Research article

Industrial development, urbanization and pollution nexus in Africa

Foluso A. Akinsola a,*, Mojeed M. Ologundudu b, Motunrayo O. Akinsola c, Nicholas M. Odhiambo c

a Department of Economics, University of Lagos, Lagos, Nigeria
b Department of Economics, Mountain Top University, Ogun, Nigeria
c Department of Economics, University of South Africa, Pretoria, South Africa

ARTICLE INFO

Keywords:
Industrial development
Urbanization
Foreign direct investment
Carbon emission
Economic growth
Population growth
Panel cointegration test
Africa

ABSTRACT

This study evaluates the relationship between industrial development, urbanization and pollution emission in Africa. The IPAT identity was used to examine the impact of industrial development and urbanization on pollution emissions. The validity of the existence of the Environmental Kuznets Curve (EKC) and the Pollution Haven Hypothesis (PHH) was also tested by comparing the econometric results of panel Pool Mean Group (PMG)-based autoregressive distributed lag (ARDL) for the period 1990-2019. The PMG results confirm the validity of the EKC and PHH in the countries under study in the long run when the entire panel was estimated. One of the major contributions of the study is to analyze the impact of urbanization and industrialization on carbon emissions. The results show that an increase in urbanization and industrialization leads to an increase in environmental degradation for the entire panel. This paper presents significant contributions to economic policy, showing that an association exists between industrial development, urbanization and pollution emission in Africa.

1. Introduction

There has been much debate on the extent of the nexus between industrial development and pollution emission in emerging economies. Nations are increasingly confronted with the daunting problem of promoting economic growth while concomitantly combating climate change problems in different countries (Munir et al., 2020; Bosah et al., 2021; Armeanu et al., 2021). The carbon emissions and industrialization debate has become very topical and controversial because of the important role they play in the advent of modern technology. Increasing innovation in many countries has induced urbanization and modernization in the world. This has consequently engendered an increase in pollution, overexploiting energy sources, and industrial progress and energy consumption. This issue has caused the current debate over environmental protection and sustainable development (Li and Lin, 2015; Armeanu et al., 2021).

Concern for environmental impact is warranted by the rapidity with which African countries are industrialising and expanding their economies. Nine countries from four different regions of Africa are represented in the study: Algeria, Egypt, South Africa, Angola, Zambia, Kenya, the Democratic Republic of the Congo, Ghana, and Nigeria (North Africa, Southern Africa, East Africa and West Africa). The chosen nations are the leading industrial economies in their respective regions and major contributors to global CO2 emissions. Seven of these nations are ranked among the top nine largest polluters in Africa, according to the UN. While the Democratic Republic of the Congo (16th) and Zambia (20th) may not be the biggest polluters globally, they are among the biggest in their regions, and both have experienced rapid industrial and economic development in recent decades.

Many theories include the “Pollution Haven Hypothesis” (PHH), race to the bottom, race to the top, theory of Coupling Decoupling and Environmental Kuznets Curve. The PHH (Mani and Wheeler, 1997; Schlesich, 1999; Gary, 2002; Temurshoev, 2006; Greaker, 2007) suggest that foreign investors are more attracted to countries with weak environmental laws. The PHH hypothesis suggests that a lot of countries’ industrial development might be linked to the quality of the environmental laws, regulations and enforcement. The PHH hypothesis suggests that foreign investors from developed countries have the ulterior motive of taking advantage of countries in developing countries with weak environmental laws to establish their industries. Most industries from developed countries that aim to maximize profit and reduce the cost of operation find developing countries a safe landing to establish their industries. Implicitly, as industries in developing countries expand without little consideration for the quality of pollution emissions in the

* Corresponding author.
E-mail address: akinfolu@yahoo.com (F.A. Akinsola).

https://doi.org/10.1016/j.heliyon.2022.e11299
Received 9 July 2022; Received in revised form 14 August 2022; Accepted 24 October 2022
2405-8440/© 2022 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
environment might endanger the citizens in these countries in the long run.

However, urbanization and industrial development have engendered energy consumption in many developed countries compared to developing countries. Recent studies by Anwar et al. (2022); Bosah et al. (2021); Armeanu et al. (2021); Adedoyin et al. (2020); Davis et al. (2019) emphasized the role of energy consumption in industrial development. Muangthai, Lewis and Lin (2014); Ozturk and Acaravci (2011), Omri (2013), Shahbaz et al. (2013), Leitão (2015), and Bakirtas and Akpolat (2018) also focused on this theme. For example, Yao et al. (2019) explored the importance of reviewing the Environmental Kuznets Curve thesis to incorporate the U-shaped RKC (renewable energy Kuznets Curve) hypothesis between renewable energy consumption rate (RER) and economic growth instead of the old EKC curve. This paper makes three novel contributions to the body of knowledge. First, it examines the effect of industrialization and urbanization on pollution control by comparing the PHH and IPAT models in often-overlooked regions designated as Annex 2 countries by the UNFCCC. Second, it establishes the significance of investment and trade as an intermediary in the energy-pollution relationship. Third, it leverages the dynamic and appropriate PMG framework for analysing heterogeneous panel data. Furthermore, the methodology is appropriate for providing country-specific data and panel estimates, giving additional evidence for countries' pollution-reduction programmes.

