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Co2 emissions and economic development in Africa: Evidence from a dynamic spatial panel model

Delphin Kamanda Espoir [a,*], Regret Sunge [b]

[a] School of Economics, College of Business and Economics, University of Johannesburg, Johannesburg, South Africa
[b] Department of Economics, Munhumutapa School of Commerce, Great Zimbabwe University, Zimbabwe

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ABSTRACT

The nexus between environmental degradation and economic growth continues to generate growing interest from environmental practitioners, industrialists, and researchers. Most existing studies in Africa have investigated the relationship based on the Environmental Kuznets Curve (EKC) theory under assumptions of homogeneity and spatial independence. In contrast, we investigate the EKC theory under more realistic possibilities of country heterogeneity and spatial dependence. Accordingly, we make two contributions. First, following estimation based on a sample of 48 African countries, we perform a quadratic regression for each country to account for heterogeneity. Second, we test and control for spatial dependence using the Global Moran's I test and the Maximum Likelihood Estimator (MLE) within the Fixed and Random effects on the Spatial-Durbin-Model, respectively. We also estimate the relationship using pooled OLS, Fixed and Random effects, and the generalised methods of moments (GMM). We document three key results: (1) the EKC hypothesis holds for the entire sample of 48 countries, even though the relationship is weak, (2) the relationship is sensitive to factor heterogeneity, with the EKC holding in some countries, while it breaks in others, and (3) there exist significant direct and spillover effects in the Co2-growth nexus across countries. Our findings provide a strong case for increased technological progress in pollution abatement, more abatement intensity, and adoption of cleaner production techniques. Specifically, we urge governments, multilateral organisations, and private investors to increase investments in renewable energy development projects. Given heterogeneity effects, we call for country specific measures which speaks to the Paris agreement.

1. Introduction

In recent years, climate change has imposed itself as a topical area of global attention. The United Nations (UN) established the Framework Convention on Climate Change (UNFCCC) in 1994 to spearhead policy towards reducing environmental pollution. The Kyoto Protocol (1997–2015) and the Paris Agreement (2016 to date) have put climate change on the development agenda. The UN Sustainable Development Goals (SDGs) have escalated the focus on climate change. Goal number 13 on climate change is the only one tagged with urgency. It calls for stakeholders to "take urgent action to combat climate change and its impacts" (United-Nations, 2016). The insistence is justifiable. The world is experiencing growing threats from climate change. The last decade (2010–2019) has been the warmest. Greenhouse gas (GHG) emissions continue to rise, are 50% higher than 1990 levels, and have reached highest levels of 48.94 million tonnes in 2019 (World Resources Institute (WRI[1]), 2021). Also, carbon dioxide (Co2) emissions, which constitute over 65% of GHG emissions, reached new record levels of 36.4 million tonnes in 2018 (Potsdam Institute for Climate Impact Research (PKI[2]), 2021). The increasing concern in combating climate change is understandable by considering its damaging effects.

Climate change is considered the biggest impediment to sustainable economic development. The United Nations Development Program (UNDP) (2021) associates 91% of geophysical disasters, which have been responsible for 1.3 million deaths between 1998 and 2017 in the world, to climate change. The Economist Intelligence Unit (EIU), 2020) estimates that if proper measures to combat climate change are not taken, climate effects may cost the world US$7.9 trillion and cause the

* Corresponding author.
E-mail addresses: espoirkamandadelphin@gmail.com (D.K. Espoir), rsunge@gzu.ac.zw (R. Sunge).

[1] Data obtained from Climate Analysis Indicators Tool (CAIT).
[2] See Gütschow et al. (2016) for data details.

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global economy to lose 3% of gross domestic product (GDP) by 2050, with the impact being severe in Africa (4.7%). A recent study by Kompas et al. (2018) found that with 3∘C global warming, the global economy faces a potential loss of US$9593.71 billion or approximately 3% of the 2100 GDP. Climate change affects economic growth through its effects on key sectors of the economy. For instance, it reduces agricultural productivity and threatens food security (Montalbano et al., 2015; Food and Agricultural Organisation (FAO), 2016), impose economical, ecological, and social constraints on industrial production (Dombrowski and Ernst, 2014), and disrupts tourism activities (Grimm et al., 2018). With such key industries adversely affected by climate change, economic development is compromised.

The relationship between environmental degradation, usually proxied by Co2 emissions, and economic growth, continues to attract undying research interest. Two strands of literature exist. The first examines the impact of economic growth on emissions. Such evidence is based on the EKC proposition. The EKC theory suggests an inverted-U association between economic growth and environmental degradation. It hypothesises that degradation levels increase with economic growth up to a certain level, beyond which the levels start to fall (Olubusoye and Musa, 2020). Evidence on this is mixed but tilted against its existence (Holtz-Eakin and Selden, 1995; Farhani and Ozturk, 2015; Abid, 2016; Aye and Edoja, 2017; Khan et al., 2020), while other studies (Kasperowicz, 2015; Adzawla et al., 2019) confirm it. We observe that the existence, or lack, of the EKC hypothesis varies with countries, circumstances, and estimation approaches, a position elaborated by Choi et al. (2010) and Aye and Edoja (2017).

The second strand of literature examines the impact of emissions on economic growth. This is less studied, yet it makes the environmental degradation-economic growth question more complicated. Again, results are mixed but in favour of a positive relationship. Olubusoye and Musa (2020) found that carbon dioxide emissions increase economic growth in 79% of the study sample countries. Similarly, Acheampong (2018) documents a positive impact at the global level. These findings tell that emissions are good for economic growth. However, Bozkurt and Akan (2014) provide an interesting finding. They find that (1) Co2 emissions negatively affect economic growth and (2) energy consumption positively affects it. From Bozkurt and Akan, we deduce on one hand that, energy consumption increases economic growth. On the other hand, it increases emissions which in turn negatively affects economic growth.

Several studies have shown that energy consumption causes emissions (Khan et al., 2014; Lu, 2017; Yusuf et al., 2020). These findings show an important yet complex relationship between economic growth, energy consumption, and emissions. Economic growth, through energy consumption, causes emissions, which may in turn negatively affect economic growth. According to Alagidede et al. (2015), two extreme views have emerged on this debate. The pessimist view posits that economic growth feeds from the environment for energy and wastes and is therefore detrimental. They suggest that growth needs to be paused. On the contrary, the optimists postulate that economic growth and environmental extraction can go hand in glove. They subscribe that technological advancements in production systems can make growth to be compatible with environmental sustainability. Given this, there is need for economies to grow with less environmental degradation.

The main objective of this study is to analyse the impact of economic development on Co2 emissions in Africa. The theoretical framework of our analysis is informed by the EKC hypothesis. While the debate on the EKC hypothesis cannot be settled by a single study, the current one moves the literature forward by posing three key questions that have not been resolved by existing studies in Africa. These are: (1) is the Co2 emissions effect of economic growth (EKC hypothesis) homogenous across countries? (2) is there any spatial dependence on Co2 emissions and economic development? and (3) is there any spatial interaction effect in the Co2-growth relationship across African countries? Answering these questions is important in understanding how economic development determines pollution in Africa. For instance, considering heterogeneity is logical given the different trends in economic growth and Co2 emissions in the region. A case in point is that of Ghana and Seychelles where over the period 1990–2018, the countries recorded economic growths of 5.44% and 19.06%, respectively. The corresponding growths in GHGs are 8.12% and −3.74%. In this case, the EKC hypothesis is expected to hold for Seychelles but break for Ghana. This suggests the possible heterogeneity that exists across countries in the region which should not be ignored.

Also, reflecting on spatial dependence is in the spirit of Tobler's (1970) Law of Geography, which suggests that no region is isolated. African countries are connected in two ways. First, several countries share common geographical and climate conditions (see Espoir et al., 2021). Second, increasing trade liberalisation, economic integration, and globalisation mean stronger ties amongst countries. As such, there is a greater likelihood of economic shock spillovers across the continent.

To answer these questions, we make two major contributions to the existing evidence on the environmental-growth relationship in Africa. First, we re-examine the EKC hypothesis in Africa using a sample group comprising 48 countries on a period spanning from 1996 to 2012. Our specificity resides in the fact that we analyse whether African countries behave homogeneously in relation to how economic development affects the environmental pollution. To do this, we performed a quadratic regression in GDP per capita for each country. Second, we recognize that available evidence on the continent (including Abid, 2016; Adzawla et al., 2019; Demissew Beyene and Kotosz, 2020; Olubusoye and Musa, 2020; Omotor, 2016; Yusuf et al., 2020) is not only inconclusive but made no attempt to consider spatial dependence in the assessment of the EKC.

Elsewhere, recent evidence shows that Co2 emissions and economic development tend to cluster across geographical space (Rio and Gianmoena, 2018). Failure to account for spatial interactions when the data generating process is clustered across space and time might yield inconsistent estimates (Espoir and Nicholas, 2020). Also, common panel data estimators pooled Ordinary Least Square (POLS), Fixed Effects (FE), Random Effect (RE), and the Generalised Method of Moment (GMM) cannot wholly overcome the problems caused by spatial autocorrelation between units (Anselin, 2010). Hence, our novelty is to provide evidence based on spatial econometric considerations by applying the MLE on the Spatial Durbin Model (SDM) using data from 48 African countries. Therefore, this study is the most thorough spatial analyses of the nexus between environmental pollution and economic development on the African continent so far.

The rest of the study is organised as follows. Section 2 highlights the environmental policy frameworks and state of environmental pollution; Section 3 covers literature review; Section 4 outlines the materials and methods used. Results are presented and discussed in section 5 and Section 6 concludes by giving policy recommendations.

2. Climate change policy frameworks and state of environmental pollution in Africa

2.1. Climate change policy frameworks

Greenhouse gas emissions, global warming, and climate change issues have been at the centre of policy debate at international and national levels in recent years. Early efforts to protect the climate are traced to the Intergovernmental Panel on Climate Change (IPCC) put in place by the World Meteorological Organisation (WMO) and the United Nations Environment Programme (ENEP) in 1988. The IPCC led to the establishment of the United Nations Framework Convention on Climate Change (UNFCCC) in 1994. Its role is to provide governments with a distinct view of the knowledge concerning climate change causes and impacts and adaption and mitigation strategies (Cubasch et al., 2017). The IPCC continues to play a leading role in climate change issues. The current guidelines on climate change responses are enshrined in the

Paris Agreement of 2016, which succeeded the Kyoto Protocol (1997–2015). The Paris Agreement is geared to fortify the global reaction to climate change threat by keeping global temperature rise below 2 °C above pre-industrial levels and to adopt efforts to cap temperature increase even further to 1.5 °C at the 2050 horizon (IPCC, 2018). In addition, it institutes obligatory commitments by all member countries to formulate, communicate and keep a nationally determined contribution (NDC). Also, members are expected to put in place and pursue homegrown measures to deliver on the goals of the Agreement. Furthermore, the Agreement stipulates that global financial flows are channeled towards low GHG and climate-resilient investment expenditures (Wei et al., 2016). Feedback on the NDCs shall be communicated to the IPCC at the global stock take convention, scheduled for 2023, and thereafter every five years. Overall, the Agreement envisages zero net GHG by 2100. Global efforts to achieve the Paris Agreement goals are being taken to continental and regional policy agenda.

In Africa, the African Union Commission (AUC) Agenda 2063 puts climate change on the map of its development trajectory. Achieving aspiration one - a prosperous Africa, based on inclusive growth and Sustainable Development - calls for environmentally sustainable and climate-resilient economies and communities (goal 7) (AUC, 2015). The policy direction under this goal complements the Paris Agreement. According to the Africa Development Bank (AfDB) (2019), all 54 countries have signed the Paris Agreement, whilst the majority have ratified it. Several institutions are supporting Africa's climate change mitigation and adaption agenda. For instance, the AfDB has put in place a Climate Change Action Plan (CCAP), now entering its 3rd phase, 2021–2025, to direct the implementation of its Climate Risk Management and Adaptation Strategy (CRMA) and Clean Energy Investment Framework (CEIF). The CCAP aims to achieve a low carbon and climate-resilient development in the continent. CCAP is anchored on four pillars namely, climate finance, mitigation, adaptation, and cross-cutting pillar which covers technology transfer, institutional reforms, and capacity development (AfDB, 2012).

At the country level, climate change policies are established through the NDCs and in tandem with national development policies. As an example, South African climate change strategies are outlined in the national climate policy (NCCRP) in line with the national development plan (NDP) (2020–2030). Zimbabwe has developed a National Climate Policy (NCP) and a National Climate Change Response Strategy (CCRS) and has already submitted its NDC to the UNFCCC. In Cameroon, under its NDC plan (2016–2020), the annual cost of adaption is financed to the tune of USD 18.150 million or 5.6% of GDP (AfDB, 2019). Ethiopia is expected to spend a cumulative US$150 billion on climate change mitigation and adaptation by 2030. In Tunisia, the government commits to reduce carbon intensity from 2010 levels by 41% by 2030. This would cost a total of US$17.422 million. We see from this section that policy frameworks to achieve environmental-friendly practices originate at the global level and are implemented at the country level through homegrown strategies and support from development partners.

2.2. The state of environmental pollution in Africa

At the global level, the amount of environmental pollution is increasing in absolute terms. In 1990 global GHG emissions were 32.64 million tonnes and have since increased to a record-high of 48.94 million tonnes in 2019 (WRI, 2021), growing at an average of 1.47% per year over the period. The same trend is observed for Sub-Saharan Africa (SSA) where GHG emissions surged from 2.3 to 3.7 million tonnes, increasing at a yearly average of 1.74% for the period 1990–2018. These trends show that the amount of environmental pollution in Africa is increasing at a higher rate than the global rate. However, data show that the trend varies significantly across the region. The greatest increases in GHG emissions from 1990 to 2018 are recorded in Ghana (8.12%), Burundi (4.14%), and Gambia (1.82%). However, some countries (Equatorial Guinea, −5.6%; Sao Tome and Principe, −4.05%; Seychelles, −3.74%) recorded significant decreases in GHG emissions.

Despite growths in GHG emissions varying across countries in Africa, there is no clear correlation between environmental degradation and economic growth. For instance, we do not see a significant difference in economic growth between the countries recording the biggest increases and decreases in GHG emissions. The GDP growth rates for Ghana, Burundi, and Gambia are 5.44%, 1.16%, and 3.06% respectively for the period 1990–2018 (World Bank, 2021). Over the same period, Equatorial Guinea, Sao Tome and Principe, and Seychelles recorded economic growth rates of 4.90%, 3.77%, and 19.06% respectively. For Ghana, a high economic growth rate (5.4%) is associated with a growth in GHG emission (8.12%) while for Seychelles, a much bigger rate of economic growth (19.06%) is accompanied by a sizeable decrease in GHG emissions (−3.74%). In these two cases, the EKC hypothesis is expected to hold for Seychelles but break for Ghana. This suggests the possible heterogeneity that exists across countries in the region.

The amount of GHG emissions is usually dominated by Co2 emission, which on average constitutes around 70% of total GHG emissions. As such, the trend in Co2 emissions parallels that of total GHG emissions. Also, statistics show that Africa is emitting Co2 gases at a relatively higher rate than global levels. Between 1960 and 1980, global Co2 emissions increased from 9.2 to 19.4 million tonnes following an annual increase of 3.83% (WRI). During that period, African emissions increased from just 0.161 million tonnes to 0.317 million tonnes on the back of a 6.34% annual increase. In the last two decades, the growth in Co2 emissions in Africa averaged 2.64% while growth in global emissions was falling to 1.3% and 1.9%. Besides, the share of Africa's Co2 emissions in global Co2 emissions has been increasing over the past 5 decades. During the period 1960–1980, the share was 2.10%, which subsequently increased consistently to 3.18% (1981–2000), and 3.64% (2001–2019).

