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Driving forces of CO_2 Emissions based on impulse response function and variance decomposition: A case of the main African countries

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Abstract

Background: The need to understand the causes of CO_2 emissions has prompted the formulation of strategies to prevent global warming. Therefore, the purpose of the study was to determine the input variable that is the most influential in contributing to CO_2 emissions and at the same time to forecast the effect of a shock in macroeconomic variables on CO_2 emissions for 6 leading African countries over the period of 1970 to 2019.

Methods: In this study, the statistical methods of impulse response function and variance decomposition techniques of analysis were used.

Results: A one-standard-deviation rise in economic growth leads to an increase in CO_2 emissions. A shifts in the square of economic growth increased CO_2 emissions, the shock was smaller than that of economic growth. This confirms the theory of environmental Kuznets curve (EKC) in Africa. A shocks to FDI had a positive influence on CO_2 emissions. A one standard deviation shock in financial development had an instantaneous positive impact on CO_2 emissions. FDI had a greater effect than other factors in explaining CO_2 emissions over the short and medium term. In the long run, economic growth contributes the most to CO_2 emissions among the explanatory variables.

Conclusion: The findings of the study can be used as a reference for international organizations and environmental policymakers in forecasting climate change and assisting in policy decision-making. Africa must boost economic growth through industrial, agricultural, and energy usage patterns and integrate innovation, research, and technology advances into their developmental agenda to fulfil sustainable development goals while lowering CO_2 emissions and their consequences.

Keywords: Economic development, Climate change, Impulse response function, Variance decomposition, Africa

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Introduction

The main objective of both advanced and developing economies is to achieve economic growth and long-term development. There are various roadblocks in the way of achieving such a goal. While environmental deterioration is the most prevalent contentious danger to achieving the required level of sustainable development, the relationship between economic growth and environmental degradation is complicated (1). Environmental degradation is on the rise due to climate change caused by green house gases vis-a-vis carbon dioxide emissions (CO_2 emissions). These resulted in a slew of issues that include inadequate water and poor air quality, desert encroachment, low life expectancy, and high infant and maternal mortality rates particularly in developing countries (2-4).

There is significant evidence of global warming and climate change across the globe, and the African continent is not an exception from the present wave of global warming. Furthermore, according to recent figures from the Intergovernmental Panel on Climatic Change (IPCC),

Africa is more vulnerable to global warming and climate issues than other parts of the world. In the same vein, there will be a decline in the number of people having access to water from 50 to 30% and a 20% drop in agricultural production across the continent (5). Indeed, two of the present world's intended Sustainable Development Goals (SDGs) which are projected to be achieved by 2030, are clean energy and a less-polluted environment (6).

The entire cost of climate change because of CO_2 emissions is projected to be comparable to a 5% decrease in the amount of gross domestic product (GDP) per year, and even 20% if prompt action is not currently taken (7). The slogans "green economy" and "low-carbon city" are now popular among developing countries when it comes to dealing with CO_2 emissions (8). As a result, many emerging countries are anticipated to curb their CO_2 emissions in the near future (9). It is now acclaimed that reducing CO_2 emissions has macroeconomic consequences (10). An attempt to limit energy consumption for CO_2 emissions reduction has a detrimental effect on economic growth because energy is a critical input in the production equation (11). Economic and environmental policies conflict because of these counter-arguments.

As a result of these opposing viewpoints, a slew of empirical studies has emerged. The relationship between environment and economic growth, which attempts to verify the environmental Kuznets curve (EKC) validity, is one of several areas of empirical study. According to the EKC, when income rises, the quality of the environment would first decrease before improving in the long term (12). As a result, initially an escalation in economic growth will boost CO_2 emissions, but as economic growth escalates, CO_2 will deteriorate. The pollution-economic growth nexus has been the subject of several empirical research with mixed results (11,13-25).

Economic development is a complicated process that results in structural changes in an economy. The size and structure of the financial sector is a significant structural shift that occurs due to economic development (26). As a result, leaving financial development out of the CO_2 emissions model produces biased and misleading empirical results (27). Although financial development has significant environmental implications, its influence on the evolution of CO_2 emissions is debatable. Some academics believe that financial development enhances environmental quality by lowering carbon emissions. For example, Awad and Ragab believe that financial development may attract foreign direct investment (FDI), a better level of R&D which can enhance economic growth and improve environmental quality (28). Financial development mentioned by these researchers allows developing nations to employ new technology, aid in clean and environmentally friendly industry, and promote global and regional environmental sustainability.

On the other hand, some researchers believe that financial development harms the environment by increasing CO_2 emissions. According to the study of Dogan and Aslan, financial development makes it easier for individuals and businesses to obtain low-cost credit, allowing them to purchase large-ticket products and expand or start new businesses, all of which increase energy consumption and CO_2 emissions (29). While there is a theoretical contradiction between financial development and CO_2 emissions, findings from existing studies are inconsistent and ambiguous. For example, some empirical studies show that financial development reduces CO_2 emissions, thereby enhancing the quality of environment (30-32), while others show that financial development increases CO_2 emissions, and hence, deteriorate the quality of environment (27,33-35). The final set of empirical research also shows that financial development has no significant effect on CO_2 emissions (36-38).

So, this question rises that whether the continued rise of FDI have a beneficial or harmful impact on the environment. There are currently two conflicting academic ideas about the environmental consequences of FDI: The "pollution haven theory" and the "pollution halo hypothesis". Walter et al (39) presented the pollution haven concept that was further expanded upon by other researchers (40). The pollution haven theory states that strict environmental laws in rich nations will induce highly polluting companies to relocate to developing countries, causing pollution in such countries. As stated by the theory of pollution halo, FDI gives sophisticated manufacturing technology and managerial expertise to developing nations, allowing them to attain cleaner and greener production and improve global environmental quality and regional sustainable development capacities (41). Researchers disagree about the environmental impact of foreign investment. Some research confirm the pollution halo theory (42-45), while others confirm the pollution haven hypothesis (46-48). However, a decision has not been made yet. Countries have begun to modify their development techniques and encourage sustainable development. As land and labor prices have escalated, and environmental regulations have been strict, the environmental consequences of introducing foreign capital are critical considerations.