Furthermore, the relationship of energy with financial development, international trade, as well as economic growth, has heightened in the literature, showing the motivation of the researchers to evaluate this link. The empirical results show that there is a long-run relationship between carbon dioxide emissions, economic growth, FDI, industrial development and urbanization. The paper examined the nexus between industrial development and pollution emissions in Africa for the period 1990–2019. This is done by examining the relationship between carbon dioxide emissions, economic growth, FDI, industrial development and urbanization. The paper is organized as follows. The literature review is presented in the next section. The methodology and the hypotheses are considered in section three. The empirical results appear in section four. The discussion and conclusions are described in the final section of this study.

2. Literature review

The theory of EKC was constructed to identify the relationship between economic development and CO2. The EKC can be divided into two portions, namely a ‘race to the bottom’ and a ‘race to the top’. The ‘race to the bottom’ posits that rising income accelerates environmental decay (Yandle, 2004). The theory highlights the role of the government in deliberately bringing down the country’s environmental standards and laws to attract foreign industries (see Baumol & Oates 1988; Dasgupta et al. 2002; Gray 2002; Greaker, 2007). The ‘race to the top’ portion, on the other hand, posits that an increase in income is associated with an increase in environmental quality (see Yandle, 2004). Most governments are at an early developmental stage, and attracting foreign investors and firms (e.g. pollution emitting firms) into their countries often lowers the environmental standard, however, as these countries become financially buoyant and economically stable, they can then restrict and tighten up environmental laws to reduce emissions.

The environmental Kuznets curve (EKC) is another popular theory that believes that economic growth has multiple relationships with environmental quality (Dasgupta et al., 2002; Stern, 2004). The EKC suggest that, at an early stage of industrial development, a country can increase the level of emissions. However, over time, when the country becomes rich, the country can now afford to control its emission by advocating low-emission technology. The EKC theory has many implications for industrial development since it speculates that most countries develop their industries without consideration to the wildlife habitat, resource depletion, air pollution and waste problems. This is evident since the economy can grow in different channels (investment, trade, income). Smulders (2000) asserts that economic growth that has enhanced the standard of living also has a dark side since it encourages global greenhouse problems in the long run. However, one should also not ignore the productivity and industrial revolution that have evolved with the augmentation of economic growth and technological progress. At the same time, Technological progress and economic growth have also helped to solve environmental problems and reduce pollutant emissions and waste problems through the use of new environmentally friendly technologies. The last theory, the ‘race to the top’, asserts that governments would rather ensure their environmental standard and laws are of a high standard to attract investors. The Race to the Top theory (Gray, 2002; Copeland and Taylor, 2004) is against the backdrop of lowering the environmental standard of countries to attract investors. Instead, the theory believes each government should be conscious of the benefits of having a higher level of environmental efficiency among firms and investors. This theory is popularly known as the “Pollution halo theory”.

Similarly, the Regulatory Chill theory, also called “stuck to the mud”, posited that there are countries that are reluctant to enforce strict environmental regulations to enhance and attract foreign investment into their countries (Neumayer, 2001; Gray, 2002). In the wake of globalization and the era of sustainable development, many countries are required to maintain a high environmental standard and reduce environmental pollution. These actions might ultimately affect the decisions of the government to deepen international trade and enhance economic growth. The IPAT identity, which is associated with the work done by Ehrlich and Holdren (1971), was constructed to explain the relationship between the environmental impact (I), population (P), affluence (A) and technology (T) of the country or region. Specifically, the IPAT identity posits that the environmental impact (I) is due to the multiplication of population (P), affluence (A) and technology (T) of the country or region.

Table 1 presents a summary of previous empirical studies on the relationship between industrial development, urbanization and pollution in both developed and developing countries.

2.1. Trend analysis of variables

We present Figures 1, 2, and 3 to depict the trend of pollution, industrialization and urbanization in selected African countries. Figure 1 shows that CO2 emissions are increasing in Africa over the period. South Africa is the leading emitter of CO2 per capita, with 8.5 metric tons (MT) of CO2 in 1990, which slightly decreased to 8.4 MT in 2000, increased to 9.2 MT in 2010 and decreased to 8.5 MT in 2020. Algeria is the second largest emitter among the selected countries, with about 2.9 MT of CO2 emission in 1990 which increased to about 3.7 MT in 2020.