Though the share remains high in Europe, it is continuously falling, recording 41.66%, 32.74%, and 19.03% over the same periods. In per-capita terms, Co2 emissions in Africa also reflect some notable differences relative to other regions. It can be seen in Fig. 1 that per-capita Co2 emissions in Africa are rising gently but still very low, albeit variations across countries. For the period 1980–2000, per capita Co2 emissions averaged 1.13, which increased marginally to 1.15 for the period 2001–2019. Over the two periods, per-capita emissions in Asia (excluding China and India) increased from 2.99 to 3.81 while China recorded 2.11 and 5.62. Again, the data here shows clearly that the increase in emission in Africa is relatively high compared to global levels. Nonetheless, the data cannot explicitly separate Africa's Co2-economic growth nexus from comparable regions. As shown in Fig. 2, save for China and East Asia and Pacific countries, there is a strong, positive relationship between Co2 emissions and economic growth across all other selected regions and countries.

3. Literature review

In this section, we review related literature, both theoretical and empirical, on the relationship between economic growth and environmental degradation. First, we consider the theoretical foundations of the Environmental Kuznets Hypothesis. Second, we review related and recent empirical evidence.

3.1. Theoretical foundations of the EKC hypothesis

The nexus between economic development and environmental degradation has its foundation in the Kuznets hypothesis (KH). The KH was developed by Simon Kuznets (1955) to explain the relationship between economic growth and inequality. According to Kuznets (1955), during earlier stages of economic growth, income inequality rises to a maximum point, beyond which further economic growth leads to a decrease in inequality. The use of the Kuznets theory in environmental economics emerged when Meadows et al. (1972), Jahoda (1973), and

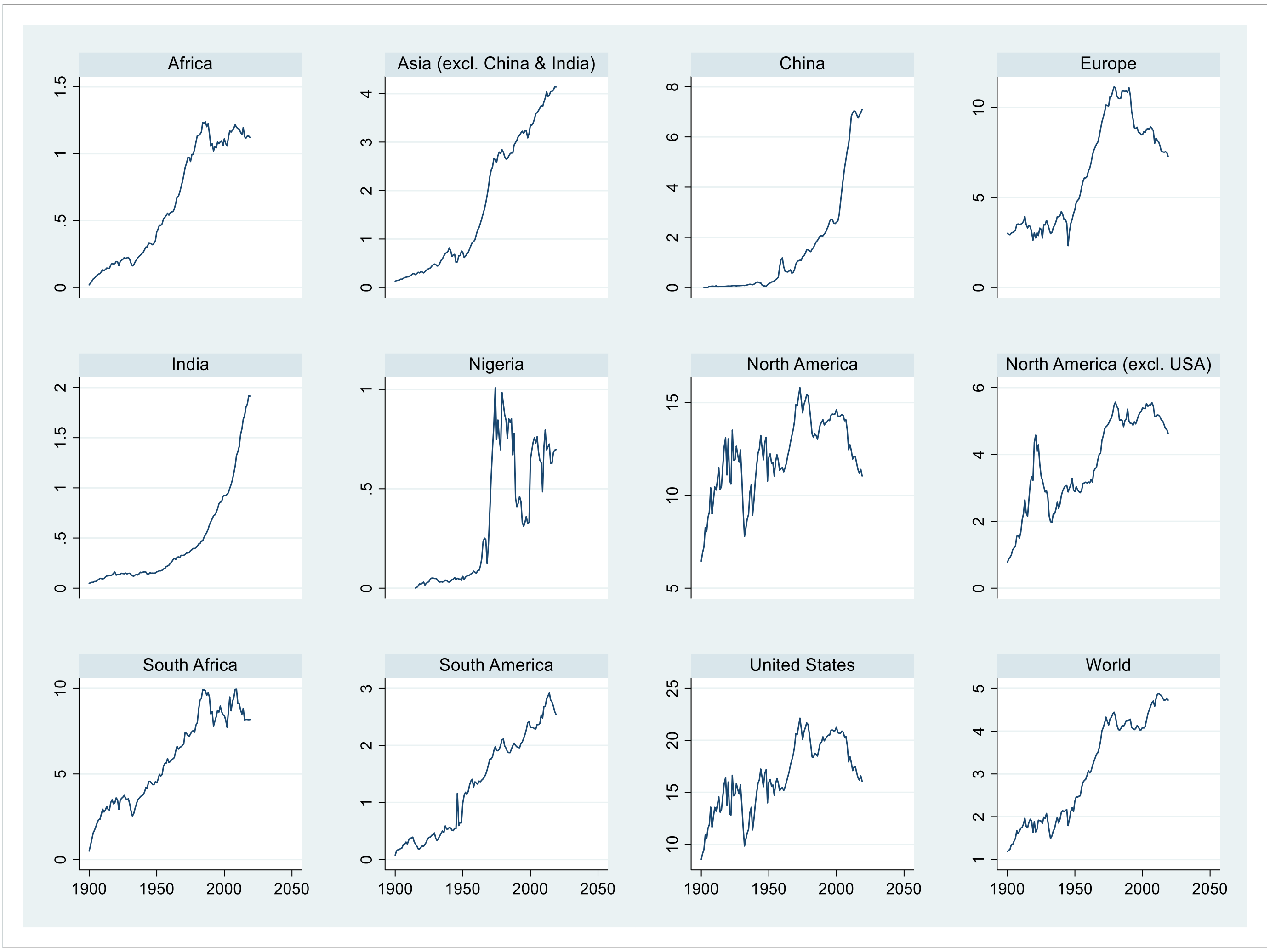

Fig. 1. Trends of Per-capita Co2 Emissions in some selected countries and regions. *Source: Authors' own computation from World Resources Institute (2021)*

Beckerman (1974) challenged the wisdom that economic growth is detrimental to economic growth. However, Grossman and Krueger (1991) and then Shafik and Bandyopadhyay (1992) were the first to formally apply and test the hypothesis on emissions and economic growth. These investigations were in tandem with Kuznets's findings. Showing the relationship graphically, it was concluded that there exists an inverted U-shaped relationship between environmental pollution and economic growth (Fig. 3). The conclusion became to be known as the EKC hypothesis.

The inverted U-shaped curve exists because, in the initial stages of economic growth, production processes rely more on natural resources such as fossil fuels with higher pollution emissions (Lu, 2017). This phase is associated with pre-industrial and low-income economies. Beyond the turning point, higher incomes increase the demand for better environmental quality (Shafik and Bandyopadhyay, 1992; Lu, 2017). Besides, more resources will be available for investment in green technologies (Abid, 2016). This phase is related to post-industrial high--income countries.

The existence of the EKC has received support from other theories, which tend to validate its existence. These are the Green Solow (Brock and Taylor, 2010), Stokey Alternative (Stokey, 1998; Brock and Taylor, 2010), and the Composition Shifts (Stern, 2004; Brock and Taylor, 2010). These three theories help explain how economic growth can reduce environmental degradation. According to the Green Solow theory, the EKC is explained by two opposing exogenous technological progress effects. On one hand, technological progress in production generates a scale effect that increases the emissions growth rate. On the other, technological progress that occurs in the abatement process leads to a decrease in emissions per unit of output (Stern, 2004). Unlike the Green Solow model in which emissions fall solely due to abatement technology, the Stokey Alternative model shows the importance of pollution abatement intensity. Increased economic growth makes demand for environmental protection more elastic. Consequently, the share of income spend on abatement increases which leads to stricter regulations and therefore decreasing pollution levels. This behavioural assumption makes it possible that at first, environmental pollution worsens only to improve at higher economic growth rates.

Lastly, the Composition shift theory relates the EKC to the source-sink relationship. With abatement technology and intensity assumed constant, the theory argues that emissions to output ratio can be reduced when a cleaner mix of production inputs and techniques are adopted (Brock and Taylor, 2010). As outlined by Stern (2004), initially, the economy switches from agriculture to heavy industries with higher emissions. Later, heavy industries are dumped for light manufacturing and services industries with less emission per output unit. These three theories house several important transmission mechanisms that lead to the existence of the EKC. Examining these mechanisms can contribute further evidence to the analysis of the EKC hypothesis. However, this can be an impetus for future investigations. Accordingly, our analysis does not examine these transmission mechanisms. Given the theoretical propositions, it sounds as if the EKC hypothesis is bound to hold. However, chances are high it can fail.

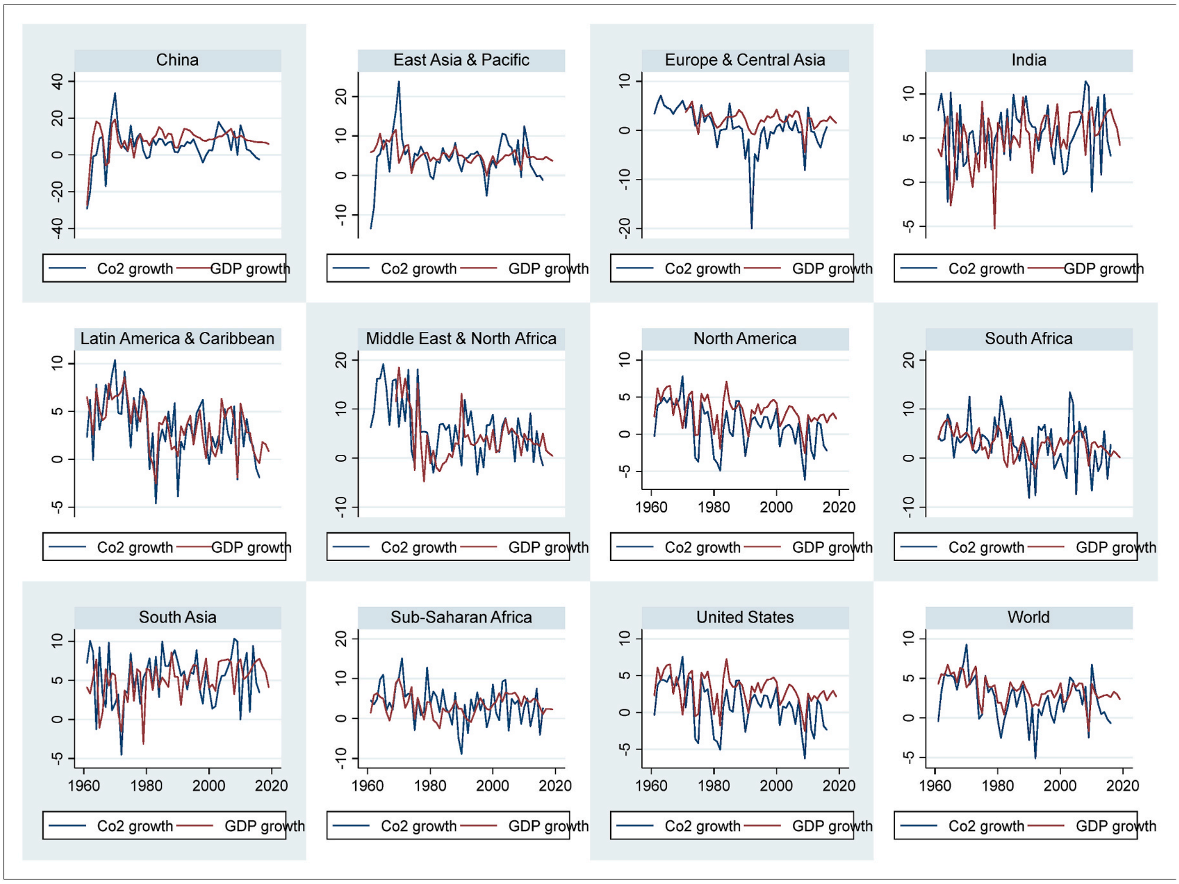

Fig. 2. Co2 Emissions Growth and Economic Growth. Source: Authors' own computation from World Bank Development Indicators (2021)

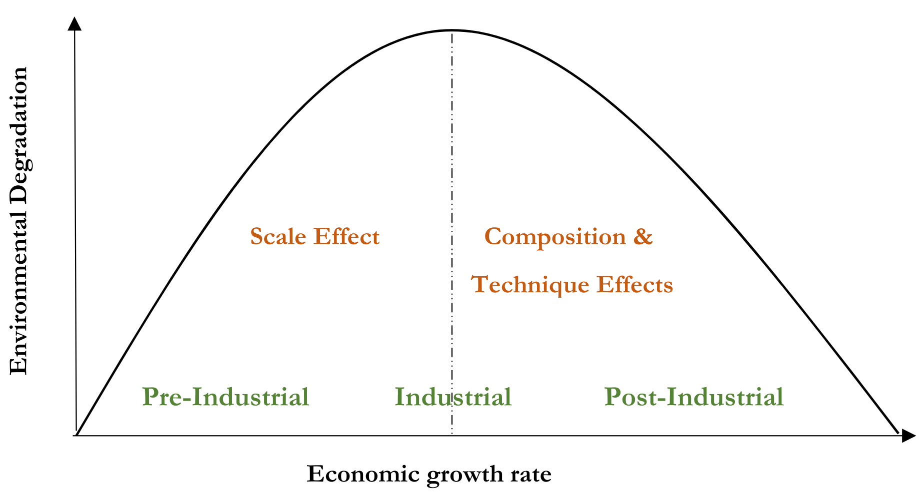

Fig. 3. The Environmental Kuznets Curve. Source: Author's illustration from the EKC, Green Solow, Stokey Alternative and Composition shift theories. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Following the breaking conclusion by Grossman and Krueger (1991) and Shafik and Bandyopadhyay (1992), the World Bank noted in its 1992 World Development Report that the argument that economic growth is detrimental to the environment is founded on the assumption of static technology, tastes and environmental investments (International Bank for Reconstruction and Development (IBRD), 1992). Weighing in, Beckerman (1992) believed that being rich is the best way to enjoy environmental sustainability. It follows that without technological advancements and environmental investments, the EKC hypothesis is likely to fail.

Abid (2016) demonstrates that several EKC shapes can be obtained if the hypothesis breaks. These are shown in Fig. 4. First, in (a) a monotonically increasing relationship can exist when the emissions continue to increase with income levels. Second, the reverse may hold, with emissions falling monotonically as income levels increase (b). Third, a u-shaped relationship may exist. As shown in (c), initial growth in income will be associated with a decrease in environmental degradation up to some minimum point. Beyond the turning point, further economic growth will be associated with increasing emissions.

We deduce from these possibilities that the EKC hypothesis is not a

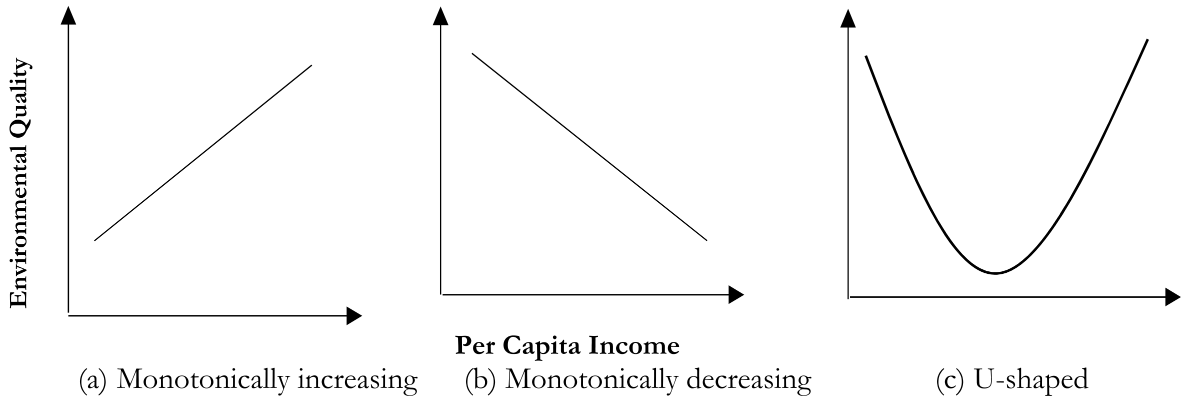

Fig. 4. EKC hypothesis failures. Source: Authors' illustration.

guarantee but only a possibility. There is a strong chance that such a hypothesis is most likely to fail in less developed and poor countries. Although the EKC is founded on the theoretical proposition above, it is largely an empirical question.