This work contributes to the literature in several ways, given the study's goal. To the best of our knowledge, this is the first research to evaluate the relationship between economic growth, financial development, foreign direct investment, and environmental quality, and offer reasonable policy suggestions, using a sample of six leading African countries. Second, there is no consensus on the exact relationship between financial development and the environment in the available research due to the many proxies employed to quantify financial development. The study contribute to the literature through the

construction of financial development index using principal component analysis (PCA) that encompasses five financial indicators. The present study will cover the research vacuum. Finally, unlike previous studies on emissions forecasting, this study uses the impulse response function (IRF) and variance decomposition to determine the most influential input variable contributing to carbon emissions even while forecasting how a shock in economic growth, financial development, and foreign direct investment will affect CO_2 emissions in the short-, medium-, and long-run for the respective countries. This will aid in the formulation of a comprehensive, widely supported policy to decrease ozone depletion and global warming caused by CO_2 emissions.

Materials and Methods

The panel vector autoregression (PVAR) method was utilized in this research. The PVAR combines the traditional VAR approach, which considers all system variables to be endogenous, with the panel data which takes into account undetected individual variation (49). The empirical model for CO_2 emissions ($lnCO_2$), economic growth (*lnGDI*), square of economic growth ($lnGDP^2$), foreign direct investment (*lnFDI*), financial development (*lnFD*), as well as the variable that is considered as control form of variable is given in equation 1. According to the study of Andrews et al. (50), the first-order PVAR was used to determine the best lag for model selection. As a result, the first order panel VAR is indicated as follows:

$$S_{it} = \pi_i + \theta(I)S_{it-1} + v_i + \varphi_t + \mu_{it} \quad (1)$$

Where the term i = 1,2,3,4,……N as well as t = 1,2,3,4,…….T, S_{it} is $lnCO_2$, *lnGDP*, $lnGDP^2$, *lnFDI*, *lnFD*, and *lnEC*, as the control variable. Then, $\theta(I)$ is regarded as the endogenous covariates lag machinist, v is considered as the individual form of specific effect, φ is specified as the fixed form of time effect, and then, μ is termed as the stochastic form of error term.

Because of the country-specific fixed and temporal impact, employing ordinary least squares (OLS) to estimate equation 1 would yield contradictory results. To eliminate the country-specific impact, the first-difference method is required to estimate equation 1.

$$\Delta S_{it} = \Delta\pi_i + \theta(I)\Delta S_{it-1} + \Delta v_i + \Delta\varphi_t + \Delta\mu_{it} \quad (2)$$

Where Δ is regarded as the difference operator, because the lag of the independent variable is related with the undetected panel response variable, employing OLS to estimate equation 2 still would lead to conflicting and misleading results (51). The IRFs were developed by Sims (52) to describe how one variable reacts to a shock in that other variable inside a system while maintaining all shocks zero value in order to obtain effective and reliable estimations under such a circumstance (49). In the model, the panel form of error-term is assumed to be distributed normally and identical. In reality, though, because the errors' true variance-covariance is improbable to be diagonal, this assumption may collapse (49,53). It is necessary to breakdown the residual in such a manner that the shocks get orthogonalized in order to isolate them to one of the VAR shocks. Depending on the extent of exogeneity, variables in a VAR should be sorted recursively (52). As a result, variables that come first in the ordering have an immediate and prolonged effect on succeeding variables, but variables that come last have just a lingering reaction on preceding variables (49).

The analysis is based on the idea that a current CO_2 emissions shock has a concurrent influence on economic growth, FDI, and financial development, but economic growth, foreign direct investment, as well as financial development only have a lag effect on CO_2 emissions. This is possible since current economic growth, FDI, and financial development will have an impact on future CO_2 emissions, but not on current CO_2 emissions. As a result, prior economic growth, FDI, and financial development have an impact on present CO_2 emissions. The CO_2 emissions came first, then, economic growth, FDI, financial development, and energy use. In order to evaluate the IRF, the standard errors of the IRF were calculated, and Monte Carlo simulations were used to provide confidence intervals. Decompositions of forecast error variance were also performed over a 20-year period.

In this study, the variance decompositions (VDC) analysis was used to examine complicated interactions between variables in the VAR technique. It determines how much of the forecast error of one variable is explained by another. As a consequence, in the context of this study, it aids in examining the relative degree of environmental quality in accounting for changes in economic activities. To assess the economic implications of VDC findings, the innovation accounting approach is utilized (52,54-56). The projected error variance of each variable is decomposed into components owing to its own innovations as well as shocks from other variables in the system using this technique.

The data for the study are over the period 1970–2019 for a total of 6 main African countries. The data for CO_2 emissions in metric tons per capita, GDP constant USD 2010, as well as net inflow of FDI percentage of GDP while for the index of financial development lending rate, market capitalization, broad money supply, domestic credit to private sector as a GDP percentage, as well as the domestic credit offered by the banking sector as a GDP percentage, were sourced from the World Bank Development Indicators (2021).

Results

The empirical results of the study are reported in this section that starts with PCA as well followed by VDC and the IRF analysis.

Principal component analysis

The studies by Ahmad et al (57) and Hotelling (58) are credited with the invention of principle component analysis, while the study of Jolliffe (59) is credited with the most recent work. This study utilized five factors as a measure of financial development, as previously stated. The PCA method was used to create a financial development index. The study divided a variable into several components and evaluated how much each component explains variance in data using PCA. In PCA, the study is looking for factors expressing the most information about the variables. The selected five main components are called Factor 1 (Lr), Factor 2 (Dcp), Factor 3 (Dcb), Factor 4 (Bmg), and Factor 5 (Mc) based on the principles of keeping the numbers of components depending on eigenvalues (60). As seen in Table 1, the eigenvalue of components 1 and 2 are greater than 1, which qualified them to be significant factors. These factors that were incidentally significant will be utilized to create another vector. In this way, a new variable will be created that will serve as an indicator of financial development.

