDPC D1.	0.5085	0.5365	0.9500	0.3430	0.0961	1.0593	0.0900	0.9280
	lnGDPC ² D1.	-0.0419	0.0435	-0.9600	0.3360	-0.0081	0.0858	-0.0900	0.9250
	lnENC L1.	0.2411	0.3081	0.7800	0.4340	0.3207	0.3800	0.8400	0.3990
	lnGDPC L1.	0.7430	2.0870	0.3600	0.7220	3.4686	2.2592	1.5400	0.1250
lnGDPC ² L1.	-0.0545	0.1618	-0.3400	0.7360	-0.2606	0.1745	-1.4900	0.1350	
	_cons	1.1060	7.0998	0.1600	0.8760	-19.4530	11.5117	-1.6900	0.0910

Table 8 (continued)

	trend	-0.0025	0.0022	-1.1300	0.2570	0.0038	0.0037	1.0300	0.3020
	ec	-0.6643	0.1723	-3.8600	0.0000	-0.1875	0.0824	-2.2800	0.0230
	lnENC D1.	0.6057	0.3846	1.5700	0.1150	1.9802	0.4144	4.7800	0.0000
	lnGDPC D1.	-1.9382	1.9137	-1.0100	0.3110	3.8248	2.1563	1.7700	0.0760
	lnGDPC ² D1.	0.1605	0.1494	1.0700	0.2830	-0.2943	0.1687	-1.7400	0.0810
Mean-group error-correction model									
		Coef.	Std. err.	Z	P>Z	Coef.	Std. err.	Z	P>Z
	lnENC L1.	0.2177	0.0641	3.4000	0.0010	0.4213	0.2112	1.9900	0.0460
	lnGDPC L1.	0.0416	0.1967	0.2100	0.8330	0.7530	0.7010	1.0700	0.2830
	lnGDPC ² L1.	0.0016	0.0150	0.1100	0.9130	-0.0474	0.0549	-0.8600	0.3880
	_cons	0.7636	2.5381	0.3000	0.7640	-23.2432	5.8856	-3.9500	0.0000
	trend	-0.0012	0.0014	-0.8600	0.3890	0.0114	0.0034	3.3600	0.0010
Estimated long-run relationship and short-run adjustment									
		Coef.	Std. err.	Z	P>Z	Coef.	Std. err.	Z	P>Z
LR	lnENC	0.0349	0.3419	0.1000	0.9190	1.2766	0.7575	1.6900	0.0920
	lnGDPC	0.0316	0.6351	0.0500	0.9600	2.4873	1.5561	1.6000	0.1100
	lnGDPC ²	0.0020	0.0512	0.0400	0.9700	-0.1765	0.1229	-1.4400	0.1510
	_cons	-1.2440	5.0903	-0.2400	0.8070	-40.7629	12.5149	-3.2600	0.0010
	trend	0.0004	0.0027	0.1600	0.8740	0.0166	0.0057	2.9000	0.0040
SR	_ec	-0.5762	0.0965	-5.9700	0.0000	-0.5519	0.0565	-9.7600	0.0000
	lnENC D1.	0.2970	0.0664	4.4700	0.0000	1.0038	0.2712	3.7000	0.0000
	lnGDPC D1.	0.3251	0.3773	0.8600	0.3890	1.2503	0.9337	1.3400	0.1810
	lnGDPC ² D1.	-0.0152	0.0293	-0.5200	0.6030	-0.0924	0.0740	-1.2500	0.2120
Statistic	Value	Z value	P value	Robust P value*	Value	Z value	P value	Robust P value*	
Gt	-3.8220	-5.2950	0.0000	0.0000	-3.6580	-4.5150	0.0000	0.0000	
G α	-23.4190	-4.0500	0.0000	0.0000	-21.1470	-2.8840	0.0020	0.0000	
Pt	-19.2090	-9.6190	0.0000	0.0000	-13.6250	-3.6860	0.0000	0.0300	
P α	-26.8170	-7.9310	0.0000	0.0000	-18.5800	-3.4720	0.0000	0.0070	

*Based on 1000 bootstrapping samples

Source: Author's construction

energy consumption is the main driver of environmental degradation in Côte d'Ivoire.

On Cameroon (CMR), the error correction ($ec = -0.56$) is negative and significant for only environmental pollution, meaning that it takes 56% speed of adjusting the disturbances in environmental pollution to equilibrium in Cameroon; nonetheless, both long-run and short-run relationships are not significant.

On Democratic Republic (DR) of Congo (COD), the error correction ($ec = -0.24$) is negative and significant for only environmental pollution. Thus, the speed of adjustment in correcting the previous adverse impact on environmental pollution is 24% in DR Congo. In addition, energy consumption increases environmental pollution in the short run.

On Congo (COG), the error correction ($ec = -0.50$) is negative and significant for only environmental degradation. Thus, it takes 50% speed to adjust the previous disturbances in environmental degradation in Congo. Moreover, economic

growth increases environmental degradation in the initial stages but reduces thereafter in the short run.

On Egypt (EGY), the error correction ($ec = -0.52, -0.89$) is negative and significant, meaning that the speed of adjustment in correcting disturbances in environmental degradation and pollution in Egypt is 52 and 89%. An increase in energy consumption increases environmental degradation in the short run. Moreover, energy consumption increases environmental pollution in both long run and short run. Economic growth increases environmental pollution and reduces thereafter in the long run.

On Ghana (GHA), the error correction ($ec = -0.71$) is negative and significant for only environmental pollution. Thus, it takes 71% speed in correcting the previous adverse impact on environmental pollution in Ghana. Energy consumption increases environmental pollution in the long run, while economic growth increases environmental pollution and decreases thereafter in both short run and long run, thus corroborating recent studies (Asumadu and Owusu 2016b, 2017a; Owusu and Samuel 2016b) in Ghana.

On Kenya (KEN), the error correction ($ec = -0.52$) is negative and significant for only environmental degradation. Hence, it takes 52% speed to adjust the previous disturbances in environmental degradation to equilibrium in Kenya. Likewise, energy consumption increases environmental pollution in the short run.

