Received: 3 October 2019 | Revised: 1 November 2019 | Accepted: 17 March 2020
DOI: 10.1002/pa.2141

ACADEMIC PAPER

WILEY

The determinants and interrelationship of carbon emissions and economic growth in African economies: Fresh insights from static and dynamic models

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This study explores the interrelationship between CO_2 emissions and economic growth in selected Africa economies from 1990 to 2014 providing evidence from both static and dynamic models. Results show that increases in energy use have a significant and positive effect on economic growth; which goes to show that growth in Africa is actually energy dependent. Further findings suggest that CO_2 emissions have no significant contemporaneous effect, however, a significant and negative effect at a one-period lag on economic growth. The significance of the impacts is consistently confirmed by both the static and dynamic estimations. Also, trade adds to economic growth and also contributes to environmental deterioration in Africa. There is a dire need for Africa to adjust its energy portfolio by shifting to clean energy sources which will enhance sustainable economic growth without deteriorating the environment.

1 | INTRODUCTION

According to the World Bank (2017), at least, about 14% of the people living in the world live in SSA, and Africa is the second most populated continent behind Asia. For the past few decades, an increase in growth/development and population witnessed in the world has been unprecedented. Urbanization and industrialization have been the key drivers of this phenomenon increase (Dong, Jiang, Sun, & Dong, 2019; Nathaniel et al., 2019). This increase is however at a cost. It results in more energy (nonrenewable) demand. This explains why global energy demand has increased to 13,105.0 (Mtoe) in 2015 from 6,642.3 in 1980 (BP, 2017). On the flip side, the global CO_2 concentration in the atmosphere also increased to 404.7 ppm in 2016 (ESRL, 2017). In the same year, global temperature increased by 1.26°C (Hansen et al., 2017). The concomitant upward surge in energy use (EUS) and urbanization has done no good to the environment especially in terms of CO_2 emissions (Dong, Sun, Li, & Liao, 2018; Shen et al., 2018; Shuai, Chen, Wu, Zhang, & Tan, 2019; Shuai, Shen, Jiao, Wu, & Tan, 2017). Between 2000 and 2017, the growth in urban population (in Africa) has increased from 30.8% to 38.8%. Also, the GDP growth rate of the region average of 2.2% between 2015 and 2017 (Wang & Dong, 2019).

The urgent need to make the environment habitable for humanity caused 196 countries to not only support but also join the United Nations Framework Convention on Climate Change (UNFCCC) in 2015. Countries in support of the UNFCCC have been holding a series of meeting since 1995 on the steps needed to abate global warming. One notable outcome of their meetings was the birth of the Kyoto Protocol in 1997. The protocol initiated binding obligations, especially for developed countries, to reduce their emissions. Good as it seems, this agreement was never a global one as the special focus was on the European Union and other few developed countries leaving out the top emitters like, the United States, India, and Canada who failed to ratify the agreement. Subsequently, parties of the UNFCCC, consisting more than 194 countries, adopted the Paris Agreement on December 2015 with the willingness to reduce GHGs well below 2°C by 2,100. This is, however, becoming doubtful with the passing of each day holding to the withdrawal of the United States (on June 1, 2017) from the agreement. The United States claimed that the agreement empowers other nations at the expense of the United States. Whichever way the coin turns out, the Paris Agreement was a landmark achievement, and adhering strictly to it, is germane for environmental sustainability. With this achievement, global cooperation, with regard to environmental protection, witnessed new dawn (Bloomberg & Pope, 2017; Zhang, Chao, Zheng, & Huang, 2017).

Securing the biodiversity is important for human survival, also for sustainable growth and development. As a result, for over two decades now, many studies on the nexus between selected macroeconomic variables and CO_2 emissions have been unprecedented (see, for instance, Ozturk & Acaravci, 2010; Ozatac, Gokmenoglu, & Taspinar, 2017; Destek & Sarkodie, 2019; Jamel & Derbali, 2016; Saboori, Sulaiman, & Mohd, 2012; Ozatac et al., 2017; Kahia, Aïssa, & Lanouar, 2017; Green & Stern, 2017). While some specifically explored growth and CO_2 emissions nexus in Africa (Aboagye & Kwakwa, 2014; Al-Mulali & Sab, 2012; Asongu, El Montasser, & Toumi, 2016; Esso & Keho, 2016; Gao & Zhang, 2014; Hamilton & Kelly, 2017; Kais & Ben Mbarek, 2017; Saidi & Hammami, 2015). Global warming caused majorly by carbon emissions (Bong et al., 2017; Lv & Xu, 2019) have made life seemingly difficult for humanity. It causes climate change. This change is a global problem. It is not exclusive to developed countries alone (Ito, 2017). The horrendous effects of climate change have been a serious challenge facing the world. If CO_2 emissions must be mitigated, a clear knowledge of its major drivers are sacrosanct (Dong et al., 2019; Sarkodie & Strezov, 2018; Sarkodie & Strezov, 2019).