Impulse response analysis

The IRFs and the 95% confidence interval band were created using 200 Monte Carlo simulations in this section. Since the concern of this subsection is to determine the main driving factor of environmental quality while considering the role of economic growth, FDI, and financial development, the analysis of variance decomposition and IRF focuses on these mentioned variables. The IRF analysis is performed on the VAR model, the outcomes are shown in Figure 1, and the time of the response is 20 years. The lag time of the impact is defined by the horizontal axis, and the degree of reaction of the endogenous variable to the impact is represented by the vertical axis. The inner solid line specifies the effective response to GDP, FDI, FD, and CO_2 emissions when GDP, FDI, FD, and CO_2 emissions obtain a standard deviation at a time. The upper, as well as the lower dashed lines, specifies the assortment of the impulse response.

The IRF's findings specifically show that CO_2 emissions in Africa have risen along with economic growth over time and that CO_2 emissions will continue to rise along with economic growth over the next 20 years (Figure 1). A one-standard-deviation rise in Africa's economic growth leads to a gradual increase in CO_2 emissions. As a result, as the economy rises, emissions will escalate, resulting in a decline in environmental quality in Africa. Figure 1 also shows that CO_2 emissions react positively to economic

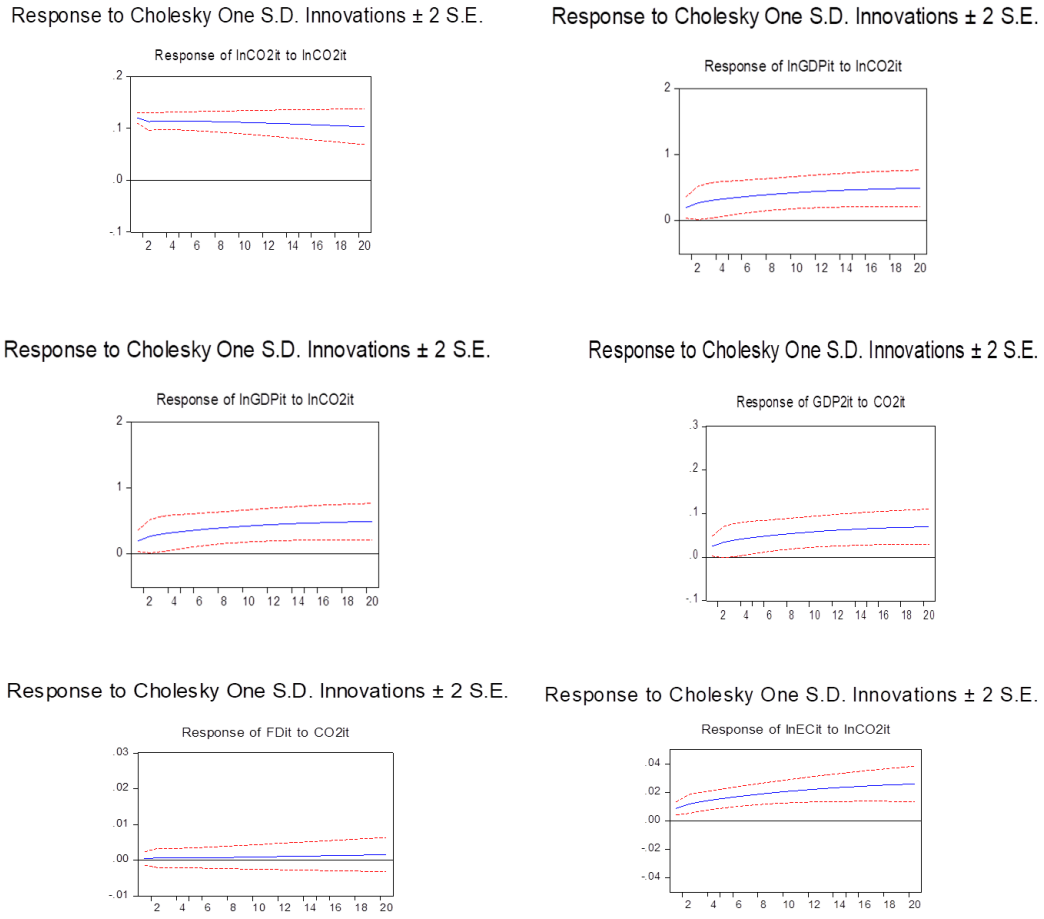

Figure 1. Impulse-response function diagram.

Table 1. Results of principal component analysis

Component	Eigenvalue	Difference	Proportion	Cumulative
Comp 1	2.561	1.543	0.512	0.512
Comp 2	1.017	0.083	0.203	0.716
Comp 3	0.934	0.571	0.187	0.903
Comp 4	0.363	0.238	0.073	0.975
Comp 5	0.125	-	0.025	1.000
Eigenvectors or Factor Loading				
Variable	**Comp1**	**Comp2**	**Comp3**	**Unexplained**
Lr	0.596	-0.084	0.057	0.080
Dcp	0.540	0.122	0.145	0.217
Dcb	0.555	0.008	0.163	0.184
Bmg	-0.108	0.895	0.401	0.005
Mc	-0.180	-0.420	0.888	0.000

Notes: Lr = Lending rate, Dcb = Direct credit to private, Dcb = Direct credit by the bank, Bmg = Broad money growth, Mc = Market capitalization.

growth in the short, medium, and long term, though to differing degrees, which is consistent with the results of the previous studies (61-63).

Furthermore, an increase in the square of economic growth has a positive effect on CO_2 emissions. The pattern started to turn positive at time horizon one and lasted until the end of the time horizon. As a result, unexpected shifts in the square of economic growth have increased CO_2 emissions in the region over the short-, medium-, and long-term runs. However, the resulting shocks are smaller than those of economic growth, as seen in the second and third images in the first row of Figure 1. This confirms the theory of the EKC for Africa. Economic growth is necessary for every country; however, according to the EKC hypothesis, every rising economy progresses with increasing environmental deterioration and emission until a certain point in time, after which it decreases; this result is consistent with the findings of other studies (17,11,64,65).

Similarly, as seen in Figure 1, shocks to foreign direct investment could have a positive influence on CO_2 emissions in the short, medium, and long term. As a result, a change in FDI inflow increases CO_2 emissions in African countries. The results is confirmed by other studies (64,66-69) that reported a positive FDI shock boosts CO_2 emissions in Turkey. The findings indicate that a one standard deviation shock in financial development has an instantaneous positive impact on CO_2 emissions growth over all the time horizons, including short-, medium-, and long-run periods, as shown in Figure 1. In general, the effect of financial development on CO_2 emissions is low and rises slowly, implying that financial institutions' exposure to the deterioration of environmental quality in African countries is very slow and weak, which is consistent with the results of earlier studies (70, 71, 33-35).