On Morocco (MOR), the error correction ($ec = -1.35, -0.74$) is negative and significant, meaning that the speed of adjustment in correcting disturbances in environmental degradation and pollution to an equilibrium state in Morocco is 135 and 74%. An increase in economic growth decreases environmental degradation and increases thereafter in the long run. Economic growth increases environmental pollution and decreases thereafter in the long run; however, economic growth progressively increases environmental pollution in the short run. Energy consumption increases environmental pollution in both the long run and short run.

On Nigeria (NGA), the error correction ($ec = -0.38, -0.40$) is negative and significant. Hence, the disturbances in environmental degradation and pollution in Nigeria are corrected at a speed of 38 and 40%. An increase in economic growth increases environmental degradation and decreases thereafter in the long run.

On Senegal (SEN), the error correction ($ec = -1.27, -0.78$) is negative and significant. Thus, the speed of adjustment in correcting disturbances in environmental degradation and pollution to an equilibrium state in Senegal is 127 and 78%, respectively. An increase in energy consumption increases environmental degradation in both the long run and short run. Moreover, energy consumption increases environmental pollution in the long run, hence confirming a previous study (Sarkodie and Owusu 2017a) in Senegal. Economic growth increases environmental pollution and decreases thereafter in the long run.

On South Africa (SOA), the error correction ($ec = -0.25, -0.52$) is negative and significant, meaning that the speed of adjustment in correcting disturbances in environmental degradation and pollution in South Africa is 25 and 52%. An increase in energy consumption increases environmental degradation in the short run. Economic growth increases environmental pollution and reduces thereafter in the long run. As expected in South Africa, energy consumption increases environmental pollution in both the long run and short run. South Africa's energy mix is dominated by more than 90% of coal production, a conventional source of energy that propels environmental pollution, due to associated carbon dioxide emissions.

On Togo (TGO), the error correction ($ec = -0.54, -0.84$) is negative and significant. Accordingly, the speed of adjusting the disturbances in previous environmental degradation and pollution in Togo is 54 and 84%. The long-run equilibrium relationship shows that energy consumption increases

environmental degradation in both the long run and short run; thus, energy consumption is the main driver of environmental degradation in Togo. However, energy consumption increases environmental pollution in the short run.

On Tunisia (TUN), the error correction ($ec = -1.09, -0.51$) is negative and significant, meaning that the speed of adjustment in correcting disturbances in environmental degradation and pollution to an equilibrium state in Tunisia is 109 and 51%. An increase in energy consumption increases environmental degradation in the long run. Economic growth increases environmental pollution and decreases thereafter in the long run. Again, energy consumption increases environmental pollution in both the long run and short run. Thus, energy consumption plays a critical role in both environmental degradation and pollution in Tunisia.

On Zambia (ZMB), the error correction ($ec = -0.31, -0.71$) is negative and significant, meaning that the speed of adjustment in correcting disturbances in environmental degradation and pollution to an equilibrium state in Zambia is 31 and 71%. An increase in energy consumption increases environmental degradation in the short run. Likewise, energy consumption increases environmental pollution in both the long run and short run. Economic growth decreases environmental pollution and increases thereafter in the long run.

On Zimbabwe (ZWE), the error correction ($ec = -0.66, -0.19$) is negative and significant. Thus, it takes 66 and 19% speed to adjust the disturbances in previous environmental degradation and pollution in Zimbabwe to an equilibrium state. Energy consumption increases environmental degradation in the short run.

U-shape analysis

As explained, the Utest analysis provides a more detailed and accurate output of the EKC hypothesis presented in Table 9. Table 9 shows the results of the U-shape estimation of environmental degradation and pollution.

Evidence from the results shows that the relationship between environmental degradation and economic growth in Algeria exhibits a monotonic trend with a lower bound (LB) GDP of US\$ 339/capita and an upper bound (UB) GDP of US\$ 5584/capita; however, the extreme point/turning point occurs at a GDP of US\$ 5815 per capita. On the other hand, the relationship between environmental pollution and economic growth in Algeria exhibits a U shape with a turning point at a GDP of US\$ 4554 per capita. In other words, increasing economic productivity corresponds with an increasing environmental degradation and environmental pollution, thus fulfilling the scale effect.

The relationship between environmental degradation and economic growth in Benin follows a U shape with LB GDP of US\$ 100/capita and UB GDP of US\$ 8050/capita; however, the turning point occurs at a GDP of US\$ 7958 per capita.