Against this backdrop, numerous research studies have been dedicated to the determinants of emissions both in a single country case (Brizga, Feng, & Hubacek, 2013; Cansino, Román, & Ordonez, 2016; Chin, Puah, Teo, & Joseph, 2018; Mrabet & Alsamara, 2017; Raggad, 2018) and for a group of countries (Balogh & Jámbor, 2017; Dogan & Seker, 2016; Iwata, Okada, & Samreth, 2012; Li & Lin, 2015; Lin, Wang, Marinova, Zhao, & Hong, 2017; Moutinho, Moreira, & Silva, 2015; Sharma, 2011; Shuai et al., 2017; Yeh & Liao, 2017). China and the United States are the two biggest emitters of CO_2 (Liu & Xiao, 2018). Although developing countries (especially countries in Africa) are not among the highest emitters of CO_2 yet they are not spared from its negative consequences. These consequences transcend all facets of human life. The continuous usage of the nonrenewable energy sources in Africa, which increased to 69% in 2017 (Dong et al., 2019) has the potential to subject the region to more environmental calamity if the 2015 Climate Change Vulnerability Index report is anything to go by. According to this report, Eritrea, Central African Republic, Ethiopia, Chad, Nigeria, South Sudan, and Sierra-Leone are among the top 10 countries most vulnerable to climate change negativity (Sarkodie, 2018). This was one of the motivating factors for this study. Whether the quality of the environment has also truncated growth in the region, was another motivation for the study.

However, unlike previous studies that either concentrated on CO_2 emissions determinants or on the determinants of growth in Africa, we simultaneously estimated both by providing evidence from both static (Feasible Generalized Least Square [FGLS] and Prais–Winsten Panel Corrected Standard Errors [PCSEs]) and dynamic (System Generalized Methods of Moments [Sys-GMM]) estimations. Our study considers growth as a determinant of CO_2 emission and vice versa. Also, the study used the second-generation estimation techniques robust for cross-sectional dependence among the countries considered, a phenomenon that was hardly considered in previous studies.

The study is outlined as follows: Section 2 shows a review of the literature. Section 3 presents the data source and methodology. The results are discussed in Section 4. Section 5 concludes with relevant policy direction.

2 | LITERATURE REVIEW

In this section, the literature is divided into two strands: those that emphasized the determinants of CO_2 emissions and those that concentrate on factors that drive growth.

2.1 | Determinants of CO_2 emissions

The reduction in the quality of the environment has been a subject of intense debate for both economists and environmentalists. As such, the literature is awash with studies directed to unveiling the factors that could be responsible for the malady. However, various factors have been unveiled as drivers of CO_2 emissions both for country-specific and regional studies. For instance, relying on data spanning 2005–2016, Ma et al. (2019) provided evidence of a well-knitted association between CO_2 emissions and EUS. Similarly for 10 industrialized countries, with data spanning 1991–2013, Ghazali and Ali (2019) discovered that population drives CO_2 emissions. A feedback causality was also discovered between population and growth, and between CO_2 emissions and energy intensity. By using a ridge regression on regional data from China, Wang, Wang, Li, Fang, and Feng (2019) were able to affirm that urbanization, population, and industrialization, which are mainly socioeconomic factors, add to CO_2 emissions. Sarkodie et al. (2019) through a dynamic ARDL simulation model discovered that EUS increases emission in Australia, and 13% emission rate can be abated with an increase in biomass consumption. Azizalrahman (2019) explored the contribution of the urban sector to emissions relying on the ARDL technique. Urbanization and energy consumption were the major factors that deteriorate the environment. Saidi and Mbarek (2017) pointed out in their study of 19 emerging economies that urbanization and trade stimulate CO_2 emissions. They, however, noted that financial development (FDM) was healthy for the environment. They concluded that aggressive financial reform is germane for sustainable growth. Studies on FDM and CO_2 emissions nexus have remained largely inconclusive (see Atici, 2009; Dogan, Seker, & Bulbul, 2017; Ertugrul, Cetin, Seker, & Dogan, 2016; Hossain, 2011; Lau, Choong, & Eng, 2014; Le, Chang, & Park, 2016; Nasir & Rehman, 2011; Rafiq, Salim, & Nielsen, 2016; Sbia, Shahbaz, & Hamdi, 2014; Sebri & Ben-Salha, 2014; Shahbaz, Nasreen, Ahmed, & Hammoudeh, 2017). Sarkodie and Strezov (2019) discovered that FDI degrades the environment in their study of five developing countries from 1982 to 2016. Apart from FDI, an increase in emissions was attributed to EUS in all the countries except Indonesia. This is similar to what Zhou, Fu, Kong, and Wu (2018) reported for China. On the flipside, Khan, Saleem, and Fatima (2018) discovered the exact opposite for the case of India, Bangladesh, and Pakistan after utilizing the FMOLS for data spanning 1980–2014. They discovered that FDI is environmentally friendly. Also, Agboola and Bekun (2019) reported that FDI is not particularly harmful to the environment in Nigeria. The contradictory findings of Sarkodie and Strezov (2019) and Khan et al. (2018) could be as a result of the differences in data, country and estimation techniques. For studies on FDI and CO_2 interaction (see Omri, Nguyen, & Rault, 2014; Shahzad, Kumar, Zakaria, & Hurr, 2017; Solarin, Al-Mulali, Musah, & Ozturk, 2017; Zakarya, Mostefa, Abbes, & Seghir, 2015; Zhang & Zhou, 2016). Balcilar, Bekun, and Uzuner (2019), Bukhari and Waseem (2017) and Mirza and Kanwal (2017) used a similar technique (ARDL) and arrived at a similar conclusion for Pakistan. They both affirmed that EUS drives CO_2 emissions. Also, energy consumption was accorded the main driver of emissions. Salahuddin, Alam, Ozturk, and Sohag (2018) applied the ARDL technique on data spanning 1980–2013 and used the DOLS to check for robustness. They reported that FDI, EUS, and growth stimulate CO_2 emission and also Granger cause CO_2 emissions. Bekun, Alola, and Sarkodie (2019) discovered that fossil fuels consumption contributes to environmental deterioration in 16-EU countries, while renewable energy consumption adds to environmental quality.