Variance decomposition

Although impulse responses may provide information about the influence of changes in one variable on other variables, they do not provide information about the extent or degree of these effects. As a result, this was determined using the variance decomposition method. The variance decomposition offers details about the difference in percentages in the dependent series due to shocks caused by other variables as well as their shocks. The results of the variance decomposition that decides which shocks are the key cause of the predicted fluctuations of the system's endogenous variables, are discussed in this section. The variance decomposition estimates are seen in Table 2, with a projection period of 20 years. The first to fifth periods are considered short term, the sixth to tenth periods are considered medium term, and the eleventh to twenties periods are considered long term.

The findings of the variance decomposition demonstrate that, according to the first variance, carbon emissions are only clarified by their shock, which contributes 100% of itself. The contribution rate of carbon emissions itself declines steadily in the short-run (periods 1-5), while the contribution rates of economic growth, the square of economic growth, financial development, and foreign direct investment rise gradually but at a very low rate. Until the fifth period, carbon emissions have contributed 98.26% of themselves, while economic growth, the square of economic growth, foreign direct investment, and financial development have contributed 0.13%, 0.08%, 1.06%, 0.39%, and 0.07%, respectively.

Nevertheless, in the medium-term (periods 6-10), the influence of carbon emissions to itself declines slowly, while the influence of economic growth, square of economic growth, foreign direct investment, and financial development increase slowly. Until the tenth period, carbon emissions contributed 95.17% to themselves, while economic growth, the square of economic growth, foreign direct investment, and financial production contributed 1.49%, 0.08%, 2.61%, 0.52%, and 0.12% to carbon emissions, respectively.

Finally, over a long period (period 11-20), the contribution rate of carbon emissions to itself declines steadily, while contributions of economic growth, the square of economic growth, foreign direct investment, and financial development increasingly rise. Up to the twentieth century, the contribution rate of carbon emissions to itself was 88.07%, with 5.95%, 0.06%, 4.79%, 0.97%, and 0.16% for economic growth, the square of economic growth, foreign direct investment, and financial development, respectively.

These findings show that foreign direct investment has a greater effect than other factors in explaining environmental quality (CO_2 emissions) in these leading African economies over the short and medium term. Henceforth, in the long-run economic growth contributes

Table 2. Variance decomposition function results

Period	Variance Decomposition of $lnCO_{2it}$						
	SE	$lnCO_{2it}$	$lnGDP_{it}$	$lnGDP_{it}^2$	$lnFDI_{it}$	$lnFD_{it}$	$lnEC_{it}$
1	0.120947	100.0000	0.000000	0.000000	0.000000	0.000000	0.000000
2	0.166280	99.32987	0.128376	0.066328	0.187521	0.262041	0.025862
3	0.202500	98.95321	0.118240	0.073772	0.472577	0.336649	0.045549
4	0.233236	98.64210	0.091805	0.076770	0.756771	0.371387	0.061163
5	0.260542	98.25507	0.132041	0.078944	1.061113	0.398764	0.074068
6	0.285434	97.77575	0.260057	0.080384	1.376092	0.422313	0.085401
7	0.308513	97.21204	0.472347	0.081245	1.693847	0.445027	0.095490
8	0.330161	96.57971	0.756734	0.081571	2.008833	0.468629	0.104526
9	0.350636	95.89617	1.099034	0.081400	2.316704	0.494052	0.112637
10	0.370114	95.17749	1.485726	0.080785	2.614219	0.521872	0.119910
11	0.388726	94.43739	1.904863	0.079789	2.899081	0.552460	0.126416
12	0.406568	93.68719	2.346291	0.078474	3.169761	0.586064	0.132218
13	0.423714	92.93595	2.801597	0.076900	3.425333	0.622847	0.137372
14	0.440221	92.19075	3.263934	0.075122	3.665346	0.662917	0.141930
15	0.456137	91.45701	3.727812	0.073192	3.889708	0.706337	0.145944
16	0.471502	90.73876	4.188893	0.071152	4.098594	0.753140	0.149459
17	0.486347	90.03893	4.643799	0.069041	4.292380	0.803328	0.152519
18	0.500702	89.35954	5.089947	0.066892	4.471577	0.856882	0.155166
19	0.514592	88.70187	5.525403	0.064732	4.636792	0.913763	0.157437
20	0.528040	88.06668	5.948760	0.062585	4.788694	0.973917	0.159367

the most when compared with the other explanatory variables, this result is consistent with the results of other studies (72-74) and many others. These findings indicate that both income and foreign direct investment are significant factors that influence the level of CO_2 emissions in African countries.

Discussion

The IRFs reveal the existence of the EKC in the main African countries. The results are stable as all the eigenvalues lie in the circle, and hence, are good for forecasting and policy recommendations. To meet sustainable development goals while reducing carbon emissions and their impacts, Africa must increase economic growth through manufacturing, agricultural, and energy use patterns, as well as integrate innovation, science, and technological advancement in their developmental agenda.

According to this finding, FDI has a distorting impact on environmental quality in African nations. The finding provides strong evidence of the pollution haven hypothesis for the African sample of countries. To boost the efficiency of FDI and keep African countries from becoming a "pollution paradise", foreign investment activities should be standardized. Since most African countries' financial markets are underdeveloped, the outcome of the study is predicted and the results are consistent with the findings of other studies (75, 76).

Furthermore, the financial liberalization policies of these countries are marked by the inefficiency of both economies and legal structures, as well as an inappropriate bureaucratic structure. Both of these aspects have led to the advent of financial and banking crises, which have weakened the position of their financial institutions and compounded their uncertainty (76). As a result, as it evolves, the financial sector should promote environmental quality by orienting banking activities toward the support of renewable energy and low-carbon ventures.