Table 9 Results of U-shape estimation

Country	ECF				CO ₂					
		LB	UB	Extreme point	Interpretation		LB	UB	Extreme point	Interpretation
ALG	Interval	339.3840	5583.6160	5814.5950	Monotone	Interval	339.3840	5583.6160	4554.5460	U shape
	Slope	0.0003	0.0000			Slope	0.0006	−0.0002		
BEN	Interval	100.6932	8049.9540	7958.2570	U shape	Interval	100.6932	8049.9540	5701.5370	Inverse U shape
	Slope	0.0003	0.0000			Slope	0.0015	−0.0006		
CIV	Interval	288.6745	1445.9110	982.2199	U shape	Interval	288.6745	1445.9110	5701.5370	Monotone
	Slope	−0.0010	0.0007			Slope	0.0014	0.0011		
CMR	Interval	177.5821	1331.2000	852.2378	U shape	Interval	177.5821	1331.2000	5701.5370	Monotone
	Slope	−0.0008	0.0006			Slope	0.0015	0.0012		
COD	Interval	100.6932	616.1832	369.6694	U shape	Interval	100.6932	616.1832	491.4519	U shape
	Slope	−0.0002	0.0002			Slope	0.0044	−0.0014		
COG	Interval	234.0725	3453.2210	3537.5760	Monotone	Interval	234.0725	3453.2210	−837.9622	Monotone
	Slope	0.0001	0.0000			Slope	0.0001	0.0004		
EGY	Interval	232.4452	3264.4500	2525.2130	U shape	Interval	232.4452	3264.4500	2415.8510	Inverse U shape
	Slope	0.0005	−0.0002			Slope	0.0020	−0.0008		
GHA	Interval	232.5399	1827.1010	1923.3990	Monotone	Interval	232.5399	1827.1010	1879.2490	Monotone
	Slope	0.0006	0.0000			Slope	0.0015	0.0000		
KEN	Interval	152.5537	1261.0930	979.9755	U shape	Interval	152.5537	1261.0930	1084.3220	U shape
	Slope	−0.0011	0.0004			Slope	0.0026	−0.0005		
MOR	Interval	264.5784	3141.7250	6974.3290	Monotone	Interval	264.5784	3141.7250	2853.7440	Inverse U shape
	Slope	0.0003	0.0002			Slope	0.0015	−0.0002		
NGA	Interval	153.0757	2943.5660	1657.8050	U shape	Interval	153.0757	2943.5660	1951.4350	Inverse U shape
	Slope	0.0003	−0.0003			Slope	0.0009	−0.0005		
SEN	Interval	243.3300	1093.7160	1018.2680	U shape	Interval	243.3300	1093.7160	1545.5630	Monotone
	Slope	−0.0008	0.0001			Slope	0.0025	0.0009		
SOA	Interval	855.3801	8049.9540	4985.7280	U shape	Interval	855.3801	8049.9540	6418.0460	Inverse U shape
	Slope	−0.0001	0.0001			Slope	0.0004	−0.0001		
TGO	Interval	131.0988	588.9875	493.9510	U shape	Interval	131.0988	588.9875	1119.6650	Monotone
	Slope	−0.0010	0.0003			Slope	0.0053	0.0029		
TUN	Interval	325.7911	4309.7800	4117.1850	U shape	Interval	325.7911	4309.7800	3607.8130	Inverse U shape
	Slope	0.0004	0.0000			Slope	0.0011	−0.0002		
ZMB	Interval	229.4718	1839.5190	656.0625	U shape	Interval	229.4718	1839.5190	1417.1610	U shape
	Slope	0.0002	−0.0005			Slope	0.0002	−0.0001		
ZWE	Interval	327.1991	1084.2120	−21,846.5400	Monotone	Interval	327.1991	1084.2120	726.1788	Inverse U shape
	Slope	0.0002	0.0002			Slope	0.0023	−0.0020		
Overall	Interval	100.6932	8049.9540	7958.2570	U shape	Interval	100.6932	8049.9540	5701.5370	Inverse U shape
	Slope	0.0003	0.0000			Slope	0.0015	−0.0006		

Source: Author's construction

Thus, environmental degradation in Benin increases with increasing economic growth. In contrast, the relationship between environmental pollution and economic growth in Algeria exhibits an inverted U shape with a turning point at a GDP of US\$ 5701 per capita, meaning that the EKC hypothesis is valid in Benin; thus, the initial stages of economic productivity exhibit a scale effect; however, at US\$ 5701 per capita, environmental pollution begins to decrease with time.

With LB GDP of US\$ 289/capita and UB GDP of US\$ 1446/capita, the relationship between environmental degradation and economic growth in Côte d'Ivoire exhibits a U shape, where the turning point occurs at a GDP of US\$ 982 per capita. But the relationship between environmental pollution and economic growth in Côte d'Ivoire follows a monotonic trend with a turning point at a GDP of US\$ 5702 per capita, meaning that increasing economic activities lead to increasing

environmental degradation and environmental pollution, thus confirming the scale effect.

The nexus between environmental degradation and economic growth in Cameroon follows a U shape at LB GDP of US\$ 178/capita and UB GDP of US\$ 1331/capita, and turning point occurs at US\$ 982 GDP per capita. However, a monotone trend occurs between environmental pollution and economic growth at a turning point at a GDP of US\$ 5702 per capita. This shows that both environmental degradation and environmental pollution exhibit a scale effect with economic productivity in Cameroon.

The relationship between environmental degradation and economic growth in DR Congo exhibits a U shape with LB GDP of US\$ 101/capita and UB GDP of US\$ 616/capita, at a turning point of US\$ 370 GDP per capita. In addition, the relationship between environmental pollution and economic growth in the Democratic Republic of Congo follows a U shape with a turning point of US\$ 491 GDP per capita, meaning that environmental degradation and pollution increases with increasing economic growth and vice versa in DR Congo.

The nexus between environmental degradation, environmental pollution, and economic growth follows a monotonic trend at LB GDP of US\$ 234/capita and UB GDP of US\$ 3452/capita, at a turning point of US\$ 3538 GDP per capita, confirming the scale effect in Congo.

Egypt's economy and environmental degradation exhibit a U shape with LB GDP of US\$ 232/capita and UB GDP of US\$ 3264/capita, at a turning point of US\$ 2525 GDP per capita, thus following the scale effect. Nonetheless, there is an inversed U-shape relationship between environmental pollution and economic growth at a turning point of US\$ 2416 GDP per capita, thus validating the EKC hypothesis in Egypt.

The EKC hypothesis is not valid in Ghana but the relationship between environmental degradation and pollution versus economic growth follows a monotone, at LB GDP of US\$ 233/capita and UB GDP of US\$ 1827/capita, at a turning point of US\$ 1923 and US\$ 1879 GDP per capita, meaning that environmental degradation and pollution increases with increasing economic productivity.

Kenya's environmental degradation and pollution versus economic growth follows a U shape, at LB GDP of US\$ 153/capita and UB GDP of US\$ 1261/capita, at a turning point of US\$ 980 and US\$ 1084 GDP per capita, meaning that Kenya is resolute to growing the economy but pays dearly for environmental degradation and pollution.

Morocco's environmental degradation against economic growth follows a monotone, but environmental pollution against economic growth exhibits an inversed U-shape relationship, at LB GDP of US\$ 265/capita and UB GDP of US\$ 3141/capita, at a turning point of US\$ 6974 and US\$ 2854 GDP per capita. As Morocco thrives to increase economic

productivity, environmental deterioration increases; however, environmental pollution increases to US\$ 2854 GDP per capita and decreases thereafter.