The empirical investigations on the EKC are traced to the initial model specification by Grossman and Krueger (1991). In their specifications, environmental pollution is regressed on income per capita, its square, and its cubic. However, earlier specifications did not include the cubic of income per capita. Going by the original specification, the EKC hypothesis can be expressed as follows:

$$ln\left(E/P\right)_{it} = \delta_i + \phi_t + \beta_1 \ln\left(GDP/P\right)_{i,t} + \beta_2\left(ln\left(GDP/P\right)\right)^2_{i,\,t} + \varepsilon_{i,t} \quad (1)$$

where ln indicates natural logarithm, E is emissions, P is population. δ_i and ϕ_t are parameters which vary across states or units i and time t. The fixed effect assumes that the income elasticity is the same for all states for any given income level. The time intercepts controls for time-varying omitted variables and shocks common to all states and units. $\beta_j = 1, 2$, are the coefficients to be estimated. The EKC hypothesis is confirmed with positive β_1 and negative β_2. The income level where emissions are maximised is given as:

$$\tau = exp(-\beta_1 / 2\beta_2) \quad (2)$$

More often, EKC studies have included additional variables to explain the variation in environmental degradation. Some common variables include governance, trade, and globalisation, energy consumption, financial development (Abid, 2016; Aye and Edoja, 2017; Demissew Beyene and Kotosz, 2020; Fang et al., 2018; Omotor, 2016; Radmehr et al., 2021; Stern, 2004; Yang and Chng, 2019). Accordingly, most empirical analyses assume an EKC model in the form:

$$ln\left(E/P\right)_{it} = \delta_i + \phi_t + \beta_1 \ln\left(GDP/P\right)_{i,t} + \beta_2\left(ln\left(GDP/P\right)\right)^2_{i,\,t} + \sum_{\beta=3}^{J} X_{it} + \varepsilon_{i,t} \quad (3)$$

where X is a vector of additional explanatory variables up to J.

3.2. Empirical literature

Our literature review reveals that the nexus between emissions and economic growth have been extensively investigated and will continue to receive increasing attention into the future. Accordingly, it is hard to give justice to such voluminous literature. As such, we summarise close and most recent studies. Less evidence has been provided at country level with the majority being on regional level. Some country evidence includes on China (Fang et al., 2018; Zou and Zhang, 2020), Turkey (Bozkurt and Akan, 2014), and Pakistan (Khan et al., 2020). Regional evidence is available for Europe (Kasperowicz, 2015; Mazuri et al., 2015; Radmehr et al., 2021), Latin America and Caribbean (Jardón et al., 2017), Asia (Lu, 2017; Yang and Chng, 2019), and Africa (Abid, 2016; Adzawla et al., 2019; Demissew Beyene and Kotosz, 2020; Olubusoye and Musa, 2020; Omotor, 2016; Yusuf et al., 2020). Other studies (Aye and Edoja, 2017; Odugbesan and Rjoub, 2020; Osobajo et al., 2020; Saidi and Hammami, 2015) are cross regional. We observe that results remain mixed within and across the same countries and regions.

There are two strands of literature on economic growth and environmental degradation. The first centres on the nexus between environmental emissions and economic growth. This group of research directly tests the EKC hypothesis. The second focuses on the relationship between energy consumption and economic growth. In this paper, we major on the first strand. Using a panel of 18 European Union member countries and data from 1995 to 2012, Kasperowicz (2015) shows that the relationship between economic growth and Co2 emission is significantly positive in the short-run and significantly negative in the long run. Hence they find support for the EKC theory based on error correction estimation. However, Mazuri et al. (2015) used panel data techniques to show that the theory does not hold for the whole of Europe. Although not directly testing the EKC theory, Radmehr et al. (2021) recently employed spatial econometric approaches to confirm a bidirectional relationship between economic growth and Co2 emissions in Europe.

Jardón et al. (2017) examined the relationship using data from 20 Latin American and Caribbean countries for the period spanning 1971–2011. They find a Kuznets turning point under assumptions of cross-sectional independence. However, after testing, confirming, and controlling for the presence of cross-sectional dependence, they failed to show a long-run relationship between the two. Therefore, they rejected the EKC proposition. Lu (2017) investigates the relationship using panel data from 16 Asian countries for the period 1990–2012. The study documents a bidirectional Granger causality between energy use, GDP and GHG emissions as well as between GDP, GHG emissions, and energy use. Also, they confirmed the existence of a non-linear quadratic for the 16 countries and a subset of newly industrialised countries. They concluded that the EKC hypothesis holds. Khan and Ozturk (2021) also confirmed the EKC hypothesis after controlling for financial development. The study used panel data from 88 developing countries over the period 2000–2014. Results from difference and system generalised method of moments suggested that financial development have got direct and indirect pollution reduction effects. Indirectly, it was established that financial development lessens the negative effects of income, FDI and, trade openness on Co2 emissions. This result was confirmed using five different proxies of financial development.

Evidence by Stern and Common (2001) show that EKC hypothesis tends to vary for different income levels. Using Sulfur instead of Co2 emissions per capita, they reveal that the former is a monotonic function of income per capita at global level. This suggests that the EKC hypothesis fails. However, for high-income countries, the results confirmed an inverted U-shaped relationship. The inconsistent results can also be seen from country-based evidence. Yang and Chng (2019) used the auto-regressive distributed lag (ARDL) estimation techniques to examine the EKC in six ASEAN countries using time series data for the period 1971–2013. These countries are Singapore, Vietnam, Malaysia, Thailand, Indonesia, and the Philippines. The results varied across countries with the EKC being confirmed in Singapore, Vietnam, and Thailand while no evidence was found in Malaysia, Indonesia, and the Philippines.

In another country study, Zou and Zhang (2020) investigated the nexus on 30 regions in China from 2000 to 2017. Estimation of a spatial Durbin model (SDM) suggested that economic growth in China is good for the environment. This implies that higher economic growth reduced environmental decay, a result consistent with the EKC theory. This finding is supported by Fang et al. (2018), who, using two kinds of pollutants, sulfur dioxide, and industrial wastewater, show that the EKC holds for the whole of China and some selected regions for the time spanning 2003–2014. However, Choi et al. (2010) provide contradicting results for China. They find a U-shaped relationship between economic growth and Co2 emissions using data from 1971 to 2006.

Despite Africa having a small share in global GHG emissions, the matter is attracting growing interest among academics and policy-makers. This may reflect the relatively bigger impact of climate change and global warming on the continent. Abid (2016) applied the GMM estimation on panel data from 25 SSA countries for the period spanning 1990–2010 to investigate the impact of financial, economic, and institutional factors on Co2 emissions. The results rejected the EKC theory. Instead, they document that institutional variables, namely government effectiveness, political stability, control of corruption, and democracy, reduce CO2 emissions. A similar study was done by Adzawla et al. (2019) for SSA using data from 1970 to 2012. Estimations from ordinary least squares (OLS) and Vector-Auto-Regressive approaches reveal a long-run monotonically decreasing association between economic growth and environmental quality. In the short run, they find that a relationship between the two exists, though they could not find any turning point. Thus, whilst they find no evidence for the EKC proposition, their findings suggest that growth in SSA is not detrimental.

Evidence on the EKC theory has also been provided for sub-sections and regions in Africa. Olubusoye and Musa (2020) disaggregates 43 African countries into three income groups for the period 1980–2016 to show mixed results on the validity of the EKC hypothesis. Pooled mean group (PMG) and mean group (MG) estimation of an ARDL model revealed that in 79% of the sample countries, economic growth increases Co2 emissions while a decrease in emissions is confirmed in only 21%. This finding reiterates the fact that the relationship is sensitive to country and regional specific characteristics and estimation methods.

Yusuf et al. (2020) brought some new evidence on the EKC theory. They tested it for countries defined by a common economic activity; six oil-producing African countries[3]- African OPEC countries. Three types of GHG emissions, Co2, nitrous oxide, and methane were used. Using the same estimation techniques as in Olubusoye and Musa (2020), they ascertain that economic growth had a long-run positive impact on all three forms of GHG emissions, though the effect on methane is insignificant. In the short run, the impact is still positive, though only significant on methane. The findings effectively reject the EKC theory. Instead, they suggest a monotonically increasing relationship.

Focusing on East African countries, Demissew Beyene and Kotosz (2020) show from panel ARDL pooled mean group (PMG) estimation that the EKC hypothesis holds in 12 countries. Using data from 1990 to 2013, they concluded the existence of a bell-shaped curve, which is an extension of the inverted U-shaped EKC. Omotor (2016) offered evidence for the Economic Community of West African Countries (ECOWAS) region. The study estimated panel OLS, FE, and RE models to show evidence for the EKC theory from two forms of environmental pollution, Co2 and sulfur dioxide (So2). As in Abid (2016), the study suggests that better quality public institutions play a significant role in reducing emissions.

In light of the findings from Africa reviewed above, we seek to contribute to the EKC empirical evidence in the continent. The novelty is that we provide evidence based on spatial econometric considerations. In the presence of regional data, Getis (2007) recommends using spatial econometric models to avoid biased outcomes, especially when there is evidence of spatial dependence among the region's units. We take wisdom from Tobler's (1970) Law of Geography which states that no region is isolated. To the best of our knowledge, no regional study in Africa has considered the spatial dependence in analysing the EKC hypothesis. As such, existing evidence is based on specifications in equations (1) and (2). These are built in ignorance of spatial interactions. According to Espoir and Nicholas, (2020), in cases where the structures of the data exhibit spatial autocorrelation or spatial dependence, both models, as specified in Eqs. (1) and (2), cannot yield consistent estimates. Also, common panel data estimators (POLS, FE, RE, and GMM) cannot wholly overcome the problems caused by spatial autocorrelation between units (Anselin, 2010). To fill this gap, we employ a spatial Durbin model for the empirical analysis in this study.

4. Research methodology and data

4.1. The model

4.1.1. Model without spatial considerations

We employed time-series cross-sectional data estimation strategies to empirically re-examine the effects of economic development on African economies' environmental degradation. Basing on the existing literature in ecological economics (Abid, 2016; Aye and Edoja, 2017; Demissew Beyene and Kotosz, 2020; Fang et al., 2018; Omotor, 2016; Radmehr et al., 2021; Stern, 2004; Yang and Chng, 2019), it was plausible to investigate the relationship between pollution and economic development, with some control variables such as trade openness, renewable energy consumption, population density, and institutional quality variables. The aim was to test for the validity of the EKC hypothesis in the African continent..[4] To ensure a comparison of the estimated results in this study with the existing empirical findings on the EKC hypothesis, we adopted the model specified by Abid (2016). We extended the existing methodological procedure by including the variable renewable energy consumption, which is shown in the environmental-growth nexus literature to be one of the most important variables determining pollution (see Radmehr et al., 2021). The inclusion of this variable was meant to avoid inaccurate results related to omission of variable bias. Therefore, we began by specifying and estimating a quadratic static panel data model, in which the functional form is presented as follows:

$$Co_{2,it} = \beta_0 + \beta_1 GDP_{i,t} + \beta_2 GDP_{i,t}^2 + + \beta_3 TRO_{i,t} + \beta_4 REC_{i,t} + \beta_5 GOVI_{i,t} + \beta_6 POP_{i,t} + \delta_i + \phi_t + \varepsilon_{i,t} \tag{4}$$

where the variable Co_2 denotes the stock of carbon dioxide emissions per capita; *GDP* is the gross domestic product per capita; *TRO* is the country's degree of openness to international trade; *REC* is renewable energy consumption; *GOVI* is the index of governance and *POP* is the population density. δ_i and ϕ_t represent the country-specific and time-specific effects, respectively, and $\varepsilon_{i,t}$, stands for the stochastic random error term. δ_i, ϕ_t, and $\beta_s = 0, 1, 2 \ldots, 10$, are the coefficients to be estimated.

[3] Angola, Algeria, Equatorial Guinea, Gabon, Libya, and Nigeria.

[4] As in Lv and Li (2021), we did not include the cube of the GDP per capita in the empirical models as the N-shaped curve is shown to be more the result of a polynomial curve fitting as opposed to a true reflection of reality.

The econometric literature suggests three fundamental techniques that could be used to obtain the coefficients ($\beta_j \delta_i$, and ϕ_t) of the variables in Eq. (4). Those techniques include cross-section Pooled Ordinary Least Square (POLS), Random Effects (RE), and Fixed Effects (FE). The use and validity of the results from these econometric techniques depend mainly on the assumptions made on the characteristics of the parameter δ_i and the covariation between δ_i and $\varepsilon_{i,t}$. According to Espoir and Nicholas, (2020), Eq. (4) can be estimated by controlling for the unobserved country-specific fixed effects δ_i. In this case, an assumption is considered that δ_i are time-invariant and partially correlate with at least one of the independent variables. This assumption is known as the FE assumption. This implies that the FE technique is an appropriate and consistent estimator of the unknown parameters.

Alternatively, one can assume that country-specific effects are not fixed but instead are pure unobserved 'random' variables identically and independently distributed (*iid*), $\delta_i \sim \mathrm{N}\ (0\sigma^2)$. This is known as the random effects assumption. In this case, the random effects (RE) estimator should be appropriate and provide consistent Eq. (4) parameters. According to Espoir and Nicholas, (2020), the main difference between FE and RE estimator is within the assumption of the orthogonality of δ_i. To choose between the fixed and random effects parameters are consistent, a χ^2 test statistic with Q degrees of freedom can be performed as suggested by Hausman (1978). Lastly, the POLS technique can also be applied when one assumes that country-specific effects do not exist and do not exercise any effect on the dependent variable.

However, a static panel model provides inaccurate results given the dynamic and persistent effects of time series. An inclusion in the model of one or two lags of the dependent variable allows accounting for the dynamism and persistence effects of time-series (Liu and Bi, 2019). Henceforth, we extended Eq. (4) by including one lag of the dependent variable as an additional explanatory variable. We then obtain a dynamic model for which the functional form is as follows:

$$Co_{2,it} = \beta_0 + \eta Co_{2,it-1} + \beta_1 GDP_{i,t} + \beta_2 GDP^2_{i,t} + + \beta_3 TRO_{i,t} + \beta_4 REC_{i,t} + \beta_5 GOVI_{i,t} + \beta_6 POP_{i,t} + \delta_i + \phi_t + \varepsilon_{i,t} \tag{5}$$

where η is the parameter of the time lag of Co_2, $\beta_s = 1,\ 2,\ \ldots,6$, are the parameters of the rest of the independent variables to be estimated and $\varepsilon_{i,t}$ is the stochastic error component which is assumed to be identically and independently distributed across all the time periods.

Notwithstanding the assumption formulated on δ_i, if POLS, RE, and FE techniques are applied to Eq. (5), this may yield biased results due to the endogeneity issue caused by the introduction in the model of the one-period lag of Co_2. To resolve this problem, we employ the GMM estimator. This method provides consistent and efficient results as it controls the variables' endogeneity (Abid, 2016). Following the common practice of dynamic models, we first apply to our data the Generalised Method of Moments in difference "Diff GMM" of Arellano and Bond (1991), which is the most commonly utilised estimator in the literature. Nevertheless, Diff GMM may be limited because it is asymptotically weak and that the accuracy of the instruments causes significant bias in finite samples. In other words, if the period of the study is not sufficient, instruments constructed based on lagged explanatory variables could be weak with regard to the difference equation (Roodman, 2007). This is the case in our sample, as the number of years is limited to 16. Given that the time series of both *GDP* and Co_2 per capita is often persistent over time, Diff GMM could yield bias results. Thus, the system Generalised Method of Moments (System GMM) estimator of Blundell and Bond (2000) was used to correct the bias of the Diff GMM.