2.2 | Determinants of economic growth

The growth of an economy indirectly affects working conditions, the sailing of enterprises and decision-making. Maintaining steady growth enhances enterprises development even when enterprises do not have any direct control of factors that drive it (He & Xu, 2019). Providing answers to questions relating to the factors that add to growth dates back to the seminar works of Barro (1991) and Mankiw, Romer, and Weil (1992). However, the literature still remains largely inconclusive. The earlier set of authors support innovation, human capital, population, income, and investments as key drivers of growth (Barro & Lee, 1993; Birdsall & Rhee, 1993; De Long & Summers, 1991; Galindo Martín, Ribeiro, & Mendez Picazo, 2012; Maria, 2010; Weng, Song, & Sheng, 2012; Ye & Sun, 2010) and complemented by recent studies (like Aydin, Alrajhi, & Jouini, 2018; Erdil Şahin, 2015; Esmail & Hemdan, 2018; Kacprzyk & Doryń, 2017; Lee, 2018; Tsaurai, 2017; Ustabaş & Ersin, 2016; Zhao, 2016) and these studies relied on the Solow model as a baseline for variables selection. Bruce and Turnovsky (2013a) have attributed the growth in the economy to demographic factors like fertility, life expectancy, age among others (see Bruce & Turnovsky, 2013b; Yew & Zhang, 2013; Mierau & Turnovsky, 2014; Bloom, Canning, & Sevilla, 2004; Well, 2007). Another strand of studies has created a link between growth and macroeconomic variables, and has also identified different directions of causality between both (Alfaro, Chanda, Kalemli-Ozcan, & Sayek, 2004; Ivanović & Stanišić, 2017; Prašnikar, Redek, & Drenkovska, 2017; Yülek, 2017). Recently, institutional qualities have also been assigned a chief role in determining economic growth (Acemoglu, Johnson, & Robinson, 2005; Barro, 2003; Bildirici, 2008; Butkiewicz & Yanikkaya, 2006; Chong & Calderon, 2000; Fraj, Hamdaoui, & Maktouf, 2018; Gwartney, Holcombe, & Lawson, 2004; Henderson, Papageorgiou, & Parmeter, 2011; Ji, Magnus, & Wang, 2014; Klein, 2005; Law, Azman-Saini, & Ibrahim, 2013; Sobel, 2008; Valeriani & Peluso, 2011). A large number of studies acknowledged energy (both nonrenewable and renewable) as determinants of growth (Alam, Ahmed, & Begum, 2017; Arifin & Syahruddin, 2011; Bildirici, 2016; Bildirici & Özaksoy, 2018; Carmona, Feria, Golpe, & Iglesias, 2017; Cetin, 2016; Destek, 2017; Koengkan, 2018; Liu, Zhang, & Bae, 2018; Menegaki & Ozturk, 2016; Ohlan, 2016; Zafar, Shahbaz, Hou, & Sinha, 2019).

Apart from the studies above, Table 1 presents the list of some more studies on the determinants of economic growth.

3 | METHODOLOGY

This section outlines the variable specification, the econometric models, the estimation methods, and the data to be used in this research.

3.1 | Variables

The study uses panel data for exploring the dynamic relationship and the determinants of economic growth and carbon emissions in African economies. To furnish the purpose, the following variables are considered in this research based on the available empirical literature. Detailed definitions of all the variables in are Table A1. All variables except for FDM are transformed in natural logarithm to remove large and extreme value bias associated with the data used for the variables. Table 2, shows the list of variables considered and their proxies.

3.2 | Econometric model

Based on the variables selected, we begin with the following specifications that can estimate the interrelationship and the determinants of GDPPC and CO_2 emission:

$$\mathrm{GDPPC}_{\mathrm{it}} = \alpha + \sum_{j=1}^{p} \beta_j X_{\mathrm{it}} + \sum_{j=1}^{m} \delta_j CFE_{\mathrm{dum}\,j} + \sum_{j=1}^{n} \theta_j Y_j + \varepsilon_{\mathrm{it}} \quad (1)$$

$$\mathrm{CO2}_{\mathrm{it}} = \alpha + \sum_{j=1}^{p} \beta_j X_{\mathrm{it}} + \sum_{j=1}^{m} \delta_j CFE_{\mathrm{dum}\,j} + \sum_{j=1}^{n} \theta_j Y_j + \varepsilon_{\mathrm{it}} \quad (2)$$

where α denotes constant, *i* for country, *t* for year, X_{it} stands for the explanatory variables, β_j is coefficient of the individual independent variable, CFE_{dum} is country fixed-effect dummy, δ_j is coefficient for