The relationship between environmental degradation and economic growth in Nigeria exhibits a U shape with LB GDP of US\$ 153/capita and UB GDP of US\$ 2944/capita; however, the extreme point occurs at a GDP of US\$ 1658 per capita. But the relationship between environmental pollution and economic growth exhibits an inversed U shape with a turning point at a GDP of US\$ 1951 per capita. In other words, increasing economic productivity corresponds with an increasing environmental degradation; however, environmental pollution increases with increasing economic productivity in Nigeria till US\$ 1951 GDP per capita and declines thereafter, thus validating the EKC hypothesis.

With LB GDP of US\$ 243/capita and UB GDP of US\$ 1094/capita, the relationship between environmental degradation and economic growth in Senegal exhibits a U shape, where the turning point occurs at a GDP of US\$ 1018 per capita. Nonetheless, the relationship between environmental pollution and economic growth in Senegal follows a monotone with a turning point at US\$ 1546 GDP per capita, meaning that increasing economic activities in Senegal lead to increasing environmental degradation and environmental pollution, thus confirming the scale effect hypothesis.

The nexus between environmental degradation and economic growth in South Africa follows a U shape at LB GDP of US\$ 855/capita and UB GDP of US\$ 8050/capita, and turning point occurs at US\$ 4986 GDP per capita. However, an inversed U shape occurs between environmental pollution and economic growth at a turning point at a GDP of US\$ 6418 per capita, thus validating the EKC hypothesis in South Africa. In other words, environmental degradation is a problem in South Africa with increasing economic productivity; nonetheless, environmental pollution increases to US\$ 6418 GDP per capita and declines thereafter.

Togo's economy and environmental degradation exhibit a U shape with LB GDP of US\$ 131/capita and UB GDP of US\$ 589/capita, at a turning point of US\$ 494 GDP per capita, hence following the scale effect. Nevertheless, there is a monotonic trend relationship between environmental pollution and economic growth at a turning point of US\$ 1120 GDP per capita, thus validating the scale effect hypothesis in Togo.

The relationship between environmental degradation and economic growth in Tunisia exhibits a U shape with LB GDP of US\$ 326/capita and UB GDP of US\$ 4310/capita, at a turning point of US\$ 4117 GDP per capita. In contrast, the relationship between environmental pollution and economic growth in Tunisia follows an inversed U shape with a turning point of US\$ 3608 GDP per capita; thus, the EKC hypothesis is valid in Tunisia. Tunisia's economic growth increases with

increasing environmental degradation; nevertheless, environmental pollution increases until US\$ 3608 GDP per capita and declines afterward.

The nexus between environmental degradation, environmental pollution, and economic growth follows a U shape in Zambia at LB GDP of US\$ 229/capita and UB GDP of US\$ 1840/capita, at a turning point of US\$ 656 and US\$ 1417 GDP per capita, confirming the scale effect hypothesis in Zambia.

As expected, Zimbabwe's economy and environmental degradation exhibit a U shape with LB GDP of US\$ 327/capita and UB GDP of US\$ 1084/capita, at a turning point of US\$ -21,847 GDP per capita, thus following the scale effect. Nonetheless, there is an inversed U-shape relationship between environmental pollution and economic growth at a turning point of US\$ 726 GDP per capita, thus validating the EKC hypothesis in Zimbabwe. Zimbabwe has suffered the worst economic crisis within the past 7 years (World Bank 2017), thus affecting agricultural productivity, food security, energy production, and utilization. But the effect of the rebound of the economy from 2016 is evident in environmental degradation and pollution. Thus, economic productivity increases environmental degradation in Zimbabwe; however, environmental pollution increases till US\$ 726 GDP per capita and declines thereafter.

Causality test analysis

To test for the direction of causality in the heterogeneous panel data, the study employs the procedure by Dumitrescu and Hurlin (2012) to investigate the null hypothesis of Granger noncausality presented in Table 10.

Evidence from the study reveals that the null hypothesis of Granger noncausality is rejected at 5% significance level in almost all the pairings, except for the causality from environmental to economic growth, carbon dioxide

emissions to energy consumption, and agricultural land to permanent crop. The revelation from the causality test shows that

- There is a unidirectional causality running from economic growth to environmental degradation. This corroborates the scale effect hypothesis; thus, increasing economic productivity in Africa increases environmental degradation; however, the reverse direction is invalid.
- There is a unidirectional causality running from energy consumption to environmental pollution. As stated, 70% of Africa's energy mix is dominated by bioenergy in the form of fuel wood and charcoal production, except South Africa whose energy mix is dominated by coal production (International Energy Agency 2014). As such, increasing the consumption of these energy sources rather than clean and renewable energy sources reduces air quality, thus polluting the environment.
- There is a bidirectional causality between environmental degradation, energy consumption, food production, permanent crop, agricultural land, environmental pollution, birth rate, and fertility rate. The main drivers of environmental deterioration in Africa include bioenergy consumption (firewood, charcoal, etc.), poor and unsustainable agricultural practices involved in food production (Asumadu and Owusu 2016a), destroying the foliage (permanent crops), converting agricultural land into illegal mining sites, environmental pollution, and high fertility rates leading to high birth rate, thus putting much pressure on the biocapacity which in turn affects the ecological footprint leading to environmental degradation.
- There is a bidirectional causality between energy consumption, environmental degradation, environmental pollution, economic growth, food production, permanent crops, agricultural land, birth rate, and fertility rate.