4.1.2. Model with spatial considerations

Tobler (1970) provided the first Law of Geography, which states that: we believe that no region is isolated. This law builds the foundation of spatial econometrics in exploring and analysing the relationship that may have spatial dependence. Getis (2007) recommended using spatial econometric models to avoid biased outcomes, especially when there is evidence of spatial dependence of the variables among the region's units. The specification in Eqs. (4) and (5) are panel data models build in ignorance of spatial interactions. However, in cases where the data structures exhibit spatial autocorrelation or spatial dependence, both models cannot yield consistent estimates (Espoir and Nicholas, 2020). Additionally, POLS, FE, RE, and GMM estimators cannot wholly overcome the problems caused by spatial autocorrelation between units (Anselin, 2010). As we shall see later, based on the positive evidence of spatial effects in the data across different African countries and over time, this study further employed spatial econometric techniques to empirically investigate the impact of economic development on environmental pollution in the African continent.

Three standard spatial econometric models are generally estimated in empirical investigations: the Spatial Autoregressive (SAR) model, the Spatial Error Model (SEM), and the Spatial Durbin Model (SDM). Elhorst (2010) suggests starting with the SDM. This model is a more general specification that includes the spatial lag of the dependent and independent variables. By restricting some parameters of the SDM to zero, one can obtain specific cases, which are the SAR and SEM. To ensure parameters restrictions, we considered a dynamic SDM for which the specification is as follows:

$$\begin{aligned} Co_{2,it} = {} & \beta_0 + \eta Co_{2,it-1} + \beta_1 GDP_{i,t} + \beta_2 GDP^2_{i,t} + + \beta_3 TRO_{i,t} + \beta_4 REC_{i,t} + \beta_5 GOVI_{i,t} + \beta_6 POP_{i,t} \\ & + \theta_1 W_{n,t} Co_{2,jt-1} + \rho W_{n,t} Co_{2,jt} + \theta_2 W_{n,t} GDP_{j,t} + \theta_3 W_{n,t} GDP^2_{j,t} + \theta_4 W_{n,t} TRO_{j,t} \\ & + \theta_5 W_{n,t} REC_{j,t} + \theta_6 W_{n,t} GOVI_{j,t} + \theta_7 W_{n,t} POP_{j,t} + \delta_i + \varepsilon_{i,t} \end{aligned} \tag{6}$$

where the $\beta_s = 1,\ 2,\ \ldots,\ 6$, are the estimated parameters expected to capture the effects of the independent variables on Co_2 emission in a given country and the $\theta_s = 1, 2, \ldots, 7$, are estimated parameters expected to capture the effects of the independent variables of a neighboring country on Co_2 emission in a given country. More technically, the θ_s are parameters known as the Spatial Autocorrelation (SAC) coefficients. ρ is the parameter expected to capture the SAR effect, that is, the effect of carbon emission of neighboring countries on local country emissions of Co2. Like in Eq. (4), δ_i and $\varepsilon_{i,t}$ respectively represent the country-specific effects and the stochastic error term. $W_{n,t}$ is the spatial weighting matrix, which defines neighboring ties between different countries of Africa.

LeSage and Pace (2009) suggested two different tests that assess whether Eq. (6) can be reduced into SAR and SEM. Their suggestion is based on the argument indicating that spatial models nest dependence on both the dependent variables and the disturbances. Therefore, LeSage and Pace (2009) recommended using two different tests: the likelihood ratio (LR) and the Wald test. These tests apply parameter restrictions on the specification in Eq. (6) and examine two main hypotheses. The first is H_0: $\theta_s = 0$. This hypothesis examines whether Eq. (6) can be reduced to a SAR model. The second is H_0: $\theta_s + \eta\beta = 0$. This hypothesis tests whether the SDM specified in Eq. (6) can be reduced to a SEM. The LR and Wald test follow the properties of a chi-square distribution with Q degrees of freedom. In cases where the SAR and the SEM models are estimated separately, the likelihood ratio (LR) test can determine which model provides the best fit for the data. If these models are not estimated, the

Wald test can complement the LR test (Elhorst, 2014a, 2014b).

Furthermore, after the appropriate spatial model has been estimated, LeSage and Pace (2009) proposed a procedure that enables the computation of the direct, indirect (spillover effect) and total effects of the explanatory variables. In the present study, the direct effect refers to the impact of the change in explanatory variables on a given country's Co_2 emissions. The indirect or spillover effect suggests the influence of the change in the explanatory variables of nearby countries on the Co_2 emissions in a given country. Therefore, the total marginal effect is the sum of the direct and indirect effects.

4.1.2.1. Spatial correlation test. The application of spatial models to cross-sectional or panel data requires evidence of spatial dependence. Anselin (1995) proposed applying Local or Global Moran's I test to measure the degree of spatial agglomeration among geographical units. The Local Moran's I is a measure of how similar countries are to their neighbours. On the contrary, the Global Moran's I operate by comparing how similar every country is to its neighbours and then averaging out all of these comparisons to give us an overall impression about the spatial pattern of the variable. In this study, we measured the degree of spatial dependence of pollution and economic development using the global Moran's I, which was calculated as follows:

$$\text{Global } Moran's\ I_i = \frac{n}{SF} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{i,j}(x_i - \overline{x})(x_j - \overline{x})}{\sum_{i=1}^{n}(x_i - \overline{x})^2} \tag{7}$$

where n is the number of countries in the sample, $W_{i,j}$ is the spatial weighting matrix that describes the association between unit i and j, x_i is the value of the variable of interest (*GDP* and Co2), and $\overline{x}$ is the mean value, $\overline{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$. Finally, SF is a standardisation factor introduced to assign equal weight to all the values of the spatial matrix, $SF = \sum_{i=1}^{n}\sum_{j=1}^{n} W_{i,j}x_i$.

We tested for the statistical significance of the Global Moran's I using z statistics by comparing the calculated Moran's I from Eq. (7) and the expected value of Moran's I, (E(I) (see Li and Zhang, 2011). The standardised z statistics and E(I) are respectively expressed as:

$$Z = \frac{I - E(I)}{\sqrt{var(I)}} \tag{8}$$

and

$$E(I) = -\frac{1}{n-1} \tag{9}$$

where $VAR(I) = \frac{n^2 w_1 + n w_2 + 3w_0^2}{w_0^2(n^2-1)} - E^2(I)$, $w_0 = \sum_{i=1}^{n}\sum_{j=1}^{n} w_{i,j}$, $w_1 = \frac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{n}(w_{i,j} + w_{j,i})^2$, $w_2 = \sum_{i=1}^{n}(w_i + w_j)^2$

4.1.2.2. Spatial weights matrix. Spatial analysis cannot be conducted without specifying neighborhood relationships among units. Typically, the so-called spatial weight matrix (W) is utilised to model mutual relationships among entities, countries, or regions. The elements constituting W can depend on geographical, cultural, economic, or political ties between entities, states, or regions. Most empirical works explore two major specifications of W. The first is a binary contiguity matrix, which is based on land or maritime borders. The second is an inverse distance matrix, which is also based on the great circle distance between the capital cities of entities, countries, or regions. For the main results of this study, we used the inverse distance matrix to get the estimates of the growth-pollution nexus in Africa. The binary contiguity was applied for robustness tests to check the stability of the estimated results.

4.2. Data and variables measurement

This study used the stock of Co2 emissions measured in metric tonnes per capita as the dependent variable and the Gross Domestic Product (GDP) per capita as the key independent variable to ascertain the relationship between economic development and environmental pollution in Africa. A set of control variables was also included to address biases associated with bivariate models due to omitted variables. Also, note that the choice of the variables included in the model was motivated by comparing our results to recent empirical findings on growth-pollution nexus. Besides GDP per capita, four different control variables were included. The first control variable was the country's degree of openness to international trade. We mainly included this variable as it is well established in the literature that some economic interactions exist between environmental pollution and trade policies (Huang and Labys, 2002). The economic analysis of these interactions treats environmental pollution and trade policies as having both positive and negative consequences, depending on the economic mechanisms involved.

The second control variable was the renewable energy consumption measured as the share of renewable energy in the total final energy consumption. According to theory, renewable energy is a significant factor predicted to impact pollution negatively since it is considered the substitute for nonrenewable energy consumption responsible for a vast amount of Co2 emissions (Karasoy and Akçay, 2019). The third variable was population density, which is shown to positively affect pollution (Borck and Schrauth, 2021).

Finally, the study also controlled for quality of institutions by including an index of governance. This index constituted the fourth control variable. We used data from the most recent version of the Worldwide Governance Indicators (WGI) to determine the quality of institutions of the African countries (Kaufmann, Kraay and Mastruzzi, 2009, 2010). WGI is a World Bank database that contains aggregate and individual indicators of governance for close to 215 countries and entities and covers the period spanning the years 1996 and 2019. The WGI is disaggregated into six dimensions: Political stability and absence of Violence (PV), Government effectiveness (GE), Control of Corruption (CC), Voice and Accountability (VA), Regulatory Quality (RQ), and the Rule of Law (RL). These variables have estimated scores that vary between −2.5 and 2.5. The highest score values correspond to more excellent institutional quality for every factor where a negative and significant effect on Co2 emissions is expected.

We constructed the Governance Index (GOVI) using the Principal Component Analysis (PCA). The PCA was used to derive the principal index of institutional quality due to the correlation between the six indicators. In constructing the composite index of governance indicators, the first step was to collect the residuals from the regression of a particular composite index of the institutional quality. The residuals obtained from each regression were aggregated through PCA. According to the literature, the PCA is a procedure that takes high dimension sets of indicators and transforms them into novel indices that capture information on a different dimension and are mutually uncorrelated (Akanbi, 2014). Then, to obtain an aggregated GOVI, the first eigenvectors (factor loadings) from the PCA could be employed as the required weights. Thus, the linear combination of the index was calculated as follows:

$$GOV_{i,t} = \varphi_1 PV_{i,t} + \varphi_2 GE_{i,t} + \varphi_3 CC_{i,t} + \varphi_4 VA_{i,t} + \varphi_5 RQ_{i,t} + \varphi_6 RL_{i,t}$$

where φ_1, φ_2, φ_3, φ_4, φ_5, and φ_6 are the eigenvectors (factor loadings) obtained from the PCA and PV, GE, CC, VA, RQ, and RL are subscriptions of the six indicators of governance or institutional quality.

Table A1 in the Appendix provides a detailed description of each variable and data source. The final dataset we employed for the econometric estimations of all models was a balanced panel, which contains data for 48 African countries and covers 16 years starting from 1996 to 2012. Give the length of the time series (16 years) and the number of cross-sections (48 countries). The sample size is large enough to provide robust results that are relevant for policy formulation. Moreover, this sample group of 48 countries is valid to represent the entire African continent, which is constituted by 54 countries. In Table A2 of the Appendix, we presented the summary statistics of the mean of each variable across countries. Through this exercise, we noted that all the selected variables present high variability in mean number, which is suitable for exploratory investigations.

5. Empirical results

5.1. Results of principal component analysis

We conducted a preliminary analysis of the data of African institutions before presenting and discussing the regression results of the Co2 and economic development relationship. We presented the results of the Government index (GOVI) variable used as one of the control variables in the regressions. As indicated earlier, we employed principal component analysis (PCA) to construct the GOVI variable mainly due to the significant high collinearity between the six governance dimensions. The results of the PCA are presented in Table 1. We considered the component that obtained an eigenvalue greater than one and those eigenvectors associated with variables whose factor loading exceeded 0.30 in absolute value. The analysis of these results revealed that one single factor (eigenvalue = 4.845) from the PCA entirely explains 80.7% of the total variance. Consequently, the study focused only on the first component, which retained approximately 80% of the variance of the initial data.

Considering as reference the measurement of quality of representation of each of the six variables (squared cosine) in the first component, the variables best represented were: the rule of law, government effectiveness, regulatory quality, and control of corruption. Each one of these variables obtained a quality measure below 75%. Another variable is voice accountability, which obtained 72%, while the variable political violence obtained approximately 65%. Fig. 5 displays on the left side the correlation circle of the first factorial plane. This represents information about the two first components, which retained 87% of the variance of the initial data. As can be seen in the plot, the first main component made clear some associations between the characteristics of the governance indicators across African countries. On the right side, the figure illustrates the correlation matrix of the variables with each of the selected components. In the first principal component, the correlation circle presents associations in the positive axes of all the six initial variables: political stability and absence of violence (PV), the rule of law (RL), governance effectiveness (GE), control of corruption (CC), voice accountability (VA), and regulatory quality (RQ). In the second principal component, the correlation circle also shows in the positive axis the relationship between the variable: political stability and absence of violence (PV), and the rule of law (RL). In contrast, in the negative axis, the correlation circle presents evidence of a relationship between governance effectiveness (GE), control of corruption (CC), voice accountability (VA), and regulatory quality (RQ).

Table 1
Principal component analysis results.

PCA results (Panel A)	Eigenvalue	Difference	Proportion	Cumulative
Components				
Component 1/ (Dimension 1)	4.845	4.433	0.807	0.807
Component 2/ (Dimension 2)	0.411	0.077	0.068	0.876
Component 3/ (Dimension 3)	0.334	0.089	0.055	0.931
Panel (B): PCA eigenvectors results				
Variable	Component 1	Component 2	Component 3	Unexplained
PV	0.371	0.871	−0.132	0.013
GE	0.424	−0.323	−0.273	0.060
CC	0.411	−0.111	−0.326	0.140
VA	0.386	−0.002	0.887	0.012
RQ	0.412	−0.350	0.014	0.126
RL	0.440	0.010	−0.113	0.055

Source: Authors' illustration from PCA results.

5.2. Results of static and dynamic panel models

We started the empirical analysis by estimating the effect of economic development on environmental pollution using static and dynamic panel models. We employed different estimation techniques such as POLS, FE, RE, and the one and two-step difference and system GMM. Table 2 presents the estimated results from POLS, FE, and RE. Although the estimates are very similar for the variable of our main interest (GDP per capita), we focused on the FE estimates than the POLS and RE for two reasons. First, the Wald test statistic rejected the null hypothesis of unobserved factor homogeneity across countries. Second, the FE estimates were preferred over the RE since the Hausman test statistic rejected the null hypothesis of coefficients not systematically different. Thus, our interpretation of the FE effects results is based on the estimates of the FE model (4).

As shown in Table 2, the estimated coefficient of GDP per capita on Co2 emissions is positive and statistically significant at the 1% significance level. This result suggests that a 1% increase in GDP per capita increased Co2 emissions by about 0.04%. In contrast, the estimated coefficient on the square of GDP was −1.38e-08 and statistically significant at the 1% significance level. This coefficient means that over time, Co2 emissions decrease as the African economies become more developed. Openness to international trade has a positive and statistically significant effect on Co2 emissions across the African continent. The estimation on the openness variable shows that a 1% increase in trade increases pollution by 0.03%. Renewable energy consumption and governance index exhibited negative and significant effects on Co2 emissions. The estimated elasticities are −0.055 and −0.093 for renewable energy consumption and governance index, respectively. These results suggest that a 1% increase in each variable reduces Co2 emissions by about 5,5% and 9.3%. The population density was the only variable found to be statistically insignificant in the static panel regressions.