TABLE 1 Summary of studies on the determinants of growth

Author	Country(s)/region	Duration	Method	Finding(s)
Radu (2015)	Central and Eastern European countries	1990–2010	Multivariate regression	Political indicators do not have a direct influence on growth
Vedia-Jerez and Chasco (2016)	10 South America countries	1960–2008	Sys-GMM	Human and physical capital drive growth
Lee and Hong (2012)	12 Asian economies	1981–2007	Growth accounting framework	Capital accumulation contributes more to growth than other factors
Mariana (2015)	Romania	1980–2013	VECM	Education increases growth
Leon-Gonzalez and Vinayagathasan (2015)	27 Asia countries	1980–2009	BMA	When inflation is greater than 5.43%, it impedes growth
Burney, Mohaddes, Alawadhi, and Al-Musallam (2018)	Kuwait	1979Q2–2013Q1	VAR	Oil revenue and technological progress drive growth
Inekwe, Jin, and Valenzuela (2019)	45 countries	1987–2011	Sys-GMM	Financial distress inhabits growth
Fraj et al. (2018)	50 countries	1996–2012	Sys-GMM	Governance cannot explain economic growth
Ihnatov and Sprincean (2015)	16 CEE countries	1990–2012	Sys-GMM	Intermediate and floating exchange rate significantly affect growth.
Smaoui and Nechi (2017)	Sukuk market	2005–2015	Sys-GMM	Development in Sukuk market encourages growth
Shahbaz, Zakaria, Shahzad, and Mahalik (2018)	10 countries	1960Q1–2015Q4	Quantile-on-Quantile regression	The association between growth and EUS was positive
Gozgor, Lau, and Lu (2018)	29 OECD	1990–2013	Panel quartile regression, ARDL	RE and NRE promote growth
Aydin and Esen (2018)	12 Commonwealth countries	1991–2013	Panel threshold analysis	Growth will be retarded if energy intensity exceeds 0.44% threshold
Aydın and Esen (2017)	5 Turkish republics	1991–2012	Panel threshold analysis	Energy consumption benefits economic growth
Arestis and Baltar (2019)	Brazil	1990–2014	GMM	Brazil economy ultimately depends on world economic growth
Akalpler and Hove (2019)	India	1971–2014	ARDL	EU, GFCC, CO_2, IM, EX affect growth
Emir and Bekun (2019)	Romania	1990–2014	ARDL	Discovered a feedback causality between economic growth and energy intensity

Note: Source: Authors' computations.
Abbreviations: ARDL, autoregressive distributed lag; BMA, Bayesian model averaging; CO_2, carbon emissions; EU, energy use; EX, export; GFCC, gross fixed capital consumption; GMM, generalized method of moment; IM, import; NRE, nonrenewable energy; RE, renewable energy; VAR, vector autoregressive; VECM, vector error correction model.

country fixed-effect dummy, Y captures time fixed effect by year dummy, and θ_j is coefficient for time fixed-effect dummy. The country fixed effects control for the heterogonous unobserved factors across the countries and the time (year) fixed effects (Y_j) to capture the time-trend effects over the years considered. Replacing the explanatory variables with necessary logarithmic forms, we reformulate the following models for estimations:

$$\ln GDPPC_{it} = \alpha + \beta_1 GCF_{it} + \beta_2 \ln T_{it} + \beta_3 \ln EUS_{it} + \beta_4 \ln CO2_{it} + \beta_5 FDM_{it} + \sum_{j=1}^{m} \delta_j CFE_{dum\,j} + \sum_{j=1}^{n} \theta_j Y_j + \varepsilon_{it} \quad (3)$$

$$\ln CO2_{it} = \alpha + \beta_1 \ln GDPPC_{it} + \beta_2 GCF_{it} + \beta_3 \ln T_{it} + \beta_4 \ln EUS_{it} + \beta_5 FDM_{it} + \sum_{j=1}^{m} \delta_j CFE_{dum\,j} + \sum_{j=1}^{n} \theta_j Y_j + \varepsilon_{it} \quad (4)$$

Equations (3) and (4) are estimated in this research using both the static and dynamic panel data estimators. However, Equations (3) and (4) could be misspecified in the current form and their straight estimations in this form could lead to inconsistent estimates, as many of the variables could be exposed to endogeneity bias. To deal with endogeneity, we introduce lags in the two equations for the necessary variables chosen based on the empirical literature. In Equation (1), GDPPC could be affected by its own lags and the lags of particularly gross capital formation (GCF), EUS, FDM, and CO_2; assuming that the effects of these four variables could take some time to reflect in the national economic performance, that is, the values of GDP. Hence, we consider a one-period (1 year) lag of GDPPC, GCF, EUS, FDM, and CO_2 in addition to their level data in Equation (3) for final estimation. In a similar approach, in Equation (3), CO_2 emission could be affected by its own lags and the lags of the explanatory variables, particularly of GDPPC, GCF, T, and EUS; assuming that a time lag is necessary to reflect the effects of these variables on CO2 emission. Therefore, to correct for endogeneity bias, we consider a one-period (1 year) lag of CO_2, GDPPC, GCF, T, and EUS in Equation (4) for final estimation. Considering the lags, Equation (3) and (4) can be rewritten as follows:

TABLE 2 List of variables selected

Variable	Rationale/proxy for
GDP per capita (GDPPC) in 2010 constant US$	To measure economic growth
CO_2 emission in kilo ton (kt)	Carbon emission, pollution, and environmental performance of at the national level
GCF as % of GDP	The level of aggregate investments in the economy
Trade (% of GDP)	The sum of import and export measured as a share of GDP
EUS (kg of oil equivalent per capita) (EUS)	The level of energy consumption in the economy
FDM as % of GDP	The degree of development, that is, access and depth, of the domestic financial sector

Note: Source: Author compiled.
Abbreviations: EUS, energy use; FDM, financial development; GCF, gross capital formation.

$$\begin{aligned} \ln GDPPC_{it} = \alpha + \beta_1 L1.\ln GDPPC_{it} + \beta_2 GCF_{it} + \beta_3 L1.GCF_{it} + \beta_4 \ln T_{it} \\ + \beta_5 \ln EUS_{it} + \beta_6 L1.\ln EUS_{it} + \beta_7 \ln CO2_{it} + \beta_8 L1.\ln CO2_{it} \\ + \beta_9 FDM_{it} + \beta_{10} L1.FDM_{it} + \sum_{j=1}^{m} \delta_j CFE_{dum\,j} + \sum_{j=1}^{n} \theta_j Y_j + \varepsilon_{it} \end{aligned} \quad (5)$$

$$\begin{aligned} \ln CO2_{it} = \alpha + \beta_1 L1.\ln CO2_{it} + \beta_2 \ln GDPPC_{it} + \beta_3 L1.\ln GDPPC_{it} \\ + \beta_4 GCF_{it} + \beta_5 L1.GCF_{it} + \beta_6 \ln T_{it} + \beta_7 L1.\ln T_{it} + \beta_8 \ln EUS_{it} \\ + \beta_9 L1.\ln EUS_{it} + \beta_{10} FDM_{it} + \sum_{j=1}^{m} \delta_j CFE_{dum\,j} + \sum_{j=1}^{n} \theta_j Y_j + \varepsilon_{it} \end{aligned} \quad (6)$$

3.3 | Estimation methods

We estimate Equations (5) and (6) using both static and dynamic panel data estimators. As the static estimation methods, we use panel FGLS regression and regression with Prais–Winsten PCSEs estimators. The PCSE and FGLS static estimators can mitigate disturbances that are heteroscedastic, serially correlated, and contemporaneously correlated across panels, and also can be implemented on both balanced and unbalanced panel data (Greene, 2012). As the dynamic method, we use one-step Sys-GMM proposed by Arellano and Bover (1995) and Blundell and Bond (1998). In the GMM approach, the lagged values of the dependent variable are used as instruments in addition to other control variables to account for the endogeneity bias. We prefer Sys-GMM over first-differenced GMM since the first-differenced method is not efficient when the sample size is small (Levine, Loayza, & Beck, 2000). In addition, Bond (2002) concluded that the first-differenced estimator may be biased if the data are not stationary, and higher accuracy of the estimation results can be achieved by using the Sys-GMM as the method uses a larger number of instruments and combines the regressions in the levels and in the first differences. Furthermore, the Sys-GMM is considered comparatively better since the instruments in the level equation are efficient

TABLE 3 Summary statistics

Variable	Obs	Mean	*SD*	Min	Max
$LNCO_2$	375	55,673.65	104,858.80	575.72	503,112.40
LNEUS	375	776.20	649.97	206.87	3,098.42
LNGDPPC	375	1,717.25	1,977.87	1.58	10,716.22
T	375	15,700.00	23,400.00	349.00	127,000.00
FDM	375	28.64	31.99	0.00	160.12
GCF	375	20.75	8.64	0.00	54.49
$lnCO_2$	375	9.52	1.69	6.36	13.13
Lneus	375	6.41	0.64	5.33	8.04
lngdppc	375	6.56	1.89	0.46	9.28
Lnt	375	22.54	1.43	19.67	25.57

Note: Significance level: ***1%, **5%, and *10%. Source: Authors' calculation.

TABLE 4 Estimations on economic growth

Explanatory variables (Equation (5)) DEP VAR: GDPPC	FGLS	PCSE	GMM
L1GDPPC	0.848*** (0.025)	0.872*** (0.039)	0.678*** (0.159)
GCF	−0.003*** (0.001)	−0.004** (0.002)	0.005 (0.006)
L1GCF	0.005*** (0.001)	0.006*** (0.002)	0.013** (0.005)
$LNCO_2$	0.023 (0.025)	0.052 (0.047)	−0.181 (0.131)
$L1LNCO_2$	−0.075*** (0.023)	−0.124*** (0.045)	−0.196* (0.109)
LNEUS	0.024 (0.059)	0.065 (0.097)	0.394** (0.147)
L1LNEUS	−0.093 (0.058)	−0.109 (0.094)	−0.052 (0.203)
FDM	0.002** (0.001)	0.002 (0.001)	0.003 (0.002)
L1FDM	−0.003*** (0.001)	−0.003** (0.001)	0.002 (0.005)
LNT	0.104*** (0.015)	0.098*** (0.028)	0.283** (0.114)
Constant	−0.439 (0.330)	−0.468 (0.615)	−3.372* (1.589)
R^2	–	.997	–
Prob > χ^2	–	0.000	0.000
No. countries	15	15	15
No. observations	360	360	360
AR (1)	–	–	−2.41**
AR (2)	–	–	−1.44
Sargan test	–	–	9.95
Hansen test	–	–	1.55
No. Instruments	–	–	13