Similarly, Figure 1 shows that pollution rises in Angola, Egypt, and Nigeria. The CO2 emission scenario in these largest sub-regional economies in Africa gives hindsight on Africa’s pollution level. Figure 2 shows the industrialization pattern in selected African countries between 1990 and 2020. The evidence shows that there has been a decline in industrialization in the selected African countries. Algeria recorded the highest level of manufacturing as a percentage of GDP throughout the years under review. Zambia, however, experienced a significant downward spiral from about 31.9% in 1990 to 7.3% in 2020.

Moreover, the evidence in Figures 1 and 2, shows there is a somewhat divergent pattern between industrialization and pollution in the sample countries. Pollution is increasing in most countries without a corresponding increase in industrialization. This suggests that other factors other than industrialization may be responsible for pollution in these countries. Figure 3 depicts the urbanization pattern in the countries under review. It shows that the urban population has continued to rise which shows a simultaneous increase between urbanization and CO2 emission trends. This suggests that urbanization can potentially drive carbon emissions in Africa.
| S/ N | Author                          | Year Covered | Country                             | Methods                                      | Findings                                                                                                                                 |
|------|--------------------------------|--------------|-------------------------------------|----------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------|
| 1.   | Destek and Ozsoy (2015)         | 1970–2010    | Turkey                              | ARDL                                         | The validity of the EKC hypothesis was supported.                                                                                           |
| 2.   | Mesagan et al. (2022)           | 1990–2019    | 36 African countries                | Pooled Mean Group (PMG)                      | Industrial growth and financial integration have a detrimental effect on Africa's short- and long-term pollution levels.                |
| 3.   | Mesagan et al. (2021)           | 1981–2017    | SANEM countries (South Africa, Algeria, Nigeria, Egypt, and Morocco) | Pooled Mean Group (PMG)                      | Energy utilisation has a short-term negative effect on CO₂ emissions for the panel of countries, but a long-term positive impact on CO₂ pollution. |
| 4.   | Rahman et al. (2021)            | 1973–2014    | Bangladesh                          | Autoregressive Distributive Lag (ARDL) bounds test and the Toda-Yamamoto Granger causality test | The usage of clean energy increased environmental quality, while urbanisation, population growth, and economic expansion were found to have a negative impact on the environment. |
| 5.   | Effong, E. L. (2018)            | 1990–2010    | 49 African countries                | IPAT framework using semi-parametric panel fixed-effects regression technique | Urbanization reduces environmental pollution.                                                                                               |
| 6.   | Salahuddin et al. (2019)        | 1980–2017    | South Africa                        | Zivot & Andrews single and Bai & Perron multiple structural break unit root tests and ARDL | Urbanization has both a short-run and long-run effect on CO₂ emissions, whereas globalisation only has a long-run impact on emissions. |
| 7.   | Haouraji et al. (2021)          | 1990–2016    | 4 North African countries (Morocco, Tunisia, Algeria, and Egypt) | ARDL bounds testing; Toda-Yamamoto Granger causality tests | The validity of the EKC hypothesis between residential CO₂ emissions and GDP per capita growth was found for only Morocco and Tunisia. |
| 8.   | Armeanu et al. (2021)           | 1990–2014    | 106 countries                       | panel unit root tests, Pedroni cointegration tests, impulse response functions and variance decomposition | Both unidirectional and bidirectional causal effects between renewable energy consumption and other types of energy, economic growth, CO₂, and urbanization were found. |
| 9.   | Tiba, S. (2019)                 | 1990–2014    | 47 African countries                | panel smooth transition regression model     | The relationship between urbanisation and CO₂ emissions was found to be non-linear. Results confirmed the validity of the EKC urbanisation theory. |
| 10.  | Wang et al. (2020).             | 1990–2014    | APEC countries                      | Dynamic Unrelated Seemingly Regression (DSUR) | The amount of environmental pollution caused by CO₂ emissions is increased by energy intensity, urbanisation, and economic expansion. Additionally, a unidirectional causal relationship between industrialization and CO₂ emissions was found. |
| 11.  | Wang et al. (2018).             | 2000–2014    | G20 countries                       | panel quantile regression                   | The EKC hypothesis linking urbanisation and PM2.5 concentrations was validated by the results.                                             |
| 12.  | Zhang et al. (2017)             | 1961–2011    | 141 countries                       | two-way fixed effects model based on the extended STIRPAT framework                                                                  | The EKC hypothesis linking urbanisation and carbon emissions was validated.                                                            |
| 13.  | Aliyu and Ismail (2015)         | 1990–2010    | 19 African countries                | The Pooled Mean Group (PMG)                  | The result validates the evidence of PHH for carbon. Energy intensity associated with FDI inflows has a significant increasing effect on the greenhouse. |
| 14.  | Davis et al. (2019)             | 1990–2016    | 59 Belt and Road countries          | Driscoll-Kraay panel regression model        | Financial development increases the ecological footprint.                                                                                   |
| 15.  | Omri et al. (2014)              | 1990–2011    | 54 countries                        | GMM approach                                | The results validate the existence of PHH.                                                                                                 |
| 16.  | Shabbaz et al. (2015)           | 1975–2012    | 99 countries                        | Fully Modified OLS(FMOLS)                   | They found an inverted U-shaped relationship between foreign direct investment (FDI) and CO₂ emissions.                                   |
| 17.  | Behera and Dash (2017)          | 1980–2012    | 17 countries in the Southeast Asian (SSEA) region | FMOLS and DOLS                              | FDI has a significant impact on CO₂ emissions in total and high- and middle-income SSEA regions.                                         |
| 18.  | Streteisky and Lynch (2009)     | 1989–2003    | 169 countries and the USA           | Fixed effect panel regression                | Exports in the 169 countries and United States exports are positively associated with per capita carbon dioxide emissions.             |
| 19.  | Dietz and Rosa (1997)           | 111 countries | Log-linear, and polynomial model    | Results show that the impact of the population is roughly proportional to its size across the range of population sizes that will characterize most nations over the next few decades. This contradicts the views of those who are complacent about population growth. |
| 20.  | Ramanathan (2006)               | 1980–2001    | USA                                 | Data Envelopment Analysis (DEA)             | Using the efficiency index, carbon dioxide emissions will be minimised and restricted in the long run.                                     |
| 21.  | Lozano and Gutierrez (2008)     | USA          | Data Envelopment Analysis (DEA)     | Higher GDP growth rates can be achieved by reducing Green gas emission consumption in the long run.                                     |
| 22.  | Soytsus and Sari (2009)         | 1960–2000    | Turkey                              | Vector Autoregressive Model (VAR)            | Carbon emission Granger causes energy consumption, but the reverse is not true. There is no long-run relationship between CO₂ and income. This consequently means Turkey does not need to reduce economic growth to reduce carbon emission |
| 23.  | Anwar et al. (2022)             | 1990–2014    | 15 Asian economies                 | Impulse response function and variance decomposition techniques are used to test the causality | CO₂ emissions are increased by urbanization, financial development, and economic growth; however, renewable energy use reduces CO₂ emissions, and agriculture has a negligible impact on CO₂ |
3. Data sources, model and methodology