Although FE effects estimation accounts for heterogeneity across African countries, its estimates are biased because they are obtained in total ignorance of the dynamism and persistence effects of time series. The specification in Eq. (5) considered this aspect by introducing one lag period of the Co2 variable as a regressor, which also introduces endogeneity in the regression equation. To get unbiased estimates from Eq. (5), the GMM technique was employed, the results of which are presented in Table 3. As shown in Table 3, the estimated coefficient of $Co2_{t-1}$ was positive and statistically significant for all the baseline regressions (from regression 1 to 10). This result provides evidence of the positive effect between Co2 and its one-period lag. This is in line with the theoretical expectation, which shows that positive lagged values are likely to positively affect the current values due to persistence effects (Liu and Bi, 2019; Espoir and Nicholas, (2020)). Looking at the estimates for all the models in Table 3, two-step difference and system GMM produced the most efficient results. Thus, our interpretation of the rest of the variables is based on the two-step system GMM. GDP per capita estimate is positive and statistically significant at the 1% level. The estimate of the square of GDP is negative and statistically significant. The magnitude of the estimated coefficient for both variables is smaller than in the FE regressions. Overall, these variables suggest that economic development increases pollution, but over time, pollution decreases as the African economies become more developed.

This result is an indication that the EKC hypothesis is observed on average in the African context. Furthermore, the positive sign of GDP

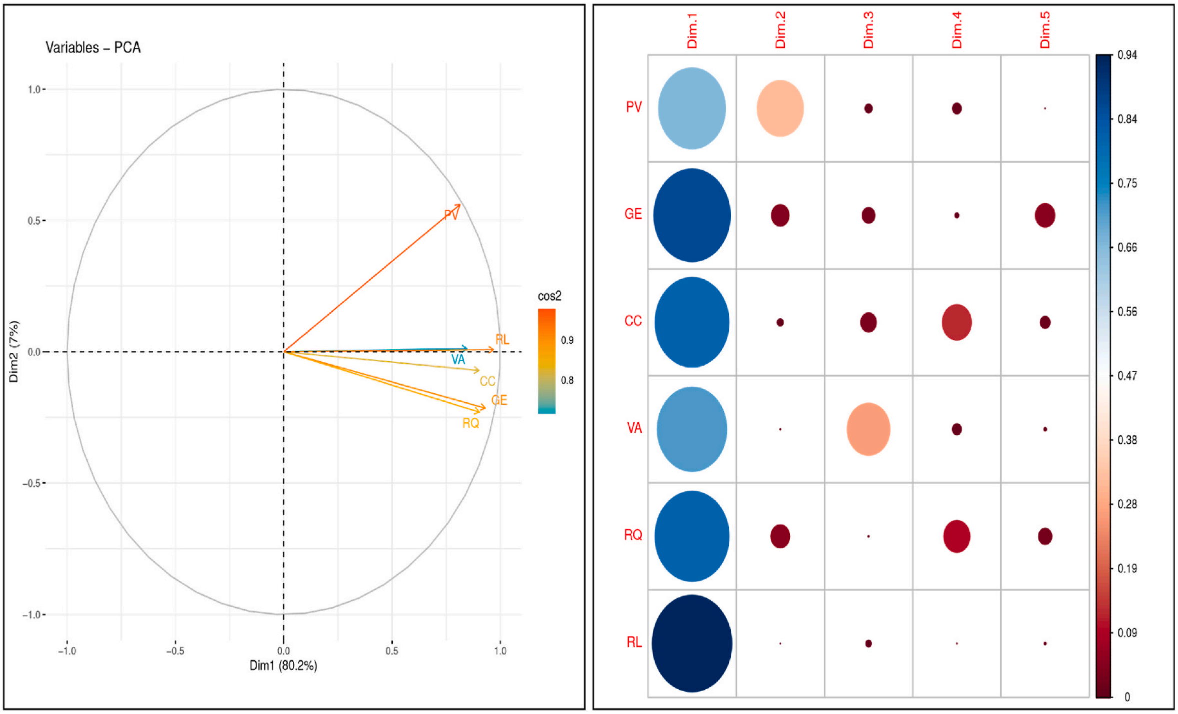

Fig. 5. Correlation circle of the 1st factorial plane (left), and correlation matrix in the chosen components (right). Source: Authors' own computation using World Bank Governance Indicators.

Table 2
Environmental pollution in Africa: Results of static panel models.

	Pooled OLS		Fixed Effects		Random Effects	
Variables	(1)	(2)	(3)	(4)	(5)	(6)
GDP	0.0006*** (0.00002)	0.001*** (0.00004)	0.0001*** (0.00001)	0.0004*** (0.00003)	0.0001*** (0.00001)	0.0004*** (0.00003)
GDP Squared	—	-3.23e-08*** (2.64e-09)	—	-1.38e-08*** (1.80e-09)	—	-1.56e-08*** (1.83e-09)
TRO	-0.002 (0.0012)	-0.005*** (0.001)	0.002*** (0.0007)	0.003*** (0.0007)	0.002*** (0.0007)	0.003*** (0.0007)
REC	-0.005*** (0.002)	-0.003** (0.001)	-0.058*** (0.003)	-0.055*** (0.003)	-0.045*** (0.003)	-0.042*** (0.002)
GOVI	-0.036 (0.023)	-0.118*** (0.023)	-0.090*** (0.030)	-0.093*** (0.029)	-0.091*** (0.03)	-0.102*** (0.029)
POP	-0.065*** (0.031)	-0.034 (0.029)	0.017 (0.097)	0.030 (0.093)	-0.00001*** (0.075)	0.011 (0.073)
Year	-0.056*** (0.009)	-0.070*** (0.009)	-0.019 (0.004)	-0.036*** (0.005)	-0.018*** (0.004)	-0.037*** (0.004)
Constant	114.895*** (19.335)	140.843*** (18.074)	43.479*** (9.173)	77.305*** (9.915)	40.265*** (9.110)	77.385*** (9.771)
Observations	935	935	935	935	935	935
R-squared	0.586	0.644	0.186	0.265	0.234	0.337
Diagnostic tests						
Breusche-Godfrey LM test	1012.65*** [0.0000]	592.31*** [0.0000]	—	—	2590.57*** [0.0000]	2854.96*** [0.0000]
White test for Heteroskedasticity	459.13*** [0.0000]	519.39*** [0.0000]				
Hausman test			60.34** [0.0000][a]	71.91** [0.0000][b]		
F test that δ_i=0				103.48*** [0.0000][c]		

Notes: Standard errors in parentheses, p-values in square brackets, *** p<0.01, ** p<0.05, * p<0.1. For the Hausman test the null hypothesis is defined as H_0: Random effects model is appropriate. The statistic of point (a) compares Fixed effects (3) and Random effects (5), while the statistic of point (b) compares Fixed effects (4) and Random effects (6).

and the negative sign of GDP squared implies that the EKC's shape depicts an inverted U-shape relationship. On the empirical front, our finding is in line with those of Wang et al. (2017), who conducted a similar analysis for China and Kasman and Selman (2015) for the case of EU member countries. Nevertheless, our finding is different from the result of an inverted N shape relationship between Co2 emission and GDP per capita reported by Özokcu and ÖÖzdemir (2017) for 26 OECD countries and 56 emerging economies. It also differs with a monotonically decreasing and increasing relationship presented by Adzawla et al. (2015) and Abid (2016) for a sample of SSA countries.

Contrary to existing empirical studies and most importantly in Africa, we further answered whether the pollution-effect of economic development is homogeneous across all African countries. To investigate the EKC hypothesis, most studies (see, for instance, Adzawla et al., 2015), as is also the case for this paper's static and dynamic results, rely heavily on the asymptotic performance. Researchers assume that the

Table 3
Environmental pollution in Africa: Results of dynamic panel models.

Variables	Pooled OLS		Difference GMM (One-step)		Difference GMM (Two-step)		System GMM (One-step)		System GMM (Two-step)	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
$Co2_{t-1}$	0.913*** (0.014)	0.887*** (0.014)	0.673*** (0.0643)	0.460*** (0.03119)	0.620*** (0.0001)	0.463*** (0.00039)	0.929*** (0.0291)	0.964*** (0.0341)	0.970*** (0.00009)	0.959*** (0.0005)
GDP	0.000146*** (0.000019)	0.00022*** (0.00002)	0.00019*** (0.00006)	0.00022*** (0.00003)	0.00020*** (1.36e-07)	0.00021*** (6.76e-07)	0.00011*** (0.00004)	0.00016*** (0.00006)	0.00008*** (1.33e-07)	0.00013*** (5.65e-07)
GDP Squared	−7.04e-09*** (1.12e-09)	−9.67e-09*** (1.21e-09)	−1.01e-08*** (1.92e-09)	−1.14e-08*** (1.54e-09)	−1.11e-08*** (4.40e-12)	−1.13e-0*** (1.82e-11)	−5.13e-09*** (1.67e-09)	−8.06e-09*** (2.49e-09)	−4.91e-09*** (3.75e-12)	−7.87e-09*** (1.60e-11)
TRO		−0.00148*** (0.0005)		−0.0051*** (0.00138)		−0.0053*** (0.00002)	−0.00290***	−0.00026 (0.00120)		−0.0019*** (0.000017)
REC		−0.0008 (0.0007)		−0.0734*** (0.0065)		−0.0732*** (0.00068)		0.00185 (0.00192)		−0.0021*** (0.00002)
GOVI		−0.0258*** (0.01016)		−0.6855*** (0.1518)		−0.5767*** (0.0174)		−0.04002 (0.03812)		−0.0534*** (0.00045)
POP		−0.00169 (0.0127)		0.2390* (0.1439)		0.2190*** (0.01223)		0.08722*** (0.04064)		0.0492*** (0.0010)
Year		−0.0308*** (0.0039)		–		–		–		–
Constant	−0.0061 (0.0256)	61.844*** (7.972)								0.295*** (0.00676)
Observations	935	935	880	880	880	880	935	935	935	935
Diagnostic tests										
R-squared	0.927	0.932								
Breusche-Godfrey LM test	128.84 [0.0000]	212.72 [0.0000]								
White test for Heteroskedasticity	92.06 [0.0000]	381.60 [0.0000]								
Sargan test overid.			580.23 [0.000]	452.28 [0.000]	584.97 [0.000]	532.58 [0.000]	456.64 [0.000]	578.33 [0.000]	551.65 [0.000]	533.13 [0.000]
AR (1)			−1.94 [0.052]	−10.28 [0.000]	−1.96 [0.051]	−1.78 [0.075]	−1.81 [0.042]	−1.98 [0.048]	−1.81 [0.070]	−1.85 [0.065]
AR (2)			1.74 [0.081]	0.55 [0.583]	1.78 [0.075]	1.58 [0.114]	1.77 [0.077]	1.73 [0.084]	1.93 [0.054]	−1.83 [0.060]

Notes: Standard errors in parentheses, p-values in square brackets, ***p < 0.01, **p < 0.05, *p < 0.1. For the GMM regressions, we have suppressed the constant term to avoid multicolinearity since the time trend variable was included in the regression.

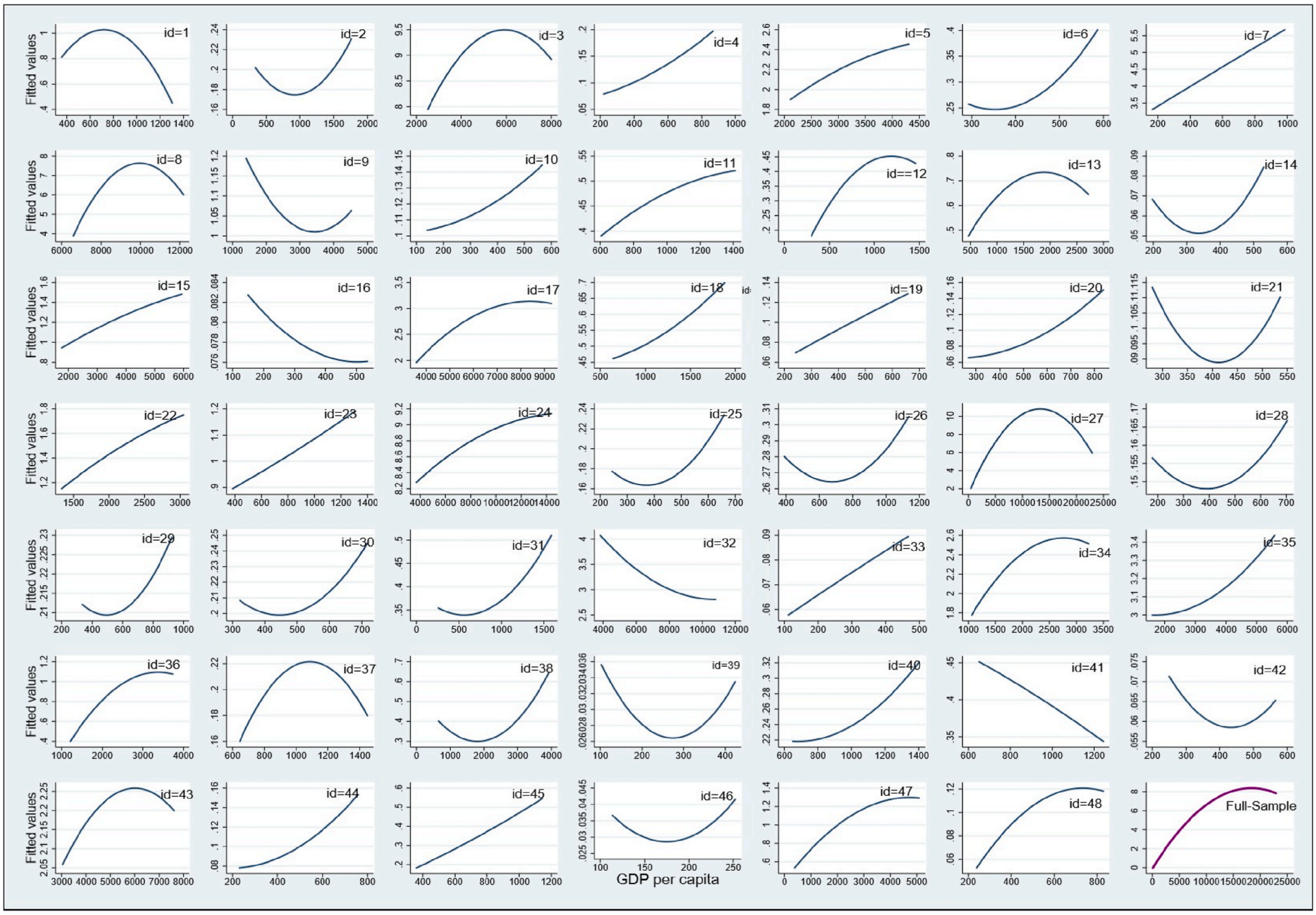

Fig. 6. Long-run Co2-growth relationship across African countries, 1996–2012. Source: Authors' own calculation.

GDP and GDP squared conditional marginal effects are the same across countries. In other words, if there is evidence of the EKC hypothesis, this should hold for every country of the sample. This assumption is not necessarily the case, especially for a region like Africa, where countries have different development levels. For example, it is well known that the development of a country like South Africa is far higher than Burundi's. Thus, one should expect both countries to exhibit different patterns concerning the EKC. We then analyzed the EKC hypothesis one step further by accounting for the economic heterogeneities of the African economies and their effects on pollution. Fig. 6 presents the country-specific results of a quadratic form of the nexus between GDP and Co2 emission.