The role of FDI as a major determinant factor of environmental quality in early development may be due to multiple emissions from multinational corporations in Africa (77,78). This is due to the ability of Africa to develop its economy by trade openness, which draws foreign direct investment (79). As a result, several foreign corporations have entered the region, contributing to the region's environmental degradation. As a result, Africa accepts FDI to improve the continent while doing nothing to mitigate the detrimental effects on the climate. Similarly, Antweiler et al (79) reported that the government of Mali has not done adequate measures to resolve the environmental problems raised by the FDI in the country, while other researchers (80,81) stated that the situation in Nigeria is similar. This limits the ability of the region to protect the climate. Because of the significant environmental effects of FDI, policies to attract MNCs should be checked to determine the environmental implications of their activities before awarding them any permits to operate.

In the long term, from the tenth to the twentieth centuries, economic growth has been the most important force affecting environmental quality. The fact that the bulk of African countries are low-income and lower-middle-income countries explains why economic growth plays such a significant role in the long term. Their income levels are insufficient to improve environmental conditions when achieving high levels of economic growth. Industrialization occurs in conjunction with economic growth, which leads to increased production and CO_2 emissions (82).

Because of increased economic growth, per capita income grows, resulting in buying cars, air conditioners, and other goods, which increases air emissions, and thereby, degrades environmental quality. Since economic growth accounts for a large portion of long-term fluctuations in CO_2 emissions, allocating funds to improve energy production in Africa would help condense CO_2 emissions as the economy expands, mitigating the associated negative environmental consequences.

Conclusion

The relationship between environmental quality, economic growth, foreign direct investment, and financial development is well documented. As environmental quality, economic growth, foreign direct investment, and financial development are all intertwined, integrating these two streams of literature using an integrated framework helps avoid variable omission bias or misspecification and makes solid policy recommendations. In this study, the IRF and variance decomposition were used for the first time to determine the most influential input variable in contributing to CO_2 emissions and to forecast how a shock in economic growth, financial development, and FDI will affect CO_2 emissions while controlling for energy consumptions for panel data of 6 main African economies. The policy implications of this study are discussed as follows:

The empirical results reveal that a one-standard-deviation rise in Africa's economic growth leads to a gradual increase in carbon dioxide emissions. An unexpected shifts in the square of economic growth have been shown to increase CO_2 emissions in the region over the short-, medium-, and long-term runs, despite the fact that the resulting shocks are smaller than those of economic growth. This confirms the theory of the EKC for Africa. Shocks to foreign direct investment could have a positive influence on carbon dioxide emissions in the short, medium, and long term. A one standard deviation shock in financial development has an instantaneous positive impact on CO_2 emissions growth over all the time horizons, including short-, medium-, and long-run periods.

Consequently, this study not only contributes to our knowledge, but it has also significant policy implications and provides some suggestions for future research. The plausibility of EKC for the main African economies implies that these economies can accomplish ecological sustainability by implementing green schemes and guaranteeing sustainable consumption and production patterns, and these economies should indeed detach their growth from CO_2 emissions by implementing sustainable technology and dissuading the use of non-renewable sources of energy.

As a result of this conclusion, policies should concentrate on recruiting clean and energy-efficient technology through FDIs. Investments that contribute significantly to long-term development should be a priority for policymakers. FDI inflows into technology-intensive and environmentally friendly businesses should also be encouraged by authorities. This can benefit the environment while also encouraging economic prosperity. Stopping businesses that produce significant quantities of pollutants, such as cement and gypsum, would be a bold move. Government attention is also required for monitoring procedures. Polluting businesses should be audited regularly to verify that they are adhering to environmental regulations. High emitters should be penalized, while strong achievers should be rewarded. Environment-related societal costs should be included in new investment proposals. Furthermore, African countries should offer financial incentives to multinational corporations introducing contemporary technology that reduces emissions and preserves the environment of the host country. High emitters might be subjected to carbon taxes. Higher levels of FDI inflow should be encouraged by African countries to grow their economies while maintaining environmental standards and being competitive.

According to these findings, omitting financial development from carbon emission models will result in the underestimation of real CO_2 emissions, rendering CO_2 emission abatement initiatives untenable. Financial institutions should inspire companies or firms to participate in ecologically responsible projects, and also, provide credit at cheaper costs to companies or industries dedicated to investing in sustainable environmental projects, while financial development impedes environmental quality. Businesses and industries should be required to report on their environmental performance under future environmental legislation. Environmental policymakers may employ other policy instruments to decrease CO_2 emissions, such as emissions trading or a cap and carbon emissions tax.

Despite the efficiency of the results produced using the panel estimate approach, the main limitation of this study is that its conclusions and policy suggestions are applicable at the regional level but may not apply to individual nations. As a result, more research utilizing time-series data is needed to investigate the nature of

the relationship between economic growth, foreign direct investment, financial development, and carbon emissions. The research work can be carried out in the future in the following areas. Similarly, this study solely used CO_2 emissions as an environmental indicator due to the lack of data. For a more thorough study and simulation, several environmental parameters related to the water environment might be used. Second, the population and environmental investment indexes may be included to the models in this study to examine their influence on environmental quality. Further studies are required to investigate the institutional framework in which economic growth, financial development, and foreign direct investment affect environmental quality in developing countries.

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Ethical issues

The authors confirm that all data acquired during the research are as stated in the paper, and no data from the study has been or will be published elsewhere.

Competing interests

The authors declare that there is no conflict of interests.

Authors' contributions

All authors have an equal share in the suggestion of the problem, design of experiments, data collection, model design simulation, and article approval.