3.1. Data sources

This study looks at the relationship between industrial development, urbanization and CO₂ emissions for a panel dataset of 9 selected African countries from 1990 to 2019. Angola, Algeria, Congo, Ghana, Egypt, Kenya, Nigeria, South Africa and Zambia are the 9 countries selected. These countries are selected based on their level of industrial and economic development in four sub-regions in Africa (North Africa-Algeria and Egypt; Southern Africa – Angola, South Africa, and Zambia; East Africa- Kenya and DR Congo; West Africa – Ghana and Nigeria). This analysis uses annual data from the WDI (World Development Indicator, 2021).

3.2. Model

This research examines the connection between industrialization, urbanisation and pollution by using the IPAT and PHH frameworks. The research also examines the validity of the EKC hypothesis. The IPAT identity (I = PAT) was first presented by Ehrlich and Holdren (1971), and it describes the changes in environmental impact caused by human activities. The population, affluence, and technological development impacts on the environment are all evaluated within the framework. An increasing population (P), affluence per capita as measured by economic output (A), and more advanced technology per unit of consumption and production (T) are all assumed to have a multiplicative effect on the environment (I):

\[ I = P \cdot A \cdot T \]  

(1)

Eq. (1) model describes the mathematical specification of human-induced influences behind environmental degradation. However, the IPAT imposes limits on the allowable ranges for the variables. Due to this drawback, Dietz and Rosa (1997) proposed STIRPAT, a stochastic variant of IPAT that serves as a malleable quantitative framework for studying environmental consequences,

\[ I = \alpha P_i + A_i + T_i + \epsilon_{it} \]  

(2)

where I, P, A, and T remain as specified previously; \( \alpha, b, c, \) and \( d \) are model parameters; \( \epsilon \) represents the idiosyncratic error factor, and the subscript \( i, t \) indicates observational units (countries and time) in panel data. The natural logarithm of Eq. (2) provides a linear equation in Eq. (3):

\[ \ln I = \alpha + b \ln P_i + c \ln A_i + d \ln T_i + \epsilon_{it} \]  

(3)