Even though the static and dynamic regression results provided evidence favouring the EKC in the African continent, it is also well visible that the quadratic regression of GDP per capita in Fig. 6 exhibited different patterns. The outcome of this analysis can be aggregated into four groups. The first group displayed an inverted U-shaped relationship and constituted countries such as South Africa, Seychelles, Sudan, Mauritius, Libya, Equatorial Guinea, Egypt, Capo Verde, Comoros, Botswana, Angola, and Uganda. The second group presented a U-shaped relationship and comprised Zimbabwe, Tanzania, Madagascar, Liberia, Kenya, Guinea-Bissau, Gambia, Guinea, Ghana, Congo Republic, DRC, CAR, and Burundi. The third group displayed a monotonic increasing relationship and comprises Tanzania, Tunisia, Chad, Senegal, Namibia, Mauritania, Mozambique, Mali, Morocco, Lesotho, Ethiopia, Algeria, Cameroon, Burkina Faso, and Benin. Finally, the fourth group displayed a monotonic decreasing relationship and is constituted by Malawi, Gabon, and Cote d'Ivoire.

Overall, the results of the quadratic regression suggest that African countries are heterogeneous in relation to how economic development affects environmental pollution. However, most African countries agreed to the Paris Agreement on climate change to limit global warming, preferably to 1.5 °C, compared to pre-industrial levels, by lowering Co2 emissions and other greenhouse emissions. As portrayed in this study, the results show that countries are far from achieving the Paris agreement on climate. While some countries focus on achieving energy transition from nonrenewable to renewable energy sources, others are still engaging in nonrenewable energy sources. This is possibly due to low or lack of enough resources. Hence, as low resources countries strive to achieve high economic development, all things remain equal, Co2 emissions will increase. To achieve the Paris Agreement, advanced economies should support less-developed economies in achieving energy transition without harming their economic expansion ambitions.

Despite that the variable GDP and GDP squared are both significant and yielded expected signs, the magnitude of their coefficient is weak. This observation implies that other factors such as trade openness, renewable energy consumption, governance, and population density influence environmental quality in addition to economic development. The coefficient on *TR* O is negative and statistically significant at the 1% level of significance, indicating that an increase of 1% in trade would reduce Co2 emissions by 0.19%. Other estimated coefficients are −0.0021, −0.0534, and 0.0492 for renewable energy consumption, governance index, and population density, respectively. They imply that a 1% increase in renewable energy consumption and governance index would lower Co2 emissions by 0.2 and 5.3%, respectively, while increasing 1% in the population density would increase Co2 emissions by 4.92%. Globally, the system GMM technique results were consistent with our initial expectations, as the estimator dealt with the endogeneity problem. However, we were careful in considering the GMM results as exhaustive for the Co2-growth relationship across African countries. This is because there might be some geographical interactions in this relationship, which should be considered once confirmed. Hence, we took the analysis a second step further to ascertain if any spatial dependence exists in the variables of our main interest (GDP and Co2 emissions).

5.3. Results of spatial panel models

5.3.1. Analysing the role of space

We started by analysing the role of space using Moran's I test. Table 4 summarises the global Moran's I for GDP per capita and Co2 emissions. As the results of this table show, the values of Moran's I are statistically significant for GDP per capita and Co2 emissions during 1996–2012.

Given the high significance of the Global Moran's I statistics, we could statistically argue that there are significant spatial dependences of these variables across countries in the period under study. However, Global Moran's I did not provide a correct insight into the level of spatial agglomeration between countries. We then obtained detailed information about spatial agglomeration by presenting the plots of the contour map of the variable GDP per capita and Co2 emissions for the years 1996 and 2012. On the left-hand side of Fig. 7, we presented the result for GDP per capita, and on the right-hand side, we presented the results of Co2 emissions. The map for GDP per capita displayed substantial spatial disparities, ranging from a low average amount of USD 522 in 1996 and 4527 in 2012 to a high average amount of USD 3900 in 1995 and 13,026 in 2015. On the other hand, the map for Co2 emissions presented significant spatial distribution, ranging from low metric tonnes of 0.90 in 1996 and 0.71 in 2012 to high metric tonnes of 4.3 in 1996 and 5.83 in 2012. Hence, these results confirmed the presence of geographical agglomeration since perceptible spatial clusters of very-high and very-low GDP per capita and Co2 emissions portray the maps. We further presented Moran's I scatter plots for GDP per capita on the left-hand side and the plots for Co2 emissions on the right-hand side of Fig. 8 for the years 1996 and 2012. The aim was to visualise the quadrants in which most African countries were situated. As shown in Fig. 8, most countries were found in the first and third quadrants, indicating positive spatial dependence in GDP. More specifically, the plots show that in 1996 and 2012, 85,2% of countries were located in the first and third quadrants while just 14.8 % of countries were situated in the second and fourth quadrant and presented negative spatial association. For Co2 emissions, the plots in Fig. 8 also show that most African countries were located in the first and third quadrant with approximately 82% of sample representation, while just 18% of countries were in the second and fourth quadrant. The comparison of two years shows that spatial dependence for most countries was centered in the first and third quadrant and was similarly the same for the two variables. These results imply that the level of economic development and environmental pollution among countries is dependent on their adjacent countries. Based on the findings of this section, the spatial regression model as presented and discussed in section 5 was performed to account for biases associated with spatial agglomeration.

Table 4
Results of global Moran's I.

Year	*GDP* per capita		Year	*Co*2 per capita	
	Moran's I	z-statistic		Moran's I	z-statistic
1996	0.141*	1.712	1996	0.166**	2.124
1997	0.156*	1.908	1997	0.169**	2.146
1998	0.146*	1.844	1998	0.176***	2.174
1999	0.153**	1.966	1999	0.175***	2.148
2000	0.166**	2.040	2000	0.177***	2.172
2001	0.182***	2.224	2001	0.190***	2.261
2002	0.183***	2.315	2002	0.189***	2.261
2003	0.225***	2.640	2003	0.170***	2.076
2004	0.251***	2.893	2004	0.150*	1.826
2005	0.262***	3.013	2005	0.171**	2.045
2006	0.250***	2.901	2006	0.148*	1.807
2007	0.253***	2.956	2007	0.160*	1.922
2008	0.246***	3.053	2008	0.172***	2.058
2009	0.262***	3.119	2009	0.181***	2.168
2010	0.271***	3.151	2010	0.210***	2.480
2011	0.303***	3.664	2011	0.181***	2.188
2012	0.262***	3.132	2012	0.224***	2.602

Note: *, ** and *** represent respectively significance levels at the 10%, 5% and 1%.

5.3.2. Empirical results of spatial model and discussion

Table 5 exhibits the results of the dynamic spatial panel model as specified in Eq. (6). The results of all the regressions in this table were obtained using the inverse-distance weighting matrix. All the estimates were obtained using a Fixed and Random Effects Maximum Likelihood estimator (MLE). The results in column 1 of Table 5 are a dynamic POLS regression considered a baseline to the dynamic regressions in columns 2 to 5. As in the two-step system GMM regression, the dynamic POLS results show that GDP per capita has a positive and statistically significant effect. GDP square has a negative and significant impact on Co2 emissions. Columns (2) and (4) are the spatial FE and RE, respectively, and the regressions did not include the time lag of the Co2 variable.

Also, note that columns (3) and (4) contain SDM FE and RE results that included the time lag of the Co2 variable. We used the log-likelihood, the Akaike Information Criteria (AIC), and Schwarz's Bayesian Information Criteria (SBIC) to decide which of the SDM FE and RE regressions techniques was efficient. All three tests indicated that the SDM FE regressions 3 and 5, where the time lag variable was included, were the most.[5] We then applied the Hausman test to determine which of the SDM FE regression 3 and the SDM RE regression 5 was the most efficient. The Hausman test result indicated that the SDM FE regression 3 should be preferred. Thus, we based our interpretation of the spatial regression results on the spatial FE estimates in regression 3. As shown in Table 5, the estimate for $Co2_{t-1}$ in a given country was positive and significant at the 1% level, while in the neighboring country, it was positive and significant. It implied that the past level of Co2 emissions in a given country positively influenced its current Co2 emissions. In contrast, the effect of past Co2 levels in the neighboring country on the country's current Co2 emissions was negative and significant.

The coefficient of GDP per capita was found positive and significant at the 1% level. In contrast, that of GDP squared was found negative and significant at the 1% level. In this regression, the magnitude of the coefficient was a bit higher for GDP per capita (0.0003) than in the two-step system GMM regression 10, and for GDP squared, the magnitude was lower, −1.24e-08 against −7.87e-09 for the GMM. This difference in the magnitude of the estimates indicated that the system GMM underestimated the effect of GDP per capita and overestimated the effect of GDP squared. Despite this difference for the two variables, one could still observe the evidence of the EKC hypothesis for the entire sample of Africa. This finding is in line with the recent finding by Lv and Li (2021). They controlled for spatial interactions in the Co2, growth, and financial development nexus and reported an inverted U-shaped curve for panel data of 97 countries.

The effect of international trade on Co2 emissions was found positive but statistically insignificant in the given country and her neighbour. The estimated coefficient of renewable energy in a given country was negative and significant at the 1% level. In contrast, the renewable

[5] According to the log-likelihood criteria, the regression with the highest value is the most efficient. For the AIC and SBIC, it is the regression with the lowest value that is preferred.

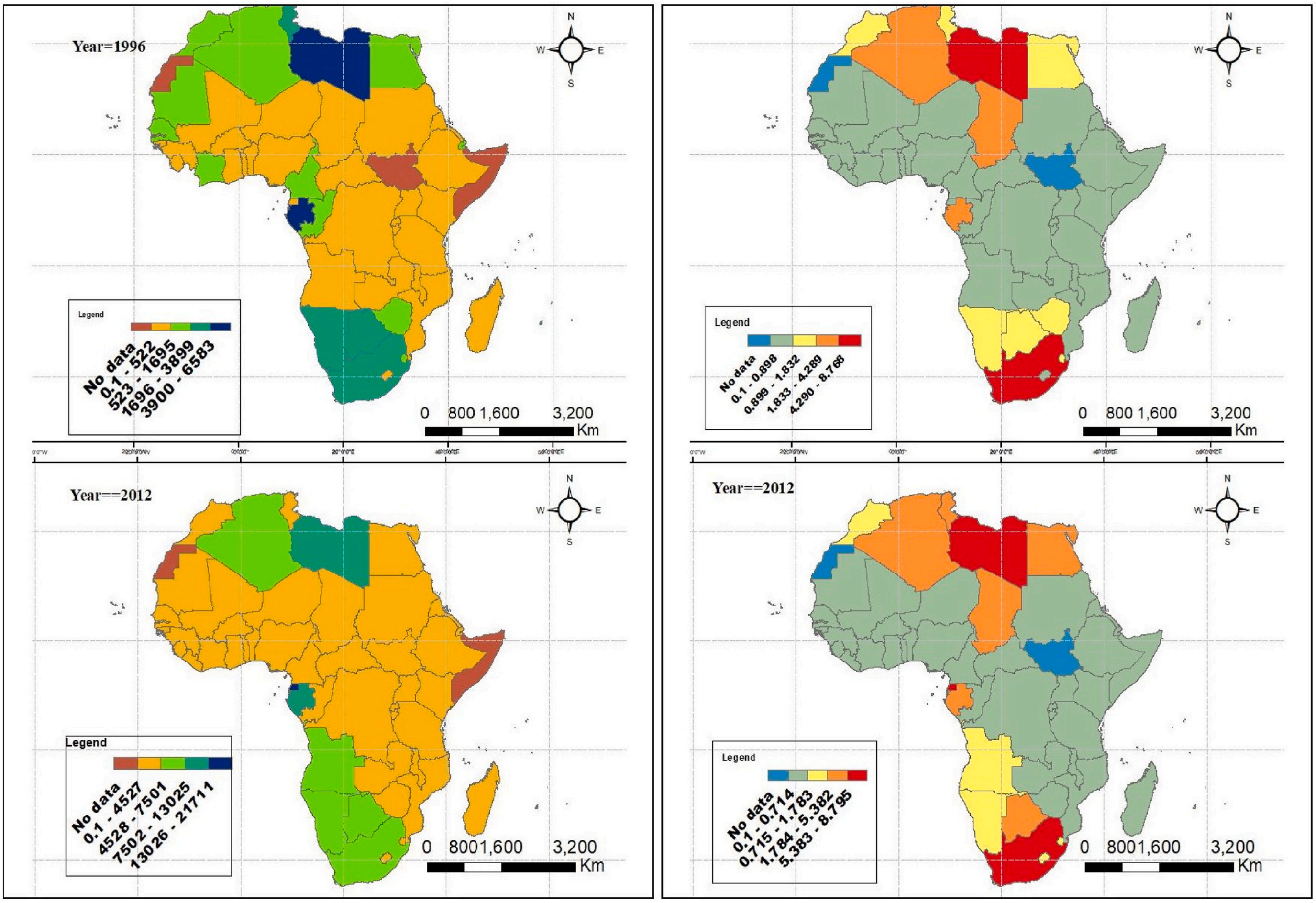

Fig. 7. Spatial distribution of GDP per capita and Co2 emissions across African countries (1996 on the left and 2012 on the right). *Source: Authors' self-painting using World Development Indicators data.*

energy effect emanating from the neighboring countries on the local country's current Co2 emissions was positive but insignificant. The estimate of governance on Co2 emissions was found positive and significant in the given country, while that of her neighbour was insignificant. Finally, the coefficient for population density on Co2 emissions was found positive and insignificant in the given country, while that of her neighbour on Co2 emissions was highly significant.

LeSage and Pace (2010) suggested computing the cumulative marginal effects as the SDM does not directly reflect the marginal effects of the corresponding independent variables on the dependent variable. Hence, the direct, indirect (spillover effect), and total effects of the independent variables on Co2 emissions were computed based on regression 3 of Table 5. Before discussing the results, it is crucial to note that the direct effects signify changes in independent variables on Co2 emissions in a given country. On the other side, the indirect effects refer either to the impact of changes in independent variables of neighboring countries on the local country's emissions or the effect of changes in explanatory variables of the local country on the Co2 emissions of neighboring countries. Then, we calculated the total marginal effects as the sum of the direct and indirect effects.

As can be observed in Table 6, the direct effect for $Co2_{t-1}$ (0.398) was positive and significant, whereas the indirect effect (−0.220) was significantly negative; thus, the total effect was positive (0.177). Concerning economic development, the results are as follows: (a) for GDP per capita, the direct effect (0.0003) was significantly positive, and the indirect effect (0.00005) was insignificant. This suggested that the economic development in a particular country produced a significantly positive effect on her pollution. In contrast, the development of the neighboring country seemed not affecting the environment of the local country. The sum of the effects gave a total significant marginal impact of 0.0003. (b) for GDP squared, the direct effect ($-1.22e-^{08}$) was significantly negative, whereas the indirect effect ($-1.02e-^{08}$) was also significantly negative. Hence, the cumulative marginal effect was significantly negative ($-2.24e-^{08}$). This implied that as the local economy and neighboring countries develop, the local country's pollution becomes low over time.

The finding of the effect of economic development on Co2 emissions in Africa has a double interpretation. On the one hand, the positive marginal impact suggested a 1% increase in GDP per capita increases Co2 emissions by 0.03%. The 0.03% represents an increase in the SSA region's 2016 stock of Co2 emissions of about 255.93 tonnes. As previously indicated, this finding is in line with the recent result by Lv and Li (2021), whose study was conducted for spatial panel data of 97 countries. One possible explanation is that most African economies are still in the pre-industrial phase (see Fig. 3). The economic production of most of those countries is centered on the agricultural and raw material extraction industry, which is mainly based on small-scale units of production. Stern (2004) argued that environmental pollution control practices might not be feasible in less developed countries like African countries. Pollution control practices in Africa are challenging to implement at a small production scale due to government inefficacity and corruption.