Note: Significance level: ***1%, **5%, and *10%. Figures in parenthesis indicate HAC adjusted standard errors. Estimates for climate-zone fixed effects reported; however, for year fixed effects not reported.

predictors of the endogenous variables when the data time series follow a random walk process (Blundell & Bond, 1998). Therefore, we consider the following generic specification of the Sys-GMM models:

$$\vartheta_{it} = \alpha_i + \gamma\vartheta_{i,t-1} + \sum_{p=1}^{p}\beta_p Z^p{}_{it} + \sum_{q=1}^{q}\beta_q Z^q{}_{it} + \sum_{r=1}^{r}\beta_r Z^r{}_{it} + \sum_{j=1}^{m}\delta_j CFE_{dum\,j} + \sum_{j=1}^{n}\theta_j Y_j + \varepsilon_{it} \tag{7}$$

$$\tau_{it} = \alpha_i + \gamma\tau_{i,t-1} + \sum_{p=1}^{p}\beta_p Z^p{}_{it} + \sum_{q=1}^{q}\beta_q Z^q{}_{it} + \sum_{r=1}^{r}\beta_r Z^r{}_{it} + \sum_{j=1}^{m}\delta_j \mathrm{CFE}_{dum\,j} + \sum_{j=1}^{n}\theta_j Y_j + \varepsilon_{it} \text{and } \varepsilon_{it} = v_{it} + e_{it} \tag{8}$$

In the models above, ϑ_{it} and τ_{it} indicate GDPPC and CO_2, respectively, of the *i* African countries for *t* years; α_i is the constant term, and $\gamma\vartheta_{i,\ t-1}$ represents the lag value of GDPPC, Z_{it} is the predictor variables and error-term is ε_{it}. Like the static estimation, the Sys-GMM estimations also include the country fixed effects (CFE_{dum}) to control for the effects of heterogonous unobserved factors across the countries and the time (year) fixed effects (Y_j) to capture the time trend effects over the years considered. In addition, the unobserved growth specific factors and the idiosyncratic errors are v_{it} and e_{it}, respectively. According to Blundell and Bond (1998) and Bond (2002), the model also takes the following assumptions:

$$E(v_{it}, v_{is}) = 0 \text{ for } i = 1, \ldots N \text{ and } t \neq s.$$

$$\text{and } E(\vartheta_{it}, v_{it}) = 0 \text{ for } i = 1, \ldots N \text{ and } t = 2, \ldots T.$$

3.4 | Data

Data with no missing values for the variables specified in this research are considered for 15 African counties covering the period from 1990 to 2014; Table A2 presents the list of the African countries selected. All data are collected from the World Development Indicators database of the World Bank.

Panel data are generally subject to autocorrelation, heteroscedasticity, and cross-sectional dependence problems, in addition to possible multicollinearity bias. Ignoring these issues can seriously compromise the statistical inferences. To account for all these issues in the base Equations (3) and (4), modified Wald for heteroscedasticity test, Wooldridge test for autocorrelation, variable inflation factor (VIF) test for multicollinearity, and Pesaran's (2004)

TABLE 5 Estimation on CO_2 emission

Explanatory Variables (Equation (6)) DEP VAR: CO_2	FGLS	PCSE	GMM
L1LNCO$_2$	0.733*** (0.035)	0.733*** (0.057)	0.982*** (0.022)
GDPPC	0.074 (0.061)	0.074 (0.065)	0.023 (0.085)
L1GDPPC	−0.069 (0.062)	−0.069 (0.066)	−0.017 (0.081)
GCF	0.004* (0.002)	0.004 (0.003)	0.001 (0.003)
L1GCF	−0.001 (0.002)	−0.001 (0.003)	−0.001 (0.003)
LNT	0.127*** (0.036)	0.127*** (0.036)	0.076*** (0.023)
L1LNT	−0.027 (0.036)	−0.027 (0.037)	−0.058*** (0.018)
LNEUS	0.187 (0.122)	0.187 (0.148)	0.101 (0.192)
L1LNEUS	−0.136 (0.113)	−0.136 (0.127)	−0.108 (0.197)
FDM	−(0.001) (0.001)	−0.000 (0.001)	−0.000 (0.000)
Constant	−0.423 (0.616)	−0.423 (0.758)	−0.132 (0.308)
R^2	–	.995	–
Prob > F	–	0.000	0.000
No. countries	15	15	15
No. observations	360	360	360
AR (1)	–	–	−2.22**
AR (2)	–	–	−1.13
Sargan test	–	–	0.11
Hansen test	–	–	0.60
No. instruments	–	–	12

Note: Significance level: ***1%, **5%, and *10%. Figures in parenthesis indicate HAC adjusted standard errors. Estimates for climate-zone fixed effects reported; however, for year fixed effects not reported.

cross-sectional dependence tests are implemented. Results for these diagnostic checks reported in Table A3 suggest that the data have significant levels of heteroscedasticity, autocorrelation, and cross-sectional dependence. The VIF stat and the correlation matrix in Tables A3 and A4 showing the general level of relationships among the variables also rules out the possibility of the existence of multicollinearity, following O'Brien (2007). Considering these results, the estimations of the equations are carried out with necessary adjustments.