Table 10 Panel causality results

Variable	lnECF	lnENC	lnGDPC	lnFOOD	lnPCROP	lnAGLND	lnCO ₂	lnCBRT	lnTFRT
lnECF	–	6.7237*	1.3912	9.3813*	3.1458*	6.1604*	2.6577*	34.1068 *	100.1390*
lnENC	13.4143*	–	4.5008*	8.1409*	7.2867*	5.4026*	2.5183*	52.6505*	67.0770 *
lnGDPC	10.8706*	3.3084*	–	6.8719*	4.5484*	4.3303*	5.4944*	55.8682*	28.6730*
lnFOOD	15.2183*	5.0803*	5.4444*	–	8.3777*	5.3366*	10.6795*	44.0843 *	82.1776*
lnPCROP	11.5509*	3.5256*	10.3040*	14.7994*	–	9.4616*	4.6229*	56.5267 *	90.8682*
lnAGLND	4.6474*	3.4091*	6.3267*	5.1329*	1.0794	–	5.8866*	83.8993 *	93.0764*
lnCO ₂	13.4165*	–0.6503	3.9421*	12.5189*	10.1095*	5.9392*	–	51.4610*	50.9071 *
lnCBRT	14.5528*	6.2480*	3.8602*	15.6974*	5.8428*	17.4992*	7.0618*	–	425.0574*
lnTFRT	14.3723*	6.9775*	6.6260*	17.6898*	5.6961*	15.0226*	9.2366*	86.3079*	–

Source: Author's construction

*Rejection of the null hypothesis at 5% significance level

- e. There is a bidirectional causality between economic growth, energy consumption, food production, permanent crops, agricultural land, environmental pollution, birth rate, and fertility rate. Shocks in Africa’s economic productivity are due to changes in energy consumption, food production levels, and permanent crops (cash crops); the use of agricultural lands for noneconomic or illegal purposes draining the public purse; environmental pollution; and changes in birth rate and fertility rate.
- f. There is a bidirectional causality between food production, environmental degradation, energy consumption, environmental pollution, economic growth, permanent crop, agricultural land, birth rate, and fertility rate.
- g. There is a bidirectional causality between environmental pollution, environmental degradation, economic growth, food production, permanent crop, agricultural land, birth rate, and fertility rate. In other words, environmental degradation; increasing economic productivity; unsustainable agricultural practices in preharvest, harvest, and postharvest; AFOLU; and social factors (birth rate and fertility rate) play a critical role in environmental pollution, thus leading to climate change.

Conclusion and policy implications

In this study, we examined the drivers of environmental degradation and pollution in 17 countries in Africa, namely, Algeria, Egypt, Morocco, Tunisia, Benin, Côte d’Ivoire, Ghana, Nigeria, Senegal, Togo, Cameroon, Congo, Congo Democratic Republic, Kenya, South Africa, Zambia, and Zimbabwe, respectively.

The study employed a data spanning from 1971 to 2013 and adopted the WECM, U-shape relationship test, fixed and random effect estimators, and panel causality test for the empirical studies. To account for cross-sectional dependence in the WECM-based panel cointegration tests, the study employed the bootstrapping approach for 1000 samples.

It is noteworthy that our findings are based on the selected variables, the duration of the data, the geographical locations of the selected countries, and the empirical methods employed in the study. However, the findings of the study have a lot of environmental, socioeconomic, and energy policy implications to help policymakers in their decision on these matters in Africa.

The findings show that environmental degradation and pollution in Africa is driven by several factors ranging from socioeconomic, demography, agricultural, forest and land use, and energy consumption patterns.

The overall Utest estimation shows that the relationship between environmental degradation and economic growth

in Africa exhibits a U shape, at LB GDP of US\$ 101/capita and UB GDP of US\$ 8050/capita, at a turning point of US\$ 7958 GDP per capita, thus following the scale effect. However, the nexus between environmental pollution and economic growth follows the inverted U shape at a turning point of US\$ 5702 GDP per capita, thus validating the EKC hypothesis in Africa. Figures 3 and 4 reveal some socioeconomic implications in Africa. The gap between the rich and the poor is very wide; for example, except South Africa (>US\$ 800), all the countries have their lower bound income between US\$ 100 and 400 per capita in Figs. 3 and 4a. However, these same countries including South Africa have their upper bound income between US\$ 1000 and 9000 per capita in Figs. 3 and 4a. This means that the cost of living by some families in Africa, except South Africa (US\$ 2.47/day, thus 900/365), is between US\$ 0.27/day and US\$ 1.10/day using the lower bound income scenario compared to the upper bound income between US\$

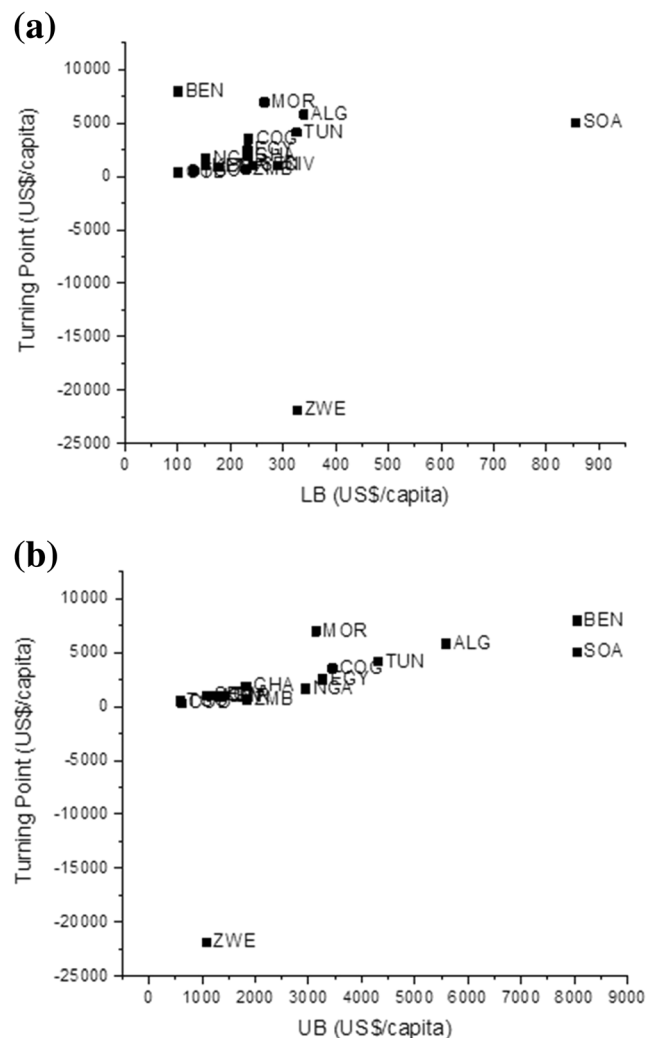


Fig. 3 a Denotes lower bound income level, b Denotes upper bound income level. Environmental degradation versus economic growth