On the other hand, the negative marginal effect indicated a 1% increase in GDP squared and decreased Co2 emissions by 0.000002%, representing about 0.02 tonnes only. Although there is some significant economic expansion in African economies in recent decades, most

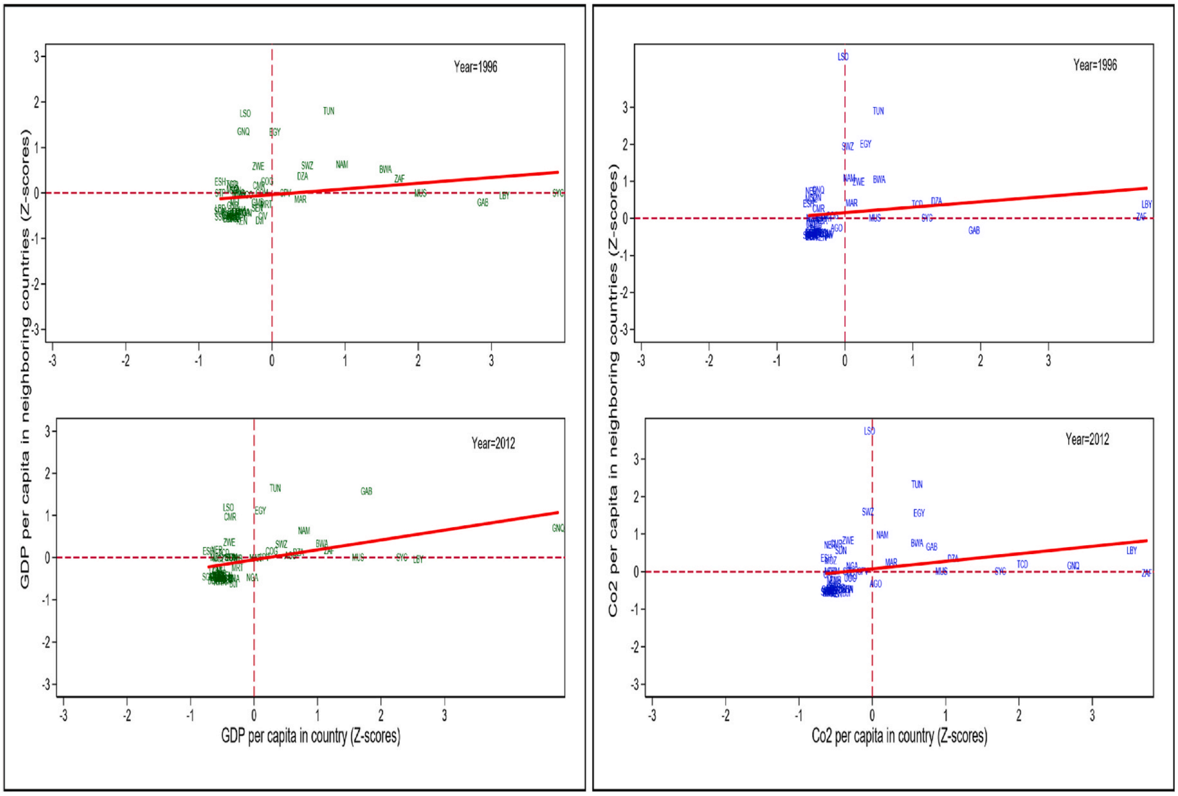

Fig. 8. Moran's scatter plots for GDP per capita and Co2 emissions across African countries (1996 on the left and 2012 on the right). *Source: Authors' self-painting using World Development Indicators data.*

Table 5
Spatial Durbin Models: Results of Dynamic OLS, Fixed and Random-effects MLE

Variables	Pooled OLS (1)	Spatial Fixed effects (2)	Spatial and time-period Fixed effects (3)	Spatial Random effects (4)	Spatial and time-period Random effects (5)
$Co2_{t-1}$	0.887*** (0.014)	—	0.398*** (0.019)	—	0.426*** (0.019)
GDP	0.00022*** (0.00002)	0.0004*** (0.00004)	0.0003*** (0.00003)	0.00046*** (0.00004)	0.0003*** (0.00003)
GDP Squared	-9.67e-09*** (1.21e-09)	-1.64e-08*** (1.86e-09)	-1.22e-08*** (1.54e-09)	-1.68e-08*** (1.83e-09)	-1.24e-08*** (1.51e-09)
TRO	-0.00148*** (0.0005)	0.0024*** (0.0007)	0.0009 (0.0005)	0.0024*** (0.0007)	0.0008 (0.0005)
REC	-0.0008 (0.0007)	-0.0551*** (0.0033)	-0.037*** (0.0028)	-0.05*** (0.003)	-0.031*** (0.0028)
GOVI	-0.0258*** (0.01016)	-0.0976*** (0.0299)	0.053*** (0.024)	-0.098*** (0.028)	0.052*** (0.023)
POP	-0.00169 (0.0127)	0.0185 (0.0953)	0.028 (0.078)	0.012 (0.083)	0.015 (0.063)
Year	-0.0308*** (0.0039)	-0.0292*** (0.0103)	-0.032*** (0.008)	-0.025*** (0.009)	-0.029*** (0.007)
Constant	61.844*** (7.972)	—	—	53.399*** (17.975)	60.061*** (14.805)
$W^*\ Co2_{t-1}$		—	-0.259*** (0.077)		-0.282*** (0.076)
W Co2*		-0.151 (0.110)	-0.010 (0.105)	-0.180* (0.104)	-0.028 (0.101)
W GDP*		-0.0001 (0.0001)	0.0001 (0.0001)	-0.00004 (0.0001)	0.0001 (0.0001)
W GDP Squared*		-1.32e-08* (7.79e-09)	-1.23e-08* (6.42e-09)	-1.53e-08** (7.80e-09)	-1.45e-08*** (6.44e-09)
W TRO*		0.003 (0.004)	0.003 (0.003)	0.002 (0.003)	0.002 (0.029)
W REC*		0.010 (0.012)	0.005 (0.010)	0.0001 (0.008)	-0.004 (0.007)
W GOVI*		0.311 (0.219)	-0.254 (0.179)	0.230 (0.201)	-0.138 (0.159)
W POP*		0.888*** (0.398)	0.763*** (0.327)	0.493*** (0.228)	0.359*** (0.170)
Observations	935	935	935	935	935
R-squared	0.932	—	—	—	—
Pseudo R^2		0.240	0.451	0.279	0.671
Model selection					
Log likelihood		-583.667	-407.136	-776.845	-576.725
AIC		1193.335	844.273	1583.692	1187.45
SBIC		1256.263	916.881	1656.3	1269.74
Hausman test			24.33 [0.0002]		

Notes: *** p<0.01, ** p<0.05, * p<0.1 imply 1%, 5% and 10% level of significance, respectively. The Hausman statistic tests the null hypothesis H_0: Random effects model is appropriate.

Table 6
Results of the cumulative marginal long-run effects.

Variables	Direct effects		Spillover effects		Total marginal effects	
	Est. coefficient	t statistics	Est. coefficient	t statistics	Est. coefficient	t statistics
$Co2_{t-1}$	0.398***	20.90	−0.220***	−3.66	0.177***	2.95
GDP	0.0003***	8.13	0.00005	0.51	0.0003***	3.23
GDP Squared	−1.22e-08***	−7.94	−1.02e-08*	−1.88	−2.24e-08***	−3.91
TRO	0.001	1.51	0.003	1.03	0.003	1.31
REC	−0.037***	−13.21	0.005	0.58	−0.032***	−3.85
GOVI	0.053***	2.17	−0.213	−1.41	−0.160	−1.01
POP	0.028	0.37	0.639***	2.23	0.668***	2.41

Notes: ***p < 0.01, **p < 0.05, *p < 0.1 imply 1%, 5% and 10% level of significance, respectively.

countries still use technologies associated with environmental pollution. The mild negative effect on Co2 emissions captured by GDP squared may be due to the energy transition happening in a few countries such as South Africa, Seychelles, Sudan, Mauritius, Libya, Equatorial Guinea, Egypt, Cape Verde, Comoros, Botswana, Angola, and Uganda. Therefore, this finding suggests no one-size-fits-all approach for the NDCs, which provides plans on how each country would cut its carbon emissions. Several African countries are taking climate action differently, from investing in renewable energy to introducing carbon taxes. If there is no harmonisation of the African country's NDCs, it is more likely that the achievement of the Paris climate agenda at the horizon of 2050 will be below the target.

The results obtained for other control variables were also revealing. For trade openness, the direct effect (0.001), spillover effect (0.003), and total effects (0.003) were all statistically insignificant. This suggests that trade openness in all neighboring countries had no impact on the environmental quality of the local country. For renewable energy consumption, the direct effect (−0.037) was significantly negative, the indirect effect (0.005) was positively insignificant, and the total effects (−0.032) were negatively significant. Although in all neighboring countries, renewable energy consumption had no impact on pollution of the local economy, the finding of the total effects recommends the variable as a significant factor of the environmental pollution in a specific country. It then implies that research, development and investment in renewable energy resources must be fundamental to the Co2 reduction programmes and energy security.

The Paris agreement on climate promotes renewable energy sources since they reduce Co2 and ensure energy security supply. An enormous energy deficit, low income, and crumbling infrastructure make Africa fertile ground for renewable energy. Hence, multilateral organisations and private investors should increase their support and investments in renewable energy development projects to decrease energy production costs. Additionally, African governments should also adopt a carbon tax policy that increases fossil fuel costs. Without constraining the fragile economic expansion that is taking place on the continent, the tax carbon policy framework may be implemented progressively, targeting the major multilateral companies of the extractive sectors responsible for the large volume of Co2 emissions. Such a measure may be a practical step toward the development of renewable energy on the continent.

The results of the government index indicated a positively significant direct effect (0.053) and an insignificant spillover effect (−0.213. Thus, the total effects (−0.160) were all statistically insignificant. The governance indicator in all neighboring countries had no impact on the pollution of the local country. Population density had an insignificant positive direct effect (0.028) and a significant positive spillover effect (0.639), thus implying that pollutant emissions in the specific country were caused by the population density of her neighboring countries.

5.3.3. *Robustness check*

We implemented two types of robustness tests to check for the validity and stability of the SDM results, as reported in Table 5. First, we conducted tests to assess whether the temporal SDM fixed effects was appropriate than the temporal SAR and temporal SEM fixed effects. As mentioned previously, we utilised the Likelihood ratio and Wald test in evaluating whether the temporal SDM fixed effects could be reduced to a temporal SAR or SEM. The results of the three regressions are reported in

Table 7
Model comparison: SDM Fixed effects versus SAR and SEM Fixed effects.

Variables	SDM and time-period Fixed effects (1)	SAR and time-period Fixed effects (2)	SEM and time-period Random effects (3)
$Co2_{t-1}$	0.398*** (0.019)	0.395*** (0.018)	0.413*** (0.019)
GDP	0.0003*** (0.00003)	0.0002*** (0.00003)	0.0002*** (0.00003)
GDP Squared	−1.22e-08*** (1.54e-09)	−1.07e-08*** (1.46e-09)	−1.06e-08*** (1.47e-09
TRO	0.0009 (0.0005)	0.0009 (0.0005)	0.0009 (0.0005)
REC	−0.037*** (0.0028)	−0.037*** (0.002)	−0.038*** (0.002)
GOVI	0.053*** (0.024)	−0.045* (0.028)	0.048** (0.024)
POP	0.028 (0.078)	0.062 (0.075)	0.066 (0.076)
Year	−0.0302*** (0.008)	−0.026*** (0.004)	−0.032*** (0.004)
W^*Co2_{t-1}	−0.259*** (0.077)	–	
W^*Co2	−0.010 (0.105)	−0.220*** (0.083)	
*W*GDP*	0.0001		
*W*GDP Squared*	(0.0001) −1.23e-08*		
*W*TRO*	(6.42e-09) 0.003		
*W*REC*	(0.003) 0.005		
*W*GOVI*	(0.010) −0.254		
*W*POP*	(0.179) 0.763***		0.184*
$W^*\lambda$	(0.327)		(0.100)
Observations	935	935	935
R-squared	–	–	–
Pseudo R^2	0.451	0.07	0.597
Model selection tests			
Log likelihood	−407.136	−425.164	−427.115
AIC	844.273	868.329	872.230
SBIC	916.881	911.894	915.795
Wald test spatial lag	23.87***	5.24***	
$H_0 : \rho = 0$	[0.0012]	[0.0022]	
LR test spatial lag $H_0 : \rho = 0$	78*** [0.0000]	54*** [0.0000]	
Wald test spatial error			6.24***
$H_0 : \lambda = 0$			[0.0000]

Notes: Standard errors in parentheses and p-values in square brackets, ***p \0.01, **p\0.05, *p\0.1, LR denotes Likelihood ratio. The results for these regressions are obtained using the inverse-distance spatial weighting matrix.

Table 7 of Appendix B. Both tests suggested a statistical rejection of the first null hypothesis at the 5 percent level of significance. This rejection indicated that the temporal SAR model was not the most suitable regression for the data used in this study. Furthermore, both tests showed that the second null hypothesis could also be rejected, which means that the temporal SEM was also not valid for this study case. In sum, both test results (LR and Wald) pointed to the SDM with time-period fixed effects as the functional form that best described the data of this study.

Second, we employed a different spatial weighting matrix to analyse the sensitivity of the SDM results. In so doing, we aligned our procedure to Zhou et al. (2019), who argued that the relevance and validity of spatial models rest on the way the spatial weighting matrix is defined. In practice, if the regression results are significant when another kind of spatial weighting matrix is used, then it can be concluded that the results are robust. The results reported in Table 5 were obtained using an inverse distance spatial weighting matrix. We used a first-order contiguity matrix. Specifically, the spatial weighting matrix we employed here is that one that satisfied the condition $W_{i,j} = 1$ when country i and j share a common land or maritime border. Otherwise, we specified $W_{i,j} = 0$. In addition, we applied the raw-standardisation procedure to $W_{i,j}$ to create proportional weights for all the countries (Pisati, 2001). As can be seen from Table 8, using contiguity spatial weighting matrices did not change our main findings.

6. Conclusion and policy implications

In recent years, climate change has imposed itself as a leading topic of global attention both for scholars and policymakers. SDG 13 on climate change is the only one tagged with urgency. It calls for stakeholders to take urgent action to combat climate change and its impacts. The insistence is justifiable. The global economy is experiencing growing threats from climate change. The Economist Intelligence Unit (2020) estimates that if proper measures to combat climate change are not taken, climate effects may cost the world US$7.9 trillion and cause the global economy to lose 3% of GDP by 2050, with the impact being severe in Africa (4.7%). The UN considers climate change the biggest impediment to sustainable economic development. Understandably, the relationship between environmental degradation and economic growth continues to attract undying research interest.

This study examined the effect of economic development on Co2 emissions in a sample group of 48 African countries spanning the years 1996 and 2012. Our study originated from the observation that despite lower contribution to GHG emissions and global warming, Africa suffers the most from climate change. We made two contributions in understanding the environmental pollution effect of economic development on the African continent. First, we re-examined the EKC hypothesis using traditional panel data methods such as pooled OLS, fixed and random effects, and the GMM. From the system GMM estimation results, we found a positive and statistically significant coefficient of GDP per capita of about 0.00013. The square of GDP per capita coefficient was found negative and statistically significant, and the magnitude was −7.87e-09. As the coefficient for the two variables was found too small, we concluded a weak relationship between economic development and environmental pollution across African countries. Overall, the results of these variables showed evidence of the EKC hypothesis for the entire sample of 48 countries. They suggested that economic development increases pollution, but pollution decreases as the African economies become more developed over time.

Unlike existing studies that impose country homogeneity assumption on the relationship between economic development and Co2, we took the analysis one step further by considering countries' factor

Table 8
Spatial Durbin Models Fixed and Random Effects using Contiguity Weighting Matrix.