References

1. Jamel L, Derbali A. Do energy consumption and economic growth lead to environmental degradation? Evidence from Asian economies. Cogent Econ Finance. 2016;4(1):1170653. doi: 10.1080/23322039.2016.1170653.
2. Alam MJ, Begum IA, Buysse J, Van Huylenbroeck G. Energy consumption, carbon emissions and economic growth nexus in Bangladesh: cointegration and dynamic causality analysis. Energy Policy. 2012;45:217-25. doi: 10.1016/j.enpol.2012.02.022.
3. Nathaniel S, Nwodo O, Adediran A, Sharma G, Shah M, Adeleye N. Ecological footprint, urbanization, and energy consumption in South Africa: including the excluded. Environ Sci Pollut Res Int. 2019;26(26):27168-79. doi: 10.1007/s11356-019-05924-2.
4. Nathaniel SP, Iheonu CO. Carbon dioxide abatement in Africa: the role of renewable and non-renewable energy consumption. Sci Total Environ. 2019;679:337-45. doi: 10.1016/j.scitotenv.2019.05.011.
5. IPCC. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I (WGI) to the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC). Cambridge: Cambridge University Press; 2013.
6. Schultz M, Tyrrell TD, Ebenhard T. The 2030 Agenda and Ecosystems-A Discussion Paper on the Links Between the Aichi Biodiversity Targets and the Sustainable Development Goals. Stockholm, Sweden: SwedBio at Stockholm Resilience Centre; 2016.
7. Acheampong AO. Economic growth, CO2 emissions and energy consumption: what causes what and where? Energy Econ. 2018;74:677-92. doi: 10.1016/j.eneco.2018.07.022.
8. Tang CF, Tan BW. The linkages among energy consumption, economic growth, relative price, foreign direct investment, and financial development in Malaysia. Qual Quant. 2014;48(2):781-97. doi: 10.1007/s11135-012-9802-4.
9. Kojima M, Bacon R. Changes in CO2 Emissions from Energy Use: A Multicountry Decomposition Analysis. Washington, DC: World Bank; 2009.
10. Danlami AH, Aliyu S, Danmaraya IA. Energy production, carbon emissions and economic growth in lower-middle income countries. Int J Soc Econ. 2019;46(1):97-115. doi: 10.1108/ijse-07-2017-0274.
11. Ahmad N, Du L, Lu J, Wang J, Li HZ, Hashmi MZ. Modelling the CO2 emissions and economic growth in Croatia: is there any environmental Kuznets curve? Energy. 2017;123:164-72. doi: 10.1016/j.energy.2016.12.106.
12. Grossman GM, Krueger AB. Economic growth and the environment. Q J Econ. 1995;110(2):353-77. doi: 10.2307/2118443.
13. Boufateh T. The environmental Kuznets curve by considering asymmetric oil price shocks: evidence from the top two. Environ Sci Pollut Res Int. 2019;26(1):706-20. doi: 10.1007/s11356-018-3641-3.
14. Ma CQ, Liu JL, Ren YS, Jiang Y. The impact of economic growth, FDI and energy intensity on China's manufacturing industry's CO2 emissions: an empirical study based on the fixed-effect panel quantile regression model. Energies. 2019;12(24):4800. doi: 10.3390/en12244800.
15. Ssali MW, Du J, Mensah IA, Hongo DO. Investigating the nexus among environmental pollution, economic growth, energy use, and foreign direct investment in 6 selected sub-Saharan African countries. Environ Sci Pollut Res Int. 2019;26(11):11245-60. doi: 10.1007/s11356-019-04455-0.
16. Dong K, Sun R, Dong X. CO2 emissions, natural gas and renewables, economic growth: assessing the evidence from China. Sci Total Environ. 2018;640-641:293-302. doi: 10.1016/j.scitotenv.2018.05.322.
17. Mikayilov JI, Galeotti M, Hasanov FJ. The impact of economic growth on CO2 emissions in Azerbaijan. J Clean Prod. 2018;197(Pt 1):1558-72. doi: 10.1016/j.jclepro.2018.06.269.
18. Anastacio JA. Economic growth, CO2 emissions and electric consumption: is there an environmental Kuznets curve? An empirical study for North America countries. Int J Energy Econ Policy. 2017;7(2):65-71.
19. Charfeddine L, Mrabet Z. The impact of economic development and social-political factors on ecological footprint: a panel data analysis for 15 MENA countries. Renew Sustain Energy Rev. 2017;76:138-54. doi: 10.1016/j.rser.2017.03.031.
20. Atif AW, Abugamos H. Income-carbon emissions nexus for Middle East and North Africa countries: a semi-parametric approach. Int J Energy Econ Policy. 2017;7(2):152-9.
21. Ben Jebli M, Ben Youssef S, Ozturk I. Testing environmental Kuznets curve hypothesis: the role of renewable and non-renewable energy consumption and trade in OECD