In our model, I represents environmental impact which is captured as CO₂ emission, P represents the urban population and a proxy for urbanisation, output growth is used as a proxy for affluence A, while industrialisation represents the growth in technology (T), \( \delta \) represents other control variables as seen in Eq. (4).

\[ CO_2 = \alpha + \delta \theta + \beta_1 Y_d + \beta_2 URB_h + \beta_3 IND_h + \delta_2 \delta_3 + \delta_4 \]  

(4)

The PHH (reviewed by Mani and Wheeler, 1997; Schlesich, 1999; Gary, 2002; Temurshoeev, 2006; Greaker, 2007) suggests that countries with inadequate environmental rules are more attractive to international investors. According to the PHH hypothesis, the quality of environmental laws, regulations, and enforcement may be connected to the industrial progress of many countries. The model modifies Omri et al. (2014), Aliu and Ismail (2015), Liu and Bae (2018), and (Seherra and Dash, 2017) that examined the nexus between foreign direct investment, energy consumption and pollution haven in Africa. Similarly, the relationship between urbanization, Foreign Direct Investment (FDI), industrialisation, and economic growth is investigated in this study. As a result, relying on the environmental Kuznets curve (EKC), which stipulates an
Figure 1. CO₂ emission per capita for selected African countries. Source: Authors’ computations from WDI (2021).

Figure 2. Manufacturing (% of GDP) for selected African countries. Source: Authors’ computations from WDI (2021).

Figure 3. Urban Population (% of the total population) for Selected African Countries. Source: Authors’ Computations from WDI (2021).
inverted U-shaped relationship between income and pollution (see Bosah et al., 2021; Armeanu et al., 2021; Stern, 2004; Mesagan et al., 2022), our model, therefore, examines the impact of FDI and economic growth on pollution emission, conditioned on some control variables (financial development and trade openness). The model is presented in Eq. (5).

\[ CO_{2i} = \alpha_i + \beta_{1i}Y_{it} + \beta_{2i}URB_{it} + \beta_{3i}IND_{it} + \beta_{6i}RER_{it} + \mu_{it} \]  

where: \( CO_{2i} \) represents the carbon emissions, and \( \beta \) are the intercepts, and they vary across countries \( i \) and \( t \) respectively. \( Y \) is the level of income, \( Y^2 \) is the quadratic function of income to capture the EKC, \( TOP \) is the trade openness defined as trade as a ratio of GDP, \( FDI \) is the net foreign direct investment inflow to the SSA region, while \( FD \) represents financial development. \( URB \) and \( IND \) represent urbanisation and industrialisation, while \( \mu \) is the white noise error term. Equation 5 can be disaggregated into Equation 6 (Model 1) and Equation 7 (Model 2), as follows:

\[ CO_{2it} = \alpha_i + \beta_{1it}Y_{it} + \beta_{2it}URB_{it} + \beta_{3it}IND_{it} + \beta_{6it}RER_{it} + \mu_{it} \]  

\[ CO_{2it} = \alpha_i + \beta_{1it}Y_{it} + \beta_{2it}Y^2_{it} + \beta_{3it}TOP_{it} + \beta_{4it}FDI_{it} + \beta_{6it}RER_{it} + \mu_{it} \]  

where: \( RER = \) Real exchange rate.

4. Results and discussions

We present the results of the unit root tests in Table 2. The objective of the test is to verify that the series has a zero mean and constant variance.

The unit root tests presented in Table 2 show that trade openness, foreign direct investment, real exchange change, and industrialization are stationary at levels, while carbon emission, real GDP per capita, and urbanization are stationary at first difference. In Table 3, we examine the cointegration test using the Kao cointegration test.

The results reported in Table 3 reject the null hypothesis that there is no long-run relationship between the variables in Models 1 and 2. This implies that there is a long-run relationship among the variables included in the two models.

Table 3 Table 4 presents the PMG estimates for Models 1 and 2. Model 1 examines the effect of urbanization and industrialization on carbon emission in Africa, while Model 2 concentrates on the effect of foreign direct investment on carbon emission. The panel results for Model 1 show that real GDP per capita (output growth), urbanization and industrialization have a significant positive effect on carbon dioxide emissions in Africa. The results for Model 2 show that the real GDP per capita, trade openness, real exchange change and foreign direct investment have a significant effect on carbon dioxide emission in the long run. However, financial development has an insignificant effect on carbon emissions in the selected African countries. The coefficient of \( Y \) and \( Y^2 \) are positive and statistically significant, showing the existence of EKC, which is inverted U-shaped in this case, showing the impact of economic growth on environmental quality in Africa. The findings are to some extent consistent with the works of (Yang et al., 2017; Liu & Bae, 2018; Omri, 2013; Shabhz et al., 2018; Leitao & Lorente, 2020).