Variables	Pooled OLS (1)	Spatial Fixed effects (2)	Spatial and time-period Fixed effects (3)	Spatial Random effects (4)	Spatial and time-period Random effects (5)
$Co2_{t-1}$	0.887*** (0.014)	–	0.409*** (0.019)	–	0.438*** (0.019)
GDP	0.00022*** (0.00002)	0.0004*** (0.00004)	0.0002*** (0.0003)	0.0004*** (0.00004)	0.0002*** (0.00003)
GDP Squared	−9.67e-09*** (1.21e-09)	−1.64e-08*** (1.86e-09)	−1.08e-08*** (1.50e-09)	−1.57e-08*** (1.83e-09)	−1.17e-08*** (1.49e-09)
TRO	−0.00148*** (0.0005)	0.0025*** (0.0007)	0.0009 (0.0006)	0.0026*** (0.0007)	0.0008 (0.0005)
REC	−0.0008 (0.0007)	−0.0520*** (0.0034)	−0.035*** (0.0028)	−0.047*** (0.003)	−0.028*** (0.0027)
GOVI	−0.0258*** (0.01016)	–1062*** (0.0298)	−0.053*** (0.024)	−0.106*** (0.028)	−0.052*** (0.023)
POP	−0.00169 (0.0127)	0.0121 (0.0298)	0.038 (0.077)	0.015 (0.082)	0.028 (0.061)
Year	−0.0308*** (0.0039)	−0.0260*** (0.006)	−0.025*** (0.005)	−0.025*** (0.006)	−0.024*** (0.005)
Constant	61.844***	–	–	53.371*** (13.489)	50.178*** (10.854)
$W^*\ Co2_{t-1}$	(7.972)	–	−0.105*** (0.027)		−0.112*** (0.026)
W Co2*		−0.025 (0.056)	−0.019 (0.052)	−0.130* (0.07)	0.001 (0.046)
W GDP*		−0.00002 (0.00007)	0.00003 (0.00005)	−0.00003 (0.00006)	0.00003 (0.00005)
W GDP Squared*		−2.16e-09*** (1.85e-09)	−2.59e-09*** (1.13e-09)	−2.20e-09*** (1.80e-09)	−2.84e-09*** (1.09e-09)
W TRO*		0.0004 (0.0016)	−0.00004 (0.0013)	−0.0004 (0.0016)	0.0001 (0.013)
W REC*		0.0192*** (0.0071)	0.010 (0.005)	0.018 (0.005)	0.009*** (0.004)
W GOVI*		0.109 (0.066)	0.078 (0.054)	0.09 (0.06)	0.066 (0.049)
W POP*		0.074 (0.46)	0.073 (0.119)	0.03 (0.119)	0.041 (0.0894)
Observations	935	935	935	935	935
R-squared	0.932	–	–	–	–
Pseudo R^2		0.248	0.637	0.314	0.723
Model selection tests					
Log likelihood		−599.400	−414.107	−788.296	−577.909
AIC		1224.801	858.215	1606.593	1189.819
SBIC		1287.728	930.823	1679.201	1272.108
Hausman test			36.62 [0.0002]		

Notes: ***p < 0.01, **p < 0.05, *p < 0.1 imply 1%, 5% and 10% level of significance, respectively. The Hausman statistic tests the null hypothesis H_0: Random effects model is appropriate. Hausman test column (2) Vs. column (5).

heterogeneity. We performed a quadratic regression in GDP per capita for each country to ascertain whether economic development determines Co2 emissions homogeneously across African countries. We found that the impact of economic growth on environmental pollution was heterogeneous across African countries. In some countries, the EKC hypothesis holds while it breaks in others. The outcome of this analysis was aggregated into four groups. The first group displayed an inverted U-shaped relationship, and the second group presented a U-shaped relationship. The third group displayed a monotonic increasing relationship, while the fourth group exhibited a monotonic decreasing relationship.

The second novelty in this study is that we provided evidence-based spatial econometric considerations, which existing studies have ignored. We sought to examine whether some spatial effects (direct and indirect) exist in the Co2-growth relationship across African countries. To do this, we first employed the Moran's I test and the plots of the distribution of GDP per capita and Co2 emissions to investigate the presence of spatial clustering. The results indicated the presence of spatial dependence for the two variables across African countries. Then, we utilised the MLE on the dynamic SDM to investigate the cumulative marginal effects of economic development on Co2 emissions. Our results indicated a positive and statistically significant marginal impact on GDP per capita and a negative and significant marginal effect on GDP squared. Moreover, the variable renewable energy consumption was found to have a significantly negative cumulative marginal impact on Co2 emissions, while the cumulative marginal effect of population density was found significantly positive. The result of international trade and governance quality on Co2 emissions was found positive and negative, respectively, but statistically insignificant.

There are some implications for society and practice, and future research. First, concerning society and practice, African governments should strengthen their environmental tax policies (ETPs), especially in countries with larger industrial sectors and Co2 emissions volumes. In this context, optimal environmental taxes (OETs) are an effective tool to solve industrial externalities. They internalise the social cost of environmental pollution and ecological destruction in an internal enterprise cost. This allows the redistribution of environmental resources through a market mechanism (Wang and Yu, 2021). Only a few African countries have undertaken substantial environmental tax reforms (Slunge and Sterner, 2012). In practice, the environmental tax rate (ETR) is frequently delayed and constrained by political and institutional factors, including a lack of an adequate legal, regulatory, and administrative framework and resistance from strong vested interests.

Nevertheless, several African countries utilise a range of different taxes and fees mainly associated with natural resources exploitation. These instruments have often been introduced for fiscal rather than environmental reasons. The OETs rates across African countries will motivate industrial companies responsible for massive amounts of Co2 emissions to turn to cleaner production technologies as the charges will be higher than the companies' (or industries') marginal abatement cost. Additionally, African governments could also set a punitive increase in the tax rate for companies that exceed emissions. Given the corruption that prevails on the African continent, governments must extend legislation that severely punishes enterprises that evade environmental taxes. These measures will constrain companies and industries to replace old and energy pollutants technologies with environmentally friendly ones.

Considering the heterogeneity of the EKC hypothesis, we recommended that African countries' NDCs be harmonised in the interest of the Paris Agreement. Also, multilateral organisations and private investors should increase their investments in renewable energy development to ensure compatibility between economic growth and environmental sustainability. Also, the African government should set ETRs by considering different countries' environmental regulation levels, country heterogeneities, and country emission reduction potential for different industries. Our results show that the GDP per capita effects are different across African countries. African governments must consider redesigning environmental regulation levels by implementing different policy instruments to avoid some areas becoming tax haven countries. For instance, some companies may relocate to countries with low environmental regulations and low tax rates, which will lead to severe pollution levels. In sum, the result of the heterogeneity of the EKC hypothesis showed that a common environmental tax policy across African countries could not fully realise the Paris Agreement objectives.

On the research and academic front, it is essential to note that our methodological procedure was limited in assessing the validity of the EKC hypothesis in Africa. We did not explore the specific channels in Africa through which Co2 emissions increase as a result of the economic development. The literature emphasises on the scale, composition, and technique effects as the key channels of the effect of growth on the environment. We recommend that future research focus its efforts on broadening the analysis by explicitly investigating the transmission mechanisms of the effect of growth on pollution in Africa.

Author contributions

Kamanda Delphin Espoir conceived the key ideas for this research paper. He collected and analyzed the data. He also worked on the introduction, literature review, methodology, results and conclusion. Regret Sunge conceived the key ideas for this research paper. He collected and analyzed the data. He also worked on the introduction, literature review, methodology, results and conclusion. The two authors have read and approved the final version of this manuscript.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Table A1
Variable definitions and data sources.

Variable	Description	Source
Co2	Co2 emissions in metric tons per capita	World Bank (2015)
GDP	Gross Domestic Product per capita (PPP current 2005 US dollars)	World Bank (2015)
GDPSQ	Square of GDP per capita	Authors' calculation
TRO	Trade openness, which is the sum of exports and imports of goods and services measured as a share of gross domestic product.	World Bank (2015)
REC	Renewable energy consumption, which is the share of renewable energy in total final energy consumption.	World Bank (2015)
PV	Political stability and absence of violence. It reflects perceptions of the probability that the government will be destabilized or overthrown by unconstitutional or violent means, including politically-motivated violence and terrorism.	World Bank (2020)
GE	Government effectiveness, reflecting perceptions of the quality of public services, the quality of the civil service and the degree of its independence from political pressures, the quality of policy formulation and implementation, and the credibility of the government's commitment to such policies	World Bank (2020)
CC	Control of corruption, reflecting perceptions of the extent to which public power is exercised for private gain, including both petty and grand forms of corruption, as well as "capture" of the state by elites and private interests.	World Bank (2020)
VA	Voice and accountability. This indicator captures perceptions of the extent to which a country's citizens are able to participate in selecting their government, as well as freedom of expression, freedom of association, and a free media.	World Bank (2020)

(*continued on next page*)

Table A1 (*continued*)

Variable	Description	Source
RQ	Regulatory quality reflects perceptions of the ability of the government to formulate and implement sound policies and regulations that permit and promote private sector development	World Bank (2020)
RL	Rule of law captures perceptions of the extent to which agents have confidence in and abide by the rules of society, and in particular the quality of contract enforcement, property rights, the police, and the courts, as well as the likelihood of crime and violence.	World Bank (2020)

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Table A2
List of Countries and Descriptive Statistics

List of countries		Summary statistics									
		Co2	*GDP*	*TRO*	*REC*	*PV*	*GE*	*CC*	*VA*	*RQ*	*RQ*
Country id	Country name	*Mean*	*Mean*	*Mean*	*Mean*	*Mean*	*Mean*	*Mean*	*Mean*	*Mean*	*Mean*
1	Zimbabwe	0.261	6.608	4.277	4.200	−0.464	−0.318	−0.278	−0.611	−0.765	−0.814
2	Zambia	−1.608	5.953	4.156	4.495	−0.159	−1.128	−0.840	−0.334	−0.482	−0.531
3	South Africa	2.154	8.158	3.843	2.858	−0.377	1.020	0.732	0.841	0.515	0.087
4	Tanzania	−2.461	5.391	3.948	4.524	−0.624	−0.687	−0.702	−0.641	−0.442	−0.186
5	Tunisia	0.592	7.656	4.451	2.665	0.263	0.375	−0.533	−0.599	0.141	−0.303
6	Togo	−1.411	5.820	4.349	4.291	−0.377	−0.688	−0.842	−0.986	−0.391	−0.731
7	Chad	1.035	5.401	3.841	4.585	−0.997	−0.636	−1.380	−0.993	−1.228	−1.256
8	Seychelles	1.122	8.792	4.634	0.829	1.048	0.644	0.545	0.122	0.307	0.599
9	Swaziland	0.015	7.435	4.941	4.324	−0.206	−0.636	0.037	−1.326	−0.270	−0.474
10	Sierra Leone	−2.142	5.386	3.903	4.500	−1.694	−1.409	−0.756	−0.587	−1.529	−1.381
11	Senegal	−0.868	6.578	4.090	3.960	−0.602	0.076	−0.142	0.108	−0.129	−0.181
12	Sudan	−1.720	5.705	2.997	4.426	−2.476	−0.987	−1.240	−1.858	−1.360	−1.708
13	Nigeria	−1.094	6.134	3.695	4.467	−1.055	−0.923	−1.189	−1.553	−0.968	−1.289
14	Niger	−2.722	5.500	3.598	4.463	0.026	−1.169	−0.865	−1.506	−0.984	−0.655
15	Namibia	0.050	7.771	4.581	3.506	0.854	0.431	0.808	0.496	0.360	0.251
16	Malawi	−2.395	5.427	4.001	4.399	−0.454	−0.286	−0.316	−0.088	−0.289	−0.376
17	Mauritius	0.542	8.268	4.850	3.571	1.088	0.202	0.034	0.852	−0.116	0.895
18	Mauritania	−0.755	6.800	4.254	3.781	0.367	−0.124	−0.555	−0.567	−0.401	−0.503
19	Mozambique	−2.668	5.487	3.882	4.533	−0.049	−0.144	−0.424	−0.281	−0.520	−0.805
20	Mali	−2.989	5.644	3.960	4.475	0.363	−0.998	−0.782	0.012	−0.525	−0.296
21	Madagascar	−2.335	5.871	3.580	4.412	0.217	−0.448	−0.371	−0.117	−0.912	−0.403
22	Morocco	0.108	7.353	3.852	2.881	−0.207	−0.104	−0.106	−0.416	−0.102	0.221
23	Lesotho	−0.106	6.192	1.254	3.927	0.232	−0.124	0.086	−0.480	−0.289	0.098
24	Libya	2.171	8.619	3.961	4.465	−0.987	−0.884	−0.871	−1.497	−1.735	−1.183
25	Liberia	−1.599	2.346	2.762	0.742	−2.436	−1.719	−1.500	−1.434	−1.826	−1.927
26	Kenya	−1.119	6.043	4.048	4.366	−0.653	−0.520	−1.158	−0.652	−0.313	−1.021
27	Equatorial Guinea	−1.391	6.110	2003	4.340	−0.132	−0.958	−1.264	−1.524	−1.437	−1.283
28	Guinea-Bissau	−1.801	5.494	3.746	4.493	−1.539	−1.409	−1.194	−0.972	−0.834	−1.672
29	Gambia	−1.665	6.591	3.930	4.078	0.559	−0.619	−0.374	−1.274	−0.841	0.016
30	Guinea	−1.699	6.250	3.773	4.486	−1.150	−1.169	−0.939	−1.229	−0.840	−1.447
31	Ghana	−1.135	5.984	4.279	4.367	−0.233	−0.119	−0.339	−0.207	−0.343	−0.233
32	Gabon	1.456	8.540	4.560	4.269	0.123	−0.199	−1.102	−0.321	0.135	−0.653
33	Ethiopia	−3.024	4.977	2.385	4.568	−1.051	−1.207	−0.930	−1.083	−1.296	−0.965
34	Egypt	0.392	6.969	3.849	2.160	−0.523	−0.473	−0.472	−0.844	−0.048	0.001
35	Algeria	1.199	7.380	3.983	−0.942	−1.780	−1.088	−0.566	−1.166	−0.907	−1.218
36	Capo Verde	−1.017	7.146	4.324	3.587	1.031	0.366	1.143	0.937	−0.532	1.044
37	Comoros	−1.847	6.697	3.576	4.107	0.506	−1.662	−0.998	−0.423	−1.131	−0.878
38	Republic of Congo	−0.484	6.815	4.855	4.322	−1.222	−1.169	−0.860	−0.827	−1.227	−1.043
39	DRC	−2.907	4.905	4.099	4.574	−2.681	−1.650	−1.647	−1.600	−1.756	−1.876
40	Cameroon	−1.349	6.623	3.838	4.441	−0.956	−1.080	−1.334	−0.938	−1.122	−1.441
41	Cote d'Ivoire	−0.626	6.718	4.297	4.304	0.034	−0.260	−0.260	−0.583	−0.398	−0.785
42	CAR	−2.645	5.719	3.851	4.518	−1.210	−1.406	−1.140	−0.827	−0.891	−1.152
43	Botswana	0.605	8.077	4.510	3.799	1.014	0.556	0.817	0.862	0.650	0.584
44	Burkina Faso	−2.684	5.518	3.642	4.523	−0.301	−0.928	0.111	−0.533	−0.295	−0.933
45	Benin	−1.572	5.959	4.034	4.432	1.048	−0.380	−0.548	0.259	−0.176	0.052
46	Burundi	−3.220	4.965	3.071	4.555	−2.113	−1.662	−0.680	−1.549	−1.641	−1.416
47	Angola	−0.319	6.258	2.348	4.292	−2.057	−0.859	−1.167	−1.578	−1.415	−1.630
48	Uganda	−2.984	5.660	3.566	4.560	−1.528	−0.687	−0.723	−0.891	−0.025	−0.580

Notes: The summary statistics presented in this table are computed from annual data spanning the period 1996 to 2012.

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