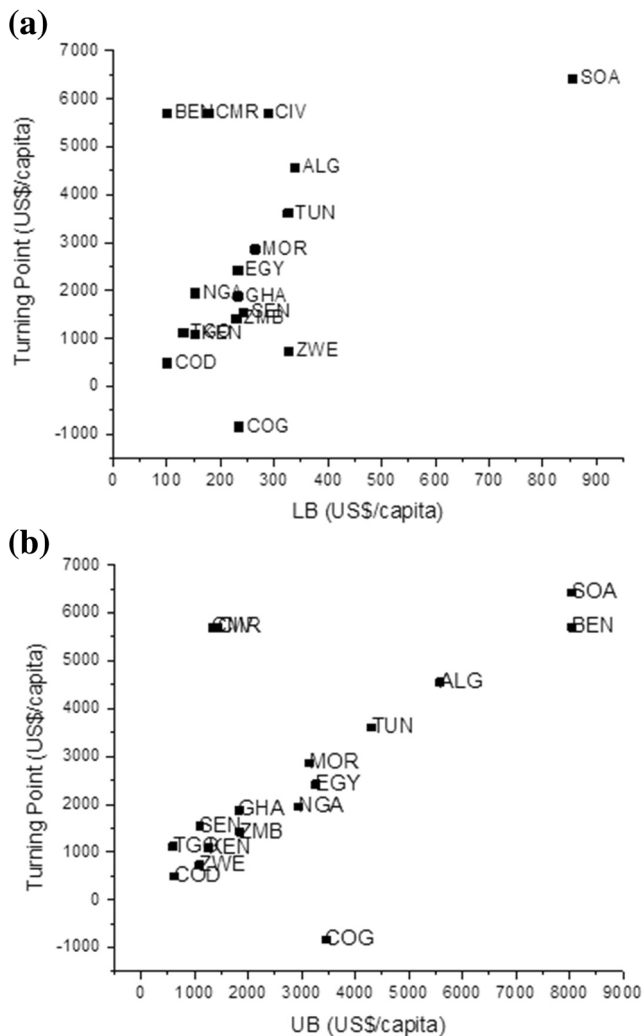


Fig. 4 **a** Denotes lower bound income level, **b** Denotes upper bound income level. Environmental pollution versus economic growth

2.74/day and US\$ 24.70/day. In other words, except South Africa, a lot of families in Africa live below the poverty line of US\$ 1.90/day in accordance with SDG (1). It is, therefore, necessary for policymakers both governmental and NGOs to help in alleviating poverty and reducing climate change and its impact on vulnerable people in Africa especially women and children.

The findings suggest that energy consumption, food production, economic growth, permanent crop, agricultural land, environmental pollution, birth rate, and fertility rate are the main drivers of environmental degradation and pollution in Africa.

The role of energy consumption in driving economic growth and industrial productivity is undeniable. However, its effect on environmental degradation and pollution cannot be equally denied. Therefore, the adoption of energy efficiency options in electricity consumption and

heat production and increasing the penetration of clean, renewable, and sustainable energy technologies to the energy mix would fulfill the technic effect, thus increasing the economic productivity while reducing environmental degradation and pollution in Africa.

In our effort to combat hunger and promote food security and good nutrition in accordance with SDG (2), the role of food production is essential; nevertheless, poor agricultural practices and unsustainable agricultural practices also contribute to the deteriorated environment and poor air quality. It is therefore important that modern agricultural practices and sustainable agriculture like technological advancement, carbon capture and sequestration in manure management, value addition, etc. be employed in Africa's agricultural systems to boost productivity while reducing its effect on the environment.

Permanent crops and agricultural land use are essential for life sustenance and critical to environmental degradation and pollution. Issues of deforestation, illegal mining activities, and illegal chainsaw operation are eminent in the subregion. These human activities result in the destruction of the natural habitat; air, water, and soil pollution; and exposure to toxic chemicals leading to air- and waterborne diseases. Instituting national policies that ensures the sustainable production and consumption patterns of these natural resources would improve environmental quality and reduce environmental degradation.

Economic growth is essential to every country. However, according to the EKC hypothesis, every growing economy progresses with increasing environmental degradation and pollution to a point in time and reduces thereafter. In as much as Africa is on the trajectory of increasing its standard living, economic productivity through industrial, agricultural, and energy consumption patterns, by incorporating innovation, research, and technological advancement are necessary to achieving SDG (8) while reducing climate change and its impact.

Finally, the role of sociodemographic factors like birth rate and fertility rate in mitigating environmental degradation and pollution cannot be underestimated in Africa. Women ensure the availability, accessibility, and utilization of food, thus play a critical role in food security, good nutrition, health, and well-being. The underlying causes of population growth are high fertility and birth rates. Increasing population growth increases the pressure on the natural resources which in turn reduces the natural biocapacity, thus leading to an ecological deficit, which results in environmental degradation. It is therefore important for governmental and nongovernmental bodies to institute policies that build the capacity of women, educate the girl child, empower women, and create awareness on the early warning signs and adaptation options of climate change and its impact.

Compliance with ethical standards

Conflict of interest The author declare that he has no conflict of interest.