3.5 | Data summary

Table 3 reveals the average value of carbon emission to be 55,673.65 metric tons per capita (mtpc) with Togo having the lowest average emission of 820.21 (mtpc) for the periods 1990–1994. The highest average, for the countries considered, was recorded by South Africa with 473,920.15 (mtpc) for the period 2010–2014. The *SD* of 104,858.80 shows a huge deviation from the sample means. For energy consumption, Senegal recorded the lowest average EUS of (216.16 kg) for the period 1990–1994. South Africa recorded (2,735 kg) which was the highest average for the period 2005–2009. Also, a wide variation in energy used (649.97 kg) and per capita GDP ($166.72) occur across the countries in the sample. Table 3 presents the descriptive statistics of all the variables, including their logarithm form.

4 | RESULTS AND DISCUSSION

Tables 4 and 5 present the FGLS, PCSE, and Sys-GMM) estimation results for Equations (5) and (6) with GDP per capita and CO_2 emission as the dependent variables, respectively. The estimations utilize a total of 360 observations for the 15 countries included. All estimates include country fixed effects and time; however, their parameter estimates are not reported. The R^2 value from the PCSE estimation is .997, suggesting a high explanatory power of the model specified. In the Sys-GMM estimation, the number of instruments is less than the number of countries, ensuring that the estimates are not weakened by too many instruments. As the variables of interest, the following discussion on the estimates focuses on CO_2 emission and EUS first and then explains the other variables.

Results in Table 4 suggest that CO_2 has no significant contemporaneous effect; however, a significant and negative effect at a one-period lag on GDP per capita. The significance of the impacts is consistently confirmed by both static and dynamic estimations. Results suggest that a 1% increase in CO_2 emission reduce economic growth at a one-period lag by about 7.5, 12.4, and 19.6% according to the FGLS, PCSE, and Sys-GMM, respectively. A one period lag would mean increases in CO_2 emission will reduce economic growth a year after for the African economies considered. These results are reasonable as CO_2 emission is not expected to have instantaneous effects and could take time to have its effect reflected on the environment (e.g., pollution, warming, and diseases) which in turn lead to negative response from resources productivity and investment behavior of economic agents. The evidence on the negative impacts of CO_2 emission on economic growth in the African economies is consistent with the previous literature (e.g., Akadiri, Bekun, Taheri, & Akadiri, 2019; Al-Mulali & Sab, 2012; Alshehry & Belloumi, 2015; Bekun, Emir, & Sarkodie, 2019; Ghosh, 2010; Kivyiro & Arminen, 2014; Menyah & Wolde-Rufael, 2010).

Results show that increases in EUS has a significant and positive effect on economic growth at a one period lag according to the Sys-GMM estimations. The result suggests a substantially large effect; a 1% increase in EUS reduces economic growth at a one-period lag by about 39.4%. This result indicates the hefty role of energy availability and use as a key driver of economic growth of the African economies, as suggested by the past studies (e.g., Bayat, Tas, & Tasar, 2017; Bekun & Agboola, 2019; Fatai, 2014; Fotourehchi, 2017; Hasanov, Bulut, & Suleymanov, 2017; Kahouli, 2018; Narayan, 2016).

Results further suggest GCF has a significant effect on economic growth; however, the effects appear to be negative at level but positive at a one period lag. While the one-period lag positive lag effects are consistently confirmed by both the static and dynamic estimators, the negative effect at level is suggested only by the static estimators. Results suggest that a 1% increase in capital formation increases economic growth by about 0.5, 0.6, and 1.3% according to the FGLS, PCSE, and Sys-GMM estimations, respectively. These results would indicate that increases in capital formulation in a certain year encourage economic growth in the following year for the African economies. This is plausible as increases in capital investment could take time to have impacts on production, employment, and markets. However, the results further suggest a concurrent negative effect in economic growth, which is possible when investments are not directed toward the necessary productive sectors rather dilutes markets and prices.

FDM appears to have a significant effect on economic growth, as suggested by the two static estimations. There is a sign of a positive concurrent effect; however, a negative one lag period effect. The differential effects of FDM on economic growth is evidenced by the past literature (e.g., Ahmed, 2017; Assefa & Mollick, 2017; Ghirmay, 2004; Hassan, Sanchez, & Yu, 2011; Kar, Nazlıoğlu, & Ağır, 2011; Nyasha & Odhiambo, 2017; Omri, Daly, Rault, & Chaibi, 2015; Sassi & Goaied, 2013; Uddin, Sjö, & Shahbaz, 2013; Wang, Li, Abdou, & Ntim, 2015).

Results further show that trade openness has a significant and positive effect on economic growth, consistently confirmed by all three estimators. A 1% increase in trade openness reduces economic growth by about 10.4, 9.8, and 28.3% according to the FGLS, PCSE, and Sys-GMM estimations, respectively. These results show the substantially influential role of trade in fostering economic growth for the African economies. International trade has been a key driver of economic growth for Africa, as evidenced by the previous literature (e.g., Gries, Kraft, & Meierrieks, 2009; Menyah, Nazlioglu, & Wolde-Rufael, 2014; Sakyi, 2011).