The individual country panel estimates for nine selected African countries are presented in Table 5 and 6. The IPAT identity examined the importance of urbanization and industrialization in engendering carbon emissions in Africa. The results reported in Table 5 show that contrary to the panel results, an increase in urbanization has no

| Table 2. Panel unit root tests. |
|-----------------------------|
| Variables | Level LLC | Level IPS | First Difference LLC | First Difference IPS |
| CO2 | -0.58711 | 0.63671 | -7.49057*** | -9.43616*** |
| Y | 0.33404 | 3.16388 | -3.63049*** | -3.47874*** |
| TOP | -1.61265** | -1.43301* | - | - |
| FDI | -2.78176** | -3.48708*** | - | - |
| RER | -1.39023* | -1.63439** | - | - |
| FD | -2.14785** | -1.90549** | - | - |
| URB | 1.03826 | 0.04632 | -4.31855*** | -3.19822*** |
| IND | -3.09883*** | -1.52093* | - | - |

Note: LLC depicts Levin, Lin & Chu (2002), IPS means Im Pesaran and Shin test. * means 10%, ** means 5%, *** means 1% significance levels. Source: Researchers’ compilation.

| Table 3. Panel kao cointegration test. |
|-------------------------------|
| Model 1 | t-statistics | Probability |
| ADF | -3.338964*** | 0.0004 |
| Residual | 0.037046 | 0.0029347 |
| HAC | 0.020761 |

| Table 4. Panel result estimates. |
|----------------------------------|
| Variables | Model 1 | Model 2 |
| Long-run Estimates | Y | 0.000357*** (0.00000) | 0.001672*** (0.00000) |
| Y^2 | - | -0.0000001*** (0.0002) |
| FDI | - | 0.018341** (0.0155) |
| FD | - | 0.002067 (0.4845) |
| TOP | - | -0.005683 (0.0618) |
| URB | 0.02005*** (0.0000) | - |
| IND | 0.012805*** (0.0001) | - |
| RER | -0.000169 (0.7994) | -0.000462** (0.0154) |

| Short-run Estimates | CO2(-1) | -0.141140** (0.0193) |
| DFCO2(-1) | 0.000224 (0.4387) | 0.004269 (0.0911) |
| DY(-1) | -0.002626 (0.3234) | - |
| Dy^2 | -0.000000 (0.1523) | - |
| Dy^3(-1) | - | -0.000000 (0.7785) |
| DFDI(-1) | - | -0.009898 (0.1126) |
| DFDI(-1) | - | -0.003410 (0.4296) |
| DTOP | - | -0.002834 (0.6556) |
| DTOP(-1) | - | -0.003505 (0.3066) |
| DURB | -0.543228 (0.4046) | - |
| DIND | -0.000481 (0.8864) | - |
| DREER | 0.034691 (0.8281) | 0.005544 (0.1838) |
| DREER(-1) | 0.266416 (0.2780) | 0.003737 (0.7384) |
| ECM | -0.495527** (0.0007) | -0.271160*** (0.0086) |
| Constant | -1.004439 (0.007) | -0.64493 (0.7452) |

*: ** and *** denotes stationarity at 10%, 5% and 1% significance levels respectively. () specifies probability. Source: Authors’ compilation.
### Table 5. Country estimates for model I.

| VARIABLES | Angola | Algeria | Congo | Ghana | Egypt | Kenya | Nigeria | South Africa | Zambia |
|-----------|--------|---------|-------|-------|-------|-------|---------|--------------|--------|
| ECT       | -1.234*** (0.00) | -0.043*** (0.00) | -0.326*** (0.00) | -0.938*** (0.00) | -0.867*** (0.00) | -0.229*** (0.00) | 0.007*** (0.00) | 0.007*** (0.00) | -0.577*** (0.00) |
| D(Y)      | 0.0001*** (0.00) | 0.0002*** (0.00) | 0.0004*** (0.00) | 0.000*** (0.00) | 0.000*** (0.00) | 0.002*** (0.00) | 0.001*** (0.00) | 0.000*** (0.00) | -0.001*** (0.00) |
| D(URB)    | -0.449** (0.01) | -0.055 (0.47) | -5.574 (0.62) | 1.909 (0.08) | 0.716*** (0.00) | -0.481 (0.32) | -0.218 (0.01) | 0.158 (0.67) | 0.005 (0.26) |
| D(REER)   | 0.001** (0.00) | 0.0004** (0.00) | -0.002** (0.00) | 0.002** (0.00) | 0.001*** (0.00) | 0.000** (0.00) | 0.000*** (0.00) | 0.001*** (0.00) | 0.002*** (0.00) |
| Constant  | -3.257** (0.01) | -0.057 (0.57) | 1.282 (0.49) | -3.193** (0.02) | -1.173*** (0.00) | -0.411 (0.05) | -0.388 (0.10) | -0.073 (0.34) | -1.769*** (0.00) |

Note: * means 10%; ** means 5%; *** means 1% significance levels () specifies probability.