countries. Ecol Indic. 2016;60:824-31. doi: 10.1016/j.ecolind.2015.08.031.
22. Dogan E, Ozturk I. The influence of renewable and non-renewable energy consumption and real income on CO2 emissions in the USA: evidence from structural break tests. Environ Sci Pollut Res Int. 2017;24(11):10846-54. doi: 10.1007/s11356-017-8786-y.
23. Jardón A, Kuik O, Tol RS. Economic growth and carbon dioxide emissions: an analysis of Latin America and the Caribbean. Atmósfera. 2017;30(2):87-100. doi: 10.20937/atm.2017.30.02.02.
24. Keho Y. The impact of trade openness on economic growth: the case of Cote d'Ivoire. Cogent Econ Finance. 2017;5(1):1332820. doi: 10.1080/23322039.2017.1332820.
25. Özokcu S, Özdemir Ö. Economic growth, energy, and environmental Kuznets curve. Renew Sustain Energy Rev. 2017;72:639-47. doi: 10.1016/j.rser.2017.01.059.
26. Abbasi F, Riaz K. CO2 emissions and financial development in an emerging economy: an augmented VAR approach. Energy Policy. 2016;90:102-14. doi: 10.1016/j.enpol.2015.12.017.
27. Shahbaz M, Shahzad SJH, Ahmad N, Alam S. Financial development and environmental quality: the way forward. Energy Policy. 2016;98:353-64. doi: 10.1016/j.enpol.2016.09.002.
28. Awad A, Ragab H. The economic growth and foreign direct investment nexus: Does democracy matter? Evidence from African countries. Thunderbird International Business Review. 2018;60(4):565-75.doi: 10.1002/tie.21948.
29. Dogan E, Aslan A. Exploring the relationship among CO2 emissions, real GDP, energy consumption and tourism in the EU and candidate countries: Evidence from panel models robust to heterogeneity and cross-sectional dependence. Renewable and Sustainable Energy Reviews. 2017 Sep 1;77:239-45. doi: 10.1016/j.rser.2017.03.111.
30. Dogan E, Seker F. The influence of real output, renewable and non-renewable energy, trade and financial development on carbon emissions in the top renewable energy countries. Renew Sustain Energy Rev. 2016;60:1074-85. doi: 10.1016/j.rser.2016.02.006.
31. Katircioğlu ST, Taşpinar N. Testing the moderating role of financial development in an environmental Kuznets curve: Empirical evidence from Turkey. Renew Sustain Energy Rev. 2017;68(Pt 1):572-86. doi: 10.1016/j.rser.2016.09.127.
32. Salahuddin M, Gow J, Ozturk I. Is the long-run relationship between economic growth, electricity consumption, carbon dioxide emissions and financial development in Gulf Cooperation Council countries robust? Renew Sustain Energy Rev. 2015;51:317-26. doi: 10.1016/j.rser.2015.06.005.
33. Al-Mulali U, Ozturk I, Lean HH. The influence of economic growth, urbanization, trade openness, financial development, and renewable energy on pollution in Europe. Nat Hazards. 2015;79(1):621-44. doi: 10.1007/s11069-015-1865-9.
34. Javid M, Sharif F. Environmental Kuznets curve and financial development in Pakistan. Renew Sustain Energy Rev. 2016;54:406-14. doi: 10.1016/j.rser.2015.10.019.
35. Sehrawat M, Giri AK, Mohapatra G. The impact of financial development, economic growth and energy consumption on environmental degradation. Manag Environ Qual. 2015;26(5):666-82. doi: 10.1108/meq-05-2014-0063.
36. Dogan E, Turkekul B. CO2 emissions, real output, energy consumption, trade, urbanization and financial development: testing the EKC hypothesis for the USA. Environ Sci Pollut Res Int. 2016;23(2):1203-13. doi: 10.1007/s11356-015-5323-8.
37. Maji IK, Habibullah MS, Saari MY. Financial development and sectoral CO2 emissions in Malaysia. Environ Sci Pollut Res. 2017;24(8):7160-76. doi: 10.1007/s11356-016-8326-1.
38. Omri A, Daly S, Rault C, Chaibi A. Financial development, environmental quality, trade and economic growth: what causes what in MENA countries. Energy Econ. 2015;48:242-52. doi: 10.1016/j.eneco.2015.01.008.
39. Walter I, Ugelow JL. Environmental policies in developing countries. Ambio. 1979;8(2-3):102-9.
40. Baumol WJ, Oates WE. The Theory of Environmental Policy. Cambridge: Cambridge University Press; 1988. doi: 10.1017/cbo9781139173513.
41. Liu Y, Hao Y, Gao Y. The environmental consequences of domestic and foreign investment: evidence from China. Energy Policy. 2017;108:271-80. doi: 10.1016/j.enpol.2017.05.055.
42. Pazienza P. The relationship between CO2 and Foreign Direct Investment in the agriculture and fishing sector of OECD countries: evidence and policy considerations. Intellect Econ. 2015;9(1):55-66. doi: 10.1016/j.intele.2015.08.001.
43. Sung B, Song WY, Park SD. How foreign direct investment affects CO2 emission levels in the Chinese manufacturing industry: evidence from panel data. Econ Syst. 2018;42(2):320-31. doi: 10.1016/j.ecosys.2017.06.002.
44. Zhu H, Duan L, Guo Y, Yu K. The effects of FDI, economic growth and energy consumption on carbon emissions in ASEAN-5: evidence from panel quantile regression. Econ Model. 2016;58:237-48. doi: 10.1016/j.econmod.2016.05.003.
45. Zhang C, Zhou X. Does foreign direct investment lead to lower CO2 emissions? Evidence from a regional analysis in China. Renew Sustain Energy Rev. 2016;58:943-51. doi: 10.1016/j.rser.2015.12.226.
46. Abdouli M, Hammami S. Economic growth, FDI inflows and their impact on the environment: an empirical study for the MENA countries. Qual Quant. 2017;51(1):121-46. doi: 10.1007/s11135-015-0298-6.
47. Seker F, Ertugrul HM, Cetin M. The impact of foreign direct investment on environmental quality: a bounds testing and causality analysis for Turkey. Renew Sustain Energy Rev. 2015;52:347-56. doi: 10.1016/j.rser.2015.07.118.
48. Solarin SA, Al-Mulali U, Musah I, Ozturk I. Investigating the pollution haven hypothesis in Ghana: an empirical investigation. Energy. 2017;124:706-19. doi: 10.1016/j.energy.2017.02.089.
49. Love I, Zicchino L. Financial development and dynamic investment behavior: evidence from panel VAR. Q Rev Econ Finance. 2006;46(2):190-210. doi: 10.1016/j.qref.2005.11.007.
50. Andrews DWK, Lu B. Consistent model and moment selection procedures for GMM estimation with application to dynamic panel data models. J Econom. 2001;101(1):123-64. doi: 10.1016/s0304-4076(00)00077-4.
51. Arellano M, Bond S. Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations. Rev Econ Stud. 1991;58(2):277-97. doi: 10.2307/2297968.
52. Sims CA. Comparison of interwar and postwar business cycles: monetarism reconsidered. Am Econ Rev.