References

- Abdallh AA, Abugamos H (2017) A semi-parametric panel data analysis on the urbanisation-carbon emissions nexus for the MENA countries. *Renew Sust Energ Rev* 78:1350–1356. <https://doi.org/10.1016/j.rser.2017.05.006>
- Al-Mulali U, Ozturk I (2016) The investigation of environmental Kuznets curve hypothesis in the advanced economies: the role of energy prices. *Renew Sust Energ Rev* 54:1622–1631. <https://doi.org/10.1016/j.rser.2015.10.131>
- Amri F (2016) The relationship amongst energy consumption, foreign direct investment and output in developed and developing countries. *Renew Sust Energ Rev* 64:694–702. <https://doi.org/10.1016/j.rser.2016.06.065>
- Asumadu SS, Owusu PA (2016a) The relationship between carbon dioxide and agriculture in Ghana: a comparison of VECM and ARDL model. *Environ Sci Pollut Res Int* 23(11):10968–10982. <https://doi.org/10.1007/s11356-016-6252-x>
- Asumadu SS, Owusu PA (2016b) Carbon dioxide emissions, GDP, energy use, and population growth: a multivariate and causality analysis for Ghana, 1971–2013. *Environ Sci Pollut Res* 23(13):13508–13520. <https://doi.org/10.1007/s11356-016-6511-x>
- Asumadu SA, Owusu PA (2017a) Recent evidence of the relationship between carbon dioxide emissions, energy use, GDP and population in Ghana: a linear regression approach. *Energy Sources, Part B: Economics, Planning, and Policy* 12(06):495–503. <https://doi.org/10.1080/15567249.2016.1208304>
- Asumadu SS, Owusu P (2017b) The relationship between carbon dioxide, crop and food production index in Ghana: by estimating the long-run elasticities and variance decomposition. *Environmental Engineering Research* 22:193–202. <https://doi.org/10.4491/eer.2016.135>
- Azam M (2016) Does environmental degradation shackle economic growth? A panel data investigation on 11 Asian countries. *Renew Sust Energ Rev* 65:175–182. <https://doi.org/10.1016/j.rser.2016.06.087>
- Azam M, Khan AQ (2016) Testing the environmental Kuznets curve hypothesis: a comparative empirical study for low, lower middle, upper middle and high income countries. *Renew Sust Energ Rev* 63:556–567. <https://doi.org/10.1016/j.rser.2016.05.052>
- Behera SR, Dash DP (2017) The effect of urbanization, energy consumption, and foreign direct investment on the carbon dioxide emission in the SSEA (South and Southeast Asian) region. *Renew Sust Energ Rev* 70:96–106. <https://doi.org/10.1016/j.rser.2016.11.201>
- Bilgili F, Kocak E, Bulut U (2016) The dynamic impact of renewable energy consumption on CO2 emissions: a revisited environmental Kuznets curve approach. *Renew Sust Energ Rev* 54:838–845. <https://doi.org/10.1016/j.rser.2015.10.080>
- Charfeddine L, Mrabet Z (2017) The impact of economic development and social-political factors on ecological footprint: a panel data analysis for 15 MENA countries. *Renew Sust Energ Rev* 76:138–154. <https://doi.org/10.1016/j.rser.2017.03.031>
- De Hoyos RE, Sarafidis V (2006) Testing for cross-sectional dependence in panel-data models. *Stata J* 6(4):482
- Dogan E, Aslan A (2017) Exploring the relationship among CO2 emissions, real GDP, energy consumption and tourism in the EU and candidate countries: evidence from panel models robust to heterogeneity and cross-sectional dependence. *Renew Sust Energ Rev* 77:239–245. <https://doi.org/10.1016/j.rser.2017.03.111>
- Dumitrescu E-I, Hurlin C (2012) Testing for Granger non-causality in heterogeneous panels. *Econ Model* 29(4):1450–1460
- Dutta CB, Das DK (2016) Does disaggregated CO2 emission matter for growth? Evidence from thirty countries. *Renew Sust Energ Rev* 66:825–833. <https://doi.org/10.1016/j.rser.2016.08.034>
- Effiong EL, Iriabije AO (2018) Let the data speak: semiparametric evidence on the environmental Kuznets curve in Africa. *Qual Quant* 52(2):771–782
- Global Footprint Network (2017a) About the data: key terms. Retrieved from <http://data.footprintnetwork.org/aboutTheData.html>
- Global Footprint Network (2017b) National footprint accounts, ecological footprint. Retrieved from <http://data.footprintnetwork.org>
- Granger CW (1969) Investigating causal relations by econometric models and cross-spectral methods. *Econometrica: Journal of the Econometric Society* 37:424–438
- Grossman GM, Krueger AB (1995) Economic growth and the environment. *Q J Econ* 110(2):353–377
- Guha-Sapir D, Below R, Hoyois P (2016) EM-DAT: international disaster database. Catholic University of Louvain, Brussels
- Hakimi A, Hamdi H (2016) Trade liberalization, FDI inflows, environmental quality and economic growth: a comparative analysis between Tunisia and Morocco. *Renew Sust Energ Rev* 58:1445–1456. <https://doi.org/10.1016/j.rser.2015.12.280>
- Hausman JA (1978) Specification tests in econometrics. *Econometrica: Journal of the Econometric Society* 46:1251–1271
- Hurlin C, Mignon V (2007) Second generation panel unit root tests. HAL ID: halshs-00159842. <https://halshs.archives-ouvertes.fr/halshs-00159842>
- International Energy Agency (2014) World energy outlook special report. Africa Energy Outlook. Retrieved from http://www.iea.org/publications/freepublications/publication/WEO2014_AfricaEnergyOutlook.pdf
- IPCC (2007) Climate change 2007: the physical science basis. Retrieved from https://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4_wg1_full_report.pdf
- IPCC (2016) IPCC report graphics. Retrieved from <https://www.ipcc.ch/report/graphics/index.php?t=Assessment%20Reports&r=AR5%20-%20Synthesis%20Report&f=SPM>
- Islam N, Vincent J, Panayotou T (1999) Unveiling the income-environment relationship: an exploration into the determinants of environmental quality. Harvard Institute for International Development, Development Discussion Paper No. 701, May 1999
- Kais S, Sami H (2016) An econometric study of the impact of economic growth and energy use on carbon emissions: panel data evidence from fifty eight countries. *Renew Sust Energ Rev* 59:1101–1110. <https://doi.org/10.1016/j.rser.2016.01.054>
- Khan SAR, Zaman K, Zhang Y (2016) The relationship between energy-resource depletion, climate change, health resources and the environmental Kuznets curve: evidence from the panel of selected developed countries. *Renew Sust Energ Rev* 62:468–477. <https://doi.org/10.1016/j.rser.2016.04.061>
- Lind JT, Mehlum H (2010) With or without U? The appropriate test for a U-shaped relationship. *Oxf Bull Econ Stat* 72(1):109–118
- Maplecroft (2015) Climate change and environmental risk atlas (CCERA). Retrieved from <https://maplecroft.com/portfolio/new-analysis/2014/10/29/climate-change-and-lack-food-security-multiply-risks-conflict-and-civil-unrest-32-countries-maplecroft/>
- Menegaki AN, Tsagarakis KP (2015) Rich enough to go renewable, but too early to leave fossil energy? *Renew Sust Energ Rev* 41:1465–1477. <https://doi.org/10.1016/j.rser.2014.09.038>
- ND-GAIN (2014) Rank countries by ND-GAIN country index, vulnerability and readiness. Retrieved from <http://index.gain.org/ranking>
- Owusu P, Samuel SA (2016a) Carbon dioxide emission, electricity consumption, industrialization and economic growth Nexus: the Beninese case. *Energy Sources, Part B: Economics, Planning, and Policy* 11(11):1089–1096. <https://doi.org/10.1080/15567249.2016.1217286>