Source: Researchers' compilation.

### Table 6. Country estimates for MODEL II.

| Variables | Angola | Algeria | Congo | Ghana | Egypt | Kenya | Nigeria | South Africa | Zambia |
|-----------|--------|---------|-------|-------|-------|-------|---------|--------------|--------|
| ECT       | -0.234*** (0.00) | -0.193*** (0.00) | -0.429*** (0.00) | -0.008** (0.00) | -0.954*** (0.00) | -0.225** (0.00) | 0.039** (0.00) | 0.009*** (0.00) | -0.406*** (0.00) |
| D(CO2_1(-1)) | -0.417*** (0.00) | -0.022 (0.17) | -0.420*** (0.00) | 0.035 (0.35) | -0.126** (0.04) | 0.092 (0.01) | -0.103** (0.01) | -0.164** (0.01) | -0.145** (0.02) |
| D(Y(-1))  | 0.001*** (0.00) | 0.001** (0.00) | -0.001*** (0.00) | 0.002*** (0.00) | 0.005*** (0.00) | -0.001*** (0.00) | 0.001*** (0.00) | 0.001*** (0.00) | 0.001*** (0.00) |
| Constant  | -0.377** (0.00) | -0.057 (0.57) | 1.282 (0.49) | -3.193*** (0.02) | -1.173*** (0.00) | -0.411 (0.05) | -0.388 (0.10) | -0.073 (0.34) | -1.769*** (0.00) |

Note: * means 10%; ** means 5%; *** means 1% significance levels () specifies probability.

Source: Researchers' compilation.
The entire sample was estimated. An increase in urbanization and industrialization leads to an increase in environmental degradation in the long run when economic development proceeds, economic growth tends to lead to an improvement in environmental quality, as confirmed by the negative and statistically significant coefficient of Y2 in the CO2 equation (Model 2). Similarly, we found that an increase in urbanization and industrialization leads to an increase in environmental degradation in the long run when the entire sample was estimated.

Several noteworthy policy recommendations are provided based on the findings of the current research. One implication is that although urbanization can reduce poverty and improve living conditions, it can also increase pollution. Thus, since urbanisation is inseparable from sustainable development and can serve as an engine for structural transformation, there is a need for strategic urban planning accompanied by consistent and forward-looking policies that will scrutinize technologies being employed in these countries, the comparative study of countries may not be applied universally. In subsequent studies, the comparative study of countries may be examined, with a variety of time-series analyses serving as supporting evidence. Secondly, the uncertainty caused by the global Covid-19 pandemic has disrupted the supply chain and production worldwide and, eventually, pollution. Future empirical research will have the opportunity to study a myriad of ways in which the effects of industrialization and urbanization on pollution can be altered as a result of an epidemic.

5. Conclusion, policy recommendation and limitation of the study

We have examined the nexus between industrial development, urbanization and pollution emissions in Africa. We used the IPAT identity to examine the impact of industrial development and urbanization on pollution emissions. We also tested the validity of the existence of the EKC and PHH in the selected African countries. We analyzed the impact of FDI, urbanization, industrialization and economic growth on carbon emissions in nine African countries from 1990 to 2019. The paper employed the panel PMG-based autoregressive distributed lag (ARDL) approach to examine these linkages.

The paper found the validity of the EKC and PHH for the entire panel in the long run, although the results of individual countries differ significantly from country to country and over time. We have evidence of a positive and significant relationship between FDI and carbon emission in Africa when panel data are used, which lend some support for the PHH. The analysis is explicit and disaggregated for different countries. We found evidence that suggests that economic growth only has a positive and significant impact on environmental quality at early stages of development when the entire panel was estimated. However, as economic development proceeds, economic growth tends to lead to an improvement in environmental quality, as confirmed by the negative and statistically significant coefficient of Y2 in the CO2 equation (Model 2). Similarly, we found that an increase in urbanization and industrialization leads to an increase in environmental degradation in the long run when the entire sample was estimated.

Several noteworthy policy recommendations are provided based on the findings of the current research. One implication is that although urbanization can reduce poverty and improve living conditions, it can also increase pollution. Thus, since urbanisation is inseparable from sustainable development and can serve as an engine for structural transformation, there is a need for strategic urban planning accompanied by consistent and forward-looking policies that will scrutinize technologies being employed in these countries, the comparative study of countries may not be applied universally. In subsequent studies, the comparative study of countries may be examined, with a variety of time-series analyses serving as supporting evidence. Secondly, the uncertainty caused by the global Covid-19 pandemic has disrupted the supply chain and production worldwide and, eventually, pollution. Future empirical research will have the opportunity to study a myriad of ways in which the effects of industrialization and urbanization on pollution can be altered as a result of an epidemic.