1980;70(2):250-7.
53. Čeh Časni A, Dumičić K, Tica J. The panel VAR approach to modelling the housing wealth effect: evidence from selected European post-transition economies. Naše gospodarstvo/ Our economy. 2016;62(4):23-32. doi: 10.1515/ngoe-2016-0021.
54. Hassan A, Babafemi OD, Jakada AH. Financial market development and economic growth in Nigeria: evidence from VECM approach. Int J Appl Econ Stud. 2016;4(3):1-13.
55. Saidu BM, Ahmed BA, Jakada AH. The determinants of long run economic growth in Nigeria. Asian Econ Financ Rev. 2018;8(1):1-8. doi: 10.18488/journal.aefr.2018.81.1.7.
56. Ahmad AU, Abdullah A, Abdullahi AT, Muhammad UA. Stock market returns and macroeconomic variables in Nigeria: testing for dynamic linkages with a structural break. Sch J Econ Bus Manag. 2015;2(8A):816-28.
57. Ahmad AU, Loganathan N, Ismail S, Streimikiene D, Mardani A, Golam Hassan AA. Financial instability, trade openness and energy prices on leading African countries sustainable growth. Econ Comput Econ Cybern Stud Res. 2018;52(1):127-42. doi: 10.24818/18423264/52.1.18.08.
58. Hotelling H. Analysis of a complex of statistical variables into principal components. J Educ Psychol. 1933; 4(6):417-41. doi: 10.1037/h0071325.
59. Jolliffe IT. Principal components in regression analysis. In: Jolliffe IT, ed. Principal Component Analysis. New York, NY: Springer; 2002. p. 167-98. doi: 10.1007/0-387-22440-8_8.
60. Kaiser HF. The application of electronic computers to factor analysis. Educ Psychol Meas. 1960;20(1):141-51. doi: 10.1177/001316446002000116.
61. Bakirtas I, Cetin MA. Revisiting the environmental Kuznets curve and pollution haven hypotheses: MIKTA sample. Environ Sci Pollut Res Int. 2017;24(22):18273-83. doi: 10.1007/s11356-017-9462-y.
62. Ojewumi SJ, Akinlo AE. Foreign direct investment, economic growth and environmental quality in sub-Saharan Africa: a dynamic model analysis. Afr J Econ Rev. 2017;5(1):48-68.
63. Jakada AH, Mahmood S, Ahmad AU, Bambale SA. Heterogeneous moderating influence of economic growth on financial development and environmental quality in Africa. J Crit Rev. 2020;7(14):127-33. doi: 10.31838/jcr.07.14.23.
64. Boamah KB, Du J, Adu D, Mensah CN, Dauda L, Khan MAS. Predicting the carbon dioxide emission of China using a novel augmented hypo-variance brain storm optimisation and the impulse response function. Environ Technol. 2021;42(27):4342-54. doi: 10.1080/09593330.2020.1758217.
65. Jakada AH, Mahmood S. An asymmetric effect of economic growth, foreign direct investment and financial development on the quality of environment in Nigeria. J Manag Theory Pract. 2020;1(1):5-13. doi: 10.37231/jmtp.2020.1.1.6.
66. Jakada AH, Mahmood S, Ahmad AU, Farouq IS, Mustapha UA. Financial development and the quality of the environment in Nigeria: an application of non-linear ARLD approach. Res World Econ. 2020;11(1):78-92. doi: 10.5430/rwe.v11n1p78.
67. Jakada AH, Mahmood S, Ahmad AU, Faruq IS, Mustapha UA. The effect of oil price on the quality of environment in Nigerian Int J Sci Technol Res. 2020;9(3):6340-7.
68. Adam IM, Jakada AH, Ahmad AU, Danmaraya IA, Marmara AD, Abubakar AA. Financial instability and the state of environmental quality in Nigeria. Int J Bus Econ Manag. 2021;8(5):318-31. doi: 10.18488/journal.62.2021.85.318.331.
69. Alkhawaldeh BY, Mahmood S, Jakada AH. An empirical assessment of the effect of taxes and interest rate on economic growth in Jordan: an application of dynamic autoregressive-distributed lag. Res World Econ. 2020;11(3):92-8. doi: 10.5430/rwe.v11n3p92.
70. Dabachi UM, Mahmood S, Ahmad AU, Ismail S, Farouq IS, Jakada AH, et al. Energy consumption, energy price, energy intensity environmental degradation, and economic growth nexus in African OPEC countries: evidence from simultaneous equations models. J Environ Treat Tech. 2020;8(1):403-9.
71. Ahmad AU, Adamu IM, Ahmad IM, Ismail S, Farouq IS, Jakada AH, et al. Empiric on the relationship between pollutant emissions, renewable energy consumption, and economic growth: evidence from sub-Saharan African countries. Int J Sci Technol Res. 2020;9(1):2888-2900.
72. Chontanawat J. Driving forces of energy-related CO2 emissions based on expanded IPAT decomposition analysis: evidence from ASEAN and four selected countries. Energies. 2019;12(4):764. doi: 10.3390/en12040764.
73. Pani R, Mukhopadhyay U. Variance analysis of global CO2 emission–a management accounting approach for decomposition study. Energy. 2011;36(1):486-99. doi: 10.1016/j.energy.2010.10.015.
74. Yao Z, Wu B, Shen X, Cao X, Jiang X, Ye Y, et al. On-road emission characteristics of VOCs from rural vehicles and their ozone formation potential in Beijing, China. Atmos Environ. 2015;105:91-6. doi: 10.1016/j.atmosenv.2015.01.054.
75. Ahmad AU, Ismail S, Dayyabu S, Adnan AA, Farouq IS, Jakada AH, et al. Non-linear causal link between central bank intervention and exchange rate volatility in Nigeria. Glob J Manag Bus Res. 2020;20(6):16-29.
76. Acheampong AO. Modelling for insight: does financial development improve environmental quality? Energy Econ. 2019;83:156-79. doi: 10.1016/j.eneco.2019.06.025.
77. Eluka J, Ndubuisi-Okolo PU, Anekwe RI. Multinational corporations and their effects on Nigerian economy. Eur J Bus Manag. 2016;8(9):59-67.
78. Ouoba Y. Economic sustainability of the gold mining industry in Burkina Faso. Resour Policy. 2017;51:194-203. doi: 10.1016/j.resourpol.2017.01.001.
79. Antweiler W, Copeland BR, Taylor MS. Is free trade good for the environment? Am Econ Rev. 2001;91(4):877-908. doi: 10.1257/aer.91.4.877.
80. Ibeto C, Anekwe C, Ihedioha J. Human exposure risk to semivolatile organic compounds via soil in automobile workshops in Awka, South Eastern, Nigeria. Environ Sci Pollut Res Int. 2019;26(16):16249-60. doi: 10.1007/s11356-019-04981-x.
81. Osuagwu GO, Obumneke E. Multinational corporations and the Nigerian economy. Int J Acad Res Bus Soc Sci. 2013;3(4):359-69.
82. Bibi F, Jamil M. Testing environment Kuznets curve (EKC) hypothesis in different regions. Environ Sci Pollut Res Int. 2021;28(11):13581-94. doi: 10.1007/s11356-020-11516-2.