- Owusu PA, Samuel SA (2016b) Multivariate co-integration analysis of the Kaya factors in Ghana. *Environ Sci Pollut Res Int* 23(10):9934–9943. <https://doi.org/10.1007/s11356-016-6245-9>
- Özokcu S, Özdemir Ö (2017) Economic growth, energy, and environmental Kuznets curve. *Renew Sust Energ Rev* 72:639–647. <https://doi.org/10.1016/j.rser.2017.01.059>
- Persyn D, Westerlund J (2008) Error-correction-based cointegration tests for panel data. *Stata J* 8(2):232–241
- Rahman MM (2017) Do population density, economic growth, energy use and exports adversely affect environmental quality in Asian populous countries? *Renew Sust Energ Rev* 77:506–514. <https://doi.org/10.1016/j.rser.2017.04.041>
- Samuel AS, Owusu PA (2017) The impact of energy, agriculture, macro-economic and human-induced indicators on environmental pollution: evidence from Ghana. *Environ Sci Pollut Res Int* 24(7):6622–6633. <https://doi.org/10.1007/s11356-016-8321-6>
- Sarkodie S, Owusu P (2017a) A multivariate analysis of carbon dioxide emissions, electricity consumption, economic growth, financial development, industrialization and urbanization in Senegal. *Energy Sources, Part B: Economics, Planning, and Policy* 12(01):77–84. <https://doi.org/10.1080/15567249.2016.1227886>
- Sarkodie S, Owusu PA (2017b) The causal nexus between carbon dioxide emissions and agricultural ecosystem—an econometric approach. *Environ Sci Pollut Res Int* 24(2):1608–1618. <https://doi.org/10.1007/s11356-016-7908-2>
- Sencer Atasoy B (2017) Testing the environmental Kuznets curve hypothesis across the U.S.: evidence from panel mean group estimators. *Renew Sust Energ Rev* 77:731–747. <https://doi.org/10.1016/j.rser.2017.04.050>
- Stern DI (1998) Progress on the environmental Kuznets curve? *Environ Dev Econ* 3(2):173–196
- Sweidan OD, Alwaked AA (2016) Economic development and the energy intensity of human well-being: evidence from the GCC countries. *Renew Sust Energ Rev* 55:1363–1369. <https://doi.org/10.1016/j.rser.2015.06.001>
- Twerefou DK, Danso-Mensah K, Bokpin GA (2017) The environmental effects of economic growth and globalization in sub-Saharan Africa: a panel general method of moments approach. *Res Int Bus Financ* 42:939–949
- UNDP (2014) Gender and climate change—Africa. Retrieved from http://www.undp.org/content/dam/undp/library/gender/Gender%20and%20Environment/PB4_Africa_Gender-ClimateChange-Food-Security.pdf?download
- UNDP (2016) Human development indicators. Retrieved from <http://hdr.undp.org/>
- United Nations (2015) Sustainable development goals. Retrieved from <https://sustainabledevelopment.un.org/?menu=1300>
- Wolde-Rufael Y, Idowu S (2017) Income distribution and CO2 emission: a comparative analysis for China and India. *Renew Sust Energ Rev* 74:1336–1345. <https://doi.org/10.1016/j.rser.2016.11.149>
- World Bank (2017) Zimbabwe economic update: the state in the economy. Retrieved from <http://www.worldbank.org/en/country/zimbabwe/publication/zimbabwe-economic-update-the-state-in-the-economy>
- Zaman K, Abd-el Moemen M (2017) The influence of electricity production, permanent cropland, high technology exports, and health expenditures on air pollution in Latin America and the Caribbean countries. *Renew Sust Energ Rev* 76:1004–1010. <https://doi.org/10.1016/j.rser.2017.03.103>
- Zaman K, Moemen M A-e (2017) Energy consumption, carbon dioxide emissions and economic development: evaluating alternative and plausible environmental hypothesis for sustainable growth. *Renew Sust Energ Rev* 74:1119–1130. <https://doi.org/10.1016/j.rser.2017.02.072>
- Zerbo E (2017) Income-environment relationship in sub-Saharan African countries: further evidence with trade openness. *Environ Sci Pollut Res* 24(19):16488–16502
- Zoundi Z (2017) CO2 emissions, renewable energy and the environmental Kuznets curve, a panel cointegration approach. *Renew Sust Energ Rev* 72:1067–1075. <https://doi.org/10.1016/j.rser.2016.10.018>