Declarations

Author contribution statement

Foluso A. Akinsola; Mojeed M. Ologundudu; Motunrayo O. Akinsola; Nicholas M. Odhiambo: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Funding statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Data availability statement

Data will be made available on request.
Declaration of interest's statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

References

Adebayo, T.S., Awosusi, A.A., Odugbesan, J.A., Akinsola, G.D., Wong, W.K., Rjoub, H., 2021. Sustainability of energy-induced growth nexus in Brazil: do carbon emissions and urbanization matter? Sustainability 13 (8), 4371.

Adedoyin, F.F., Gumede, M.I., Bekun, F.V., Bokakpan, M.U., Balsalobre-Lorente, D., 2020. Modelling coal rent, economic growth and CO₂ emissions: does regulatory quality matter in BRICS economies? Sci. Total Environ. 710, 136284.

Aliyu, A.J., Izzam, N.W., 2015. Foreign direct investment and pollution haven: does energy consumption matter in African countries? International Journal of Economics and Management 9 (2015), 21–23.

Anwar, A., Sinha, A., Sharif, A., Siddique, M., Irshad, S., Anwar, W., Malik, S., 2022. The nexus between urbanization, renewable energy consumption, financial development, and CO₂ emissions: evidence from selected Asian countries. Environ. Dev. Sustain. 24 (5), 6556–6576.

Armeanu, D.S., Joldes, C.C., Gherghina, S.C., Andrei, J.V., 2021. Understanding the multidimensional linkages among renewable energy, pollution, economic growth and urbanization in contemporary economies: quantitative assessments across different income countries’ groups. Renew. Sustain. Energy Rev. 142, 110818.

Behera, S.R., Dash, D.P., 2017. The effect of urbanization, energy consumption, and foreign direct investment on the carbon dioxide emission in the SSEA (South and Southeast Asian) region. Renew. Sustain. Energy Rev. 70, 96–106.

Bosah, C.P., Li, S., Ampofo, G.K.M., Liu, K., 2021. Dynamic nexus between energy consumption, economic growth, and urbanization with carbon emission: evidence from panel PMG-ARDL estimation. Environ. Sci. Pollut. Control Ser. 28 (20), 29938–29948.

Muangthai, L., Lewis, C., Lin, S.J., 2014. Decoupling effects and decomposition analysis of CO₂ emissions from Thailand’s thermal power sector. Aerosol Air Qual. Res. 14, 1929–1938.

Munir, Q., Lean, H.H., Smyth, R., 2020. CO₂ emissions, energy consumption and economic growth in the ASEAN-5 countries: a cross-sectional dependence approach. Energy Econ. 85.

Rahman, M.M., Alam, K., 2021. Clean energy, population density, urbanization and environmental pollution nexus: evidence from Bangladesh. Renew. Energy 172, 1063–1072.

Ramanathan, R., 2006. A multi-factor efficiency perspective to the relationships among world GDP, energy consumption and carbon dioxide emissions. Technol. Forecast. Soc. Change 73 (5), 483–494.

Salahuddin, M., Gow, J., Ali, M.I., Hossain, M.R., Al-Azami, K.S., Akbar, D., Gedikli, A., 2019. Urbanization globalization-CO₂ emissions nexus revisited: empirical evidence from South Africa. Heliyon 5 (6), e01974.

Tiba, S., 2019. A non-linear assessment of the urbanization and climate change nexus: the African context. Environ. Sci. Pollut. Control Ser. 26 (31), 32311–32321.

Wang, N., Zhu, H., Guo, Y., Peng, C., 2018. The heterogeneous effect of democracy, political globalization, and urbanization on PM2.5 concentrations in G20 countries: evidence from panel quantile regression. J. Clean. Prod. 194, 54–68.

Wang, Z., Rasool, Y., Zhang, B., Ahmed, Z., Wang, B., 2020. Dynamic linkage among industrialization, urbanization, and CO₂ emissions in APEC realms: evidence based on DOLS estimation. Struct. Change Econ. Dynam. 52, 32321.

Yandle, B., 2004. Environmental turning points, institutions, and the race to the top., 2 (Fall 2004). The Independent Review, pp. 211–226.

Yao, S.J., Zhang, S., Zhang, X.M., 2019. Renewable energy, carbon emission and economic growth: a revised environmental Kuznets Curve perspective. J. Clean. Prod. 235, 1338–1352.

Zhang, N., Yu, K., Chen, Z., 2017. How does urbanization affect carbon dioxide emissions? A cross-country panel data analysis. Energy Pol. 107, 678–687.