Findings from the results in Table 5 reveal that all the estimation techniques are in harmony. The result affirms that trade openness significantly increases CO_2 emission contemporaneously in African countries. A 1% increase in trade openness could lead to an increase of CO_2 emission by 7.6–.7%, as suggested by the different estimations produced. Results also show that other variables such as growth, and FDM have no significant effect on CO_2 emission. Energy consumption adds to environmental degradation infinitesimally as confirmed by the three models. These results overall suggest the pivotal role of economic or trade openness in driving up pollution in the African nations; among the macroeconomic factors, it is trading activities that significantly increase emission in these countries. This goes to show that openness to trade in Africa adds to environmental deterioration. The continent's trade is at a cost to the environment. However, the components of the trade of the continents with the outside world, which is predominantly capital goods, are by no way helping the environment. Results further show limited significant and positive impact of GCF (our proxy for investment). A 1% increase in GCF could lead to a 0.4% increase in CO_2 emission, as suggested by FGLS estimation. The result confirms the potential contribution of capital investments in driving up pollution in the African nations.

5 | CONCLUSION AND POLICY DIRECTIONS

This study investigated the interrelationship between economic growth and CO_2 emissions in Africa. The study relied on data spanning 1990–2014 and provided from both static and dynamic models. Our findings are in support of the energy-led growth hypothesis for Africa. We discovered that EUS adds to economic growth. Africa's energy mix is largely nonrenewable. Nonrenewable energy increases emissions thereby reducing environmental quality (Balsalobre-Lorente, Driha, Bekun, & Osundina, 2019; Bekun, Emir, & Sarkodie, 2019; Nathaniel, 2019; Nathaniel & Iheonu, 2019). Therefore, for environmental sustainability, which is in line with the SDG 7, there is a need for the adoption of renewable energy sources like tidal power, biogas, geothermal, solar, wave power, and so forth. These energy sources are actually low in emissions and can make growth sustainable. Some selected Africa countries have invested in these clean energy sources, but these investments have yielded very little or no impact at all on the environmental wellness in the continent. Just as Nathaniel and Iheonu (2019) have suggested, the institutions in Africa are weak, and needs strengthening. Strong institutions can curtail harmful trade, promote FDM, and improve economic growth. Since no country can survive in a vacuum, the need for trade is sacrosanct. However, since our findings have confirmed the horrendous effects of trade on the environment, the expansion of trade in the continent should be carried out with utmost diligence. A greater openness to trade can add to byproducts which will increase environmental pressure, cumulating to lower environmental quality. Perhaps, with the SDGs in sight, policymakers in these countries can do more in terms of adopting clean energy sources and strengthening of the already weak institutions. The continent should be involved in the importation of environmentally friendly technologies to aid production rather than concentrating on technological equipment that enhances emissions thereby encouraging environmental deterioration.

Strong institutions can regulate imports, and clean energy sources can encourage energy efficiency. Policymakers should also concentrate on the development of the financial sector in Africa. This sector suffers from inadequate financing amid internal and external macroeconomic shocks. An efficient financial sector can enhance economic growth and make it sustainable.

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How to cite this article: Nathaniel S, Barua S, Hussain H, Adeleye N. The determinants and interrelationship of carbon emissions and economic growth in African economies: Fresh insights from static and dynamic models. *J Public Affairs*. 2020; e2141. https://doi.org/10.1002/pa.2141

APPENDIX

TABLE A1 Definition of the variables used

Notation	Variable name	Definition
GDPPC	GDP per capita (in constant $2010)	This is the ratio of GDP to the total population
CO_2	CO_2 emission in kilo ton (kt)	EUS refers to use of primary energy before transformation to other end-use fuels, which is equal to indigenous production plus imports and stock changes, minus exports and fuels supplied to ships and aircraft engaged in international transport
GCF	GCF as % of GDP	Annual gross capital formation based on constant $2010. GCF consists of outlays on additions to the fixed assets of the economy plus net changes in the level of inventories
T	Trade (% of GDP)	The sum of import and export measured as a share of GDP
EUS	in kg of oil equivalent per capita	It encompasses primary energy before transformation to other end-use fuel
FDM	Financial development	Financial sector development is a set of institutions and markets in addition to a regulatory and legal framework that allows transactions to be made by given credit, particularly to the private sector

Note: Source: Author compiled.

TABLE A2 List of countries considered in the research

Algeria	Morocco
Cameroon	Nigeria
Congo rep	Senegal
Egypt	South Africa
Ethiopia	Sudan
Gabon	Togo
Ghana	Tunisia
Kenya	

Note: Source: Author compiled.

TABLE A3 Diagnostic checks for Equations (3) and (4)

Tests and reported statistics	Heteroscedasticity Modified Wald test (χ^2 statistic)	Autocorrelation Wooldridge test (*F* statistic)	Cross-sectional dependence Pesaran (2004) CD test	Multicollinearity VIF test (mean VIF)
Equation (5)	703.02***	81.241***	−2.894***	1.55
Equation (6)	1831.28***	58.919***	−1.249	1.49

Note: Significance level: ***1%, **5%, and *10%.
Note: Source: Author compiled.

TABLE A4 Correlation matrix

	lnCO_2	lnEUS	lnGDPPC	lnT	FDM	lnGCF
lnCO_2	1.000					
lnEUS	0.584	1.000				
lnGDPPC	−0.063	0.282	1.000			
lnT	0.873	0.559	0.139	1.000		
FDM	0.627	0.521	0.171	0.521	1.000	
lnGCF	0.130	0.086	0.345	0.301	0.038	1.000

Note: Source: Author compiled.