Scientific African 26 (2024) e02362

Contents lists available at ScienceDirect

Scientific African

journal homepage: www.elsevier.com/locate/sciaf

Energy efficiency and greenhouse gas emissions: A panel ARDL model of top five emitters in Africa

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A R T I C L E I N F O

Editor: DR B Gyampoh

Keywords:
Decarbonization
Energy utilization efficiency
Environmental quality
Sustainability
Renewable energies
Africa

A B S T R A C T

The Paris Agreement has mandated drastic decarbonization by developed and developing economies. Many of the top African emitters are now exploring drastic restructuring of the production processes in a way that promotes energy utilization efficiency. This is critical for ensuring an environmentally benign growth process. This study presents a unique addition to the body of existing knowledge by analysing the effect of some indicators of energy efficiency on three indicators of environmental quality among the top five emitters of GHG in Africa. The data were from the World Development Indicators (WDI), covering the 1990–2020 periods for South Africa, Egypt, Nigeria, Algeria, and Libya. The panel Autoregressive Distributed Lag (ARDL) model was used for data analysis. The results showed that all the included series were stationary at first difference. The optimum lag lengths were determined independently in STATA 17 software, and the most frequent lags across the countries were selected. The Hausman test revealed that the pooled mean group (PMG) estimation was preferred to other estimators. The results showed that in the long-run, particulate emission damages, CO_2 intensity, and energy use intensity positively impacted GHG emissions, while GDP per capita and renewable energy utilization produced mixed results. In the short run, the error correction mechanism parameters were all significant ($p < 0.01$) in Libya for all emission indicators, while Algeria showed significance ($p < 0.01$) in total GHG and CO_2 per capita models. The coefficient of particulate emission damages significantly reduced ($p < 0.01$) total GHG emissions in Libya and Nigeria and renewable energy significantly increased ($p < 0.01$) GHG emissions in South Africa but reduced them in Nigeria. Also, CO_2 emission intensity significantly ($p < 0.01$) and positively impacted GHG emissions in South Africa, Egypt, Libya, and Nigeria, while electricity power transmission losses increased total emissions and CO_2 emissions in Libya and Algeria. It was concluded that initiatives to reduce GHG emissions should focus on developing countries' sensitivity to emission damages, and promotion of initiatives for using renewable energies. Also, promotion of energy efficiency across industries offers a prospect for ensuring environmental sustainability.

Introduction

Climate change is a global development challenge that disproportionately affects developed and developing economies. Although developing economies are the least contributors to global emission of greenhouse gases (GHGs), they are going to be worst affected by their consequences. Periodic manifestation of several environmental hazards in the form of droughts, floodings, heat waves, wildfires,

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https://doi.org/10.1016/j.sciaf.2024.e02362
Received 30 April 2024; Received in revised form 9 August 2024; Accepted 13 September 2024
Available online 15 September 2024

cyclones, and hurricanes are confirmations that some drastic steps are needed to reduce GHG emissions [1,2]. The Paris Agreement has emphasized rapid decarbonization for the long-term reduction in global warming. This Agreement mandates signatory countries to come up with some comprehensive GHG emission reduction pathways in a Nationally Determined Contribution (NDC) (United Nations Framework Convention on Climate Change, undated). Therefore, the current commitment of world's leaders towards the Paris Agreement reflects the seriousness of the problem [3].

In Africa, the consequences of climate change are manifesting in the form of droughts, flooding, and severe heat waves with significant socioeconomic consequences. Although Africa is among the least emitters of GHG in the world, the continent is not shielded from the negative consequences of emissions. Specifically, in 2022, the Asia-Pacific region emitted 17.96 billion metric tons of carbon dioxide (CO_2), which was higher than the amount emitted by the combination of other continents [4]. Africa was the second least emitter with 1307 million metric tonnes of CO_2 [4]. A drastic reduction in Africa's CO_2 emissions requires specific focus on the top emitters, among which South Africa, Egypt, Nigeria, Algeria, and Libya are notable. Specifically, South Africa is the topmost GHG emitter and the most industrialized economy in Africa. With fourteenth global emission ranking, GHG emission reduction is one of the major agendas of the South African government [5]. Similarly, there is a perplexing inequity in CO_2 emissions within Africa, with South Africa, Egypt, and Algeria accounting for >60 percent of the continent's total GHG emissions [6].

Therefore, among their African counterparts, the challenge of decarbonization for absolute mitigation of climate change directly rests on some African countries. Specifically, as the highest emitter of GHGs in the continent (International Monetary Fund [7], South Africa, Egypt, Algeria, Nigeria, and Libya have some absolute responsibilities to address their economic development plans, vis-a-vis the global challenge of decarbonization. In a bid to ensure compliance with the Paris Agreement, the South African Government has come up with a NDC, which seeks to reduce GHG emissions to 350–420 $MtCO_2e$ by 2030 (IMF, undated). The Egyptian government has also developed a revised NDC, which seeks to reduce emissions from electricity, oil and gas and transportation by 37 %, 65 %, and 7 %, respectively, by 2030. Similarly, the Egyptian government projected that total electricity generation from renewable sources is expected to be 42 % of total energy consumption by 2035 United Nations Development Programme [8].

On Nigeria's part, the government plans to increase renewable energy composition in total energy utilization to 36 % by 2030 [7, 9]. In accordance with the Paris Agreement, the country's NDC seeks an end to gas flaring by 2030, and reduce methane emissions by 60 % in 2031 [10,11] . The country will therefore conditionally and unconditionally reduce GHG emissions by 47 % and 20 %, respectively, in 2030 [12]. The Algerian government plans to reduce gas flaring to <1 % by 2030 and ensure that 27 % of total electricity is generated from renewable sources [13]. Furthermore, Libya seeks to reduce emission of GHG through increase in the renewable energy to 10 % of the total energy generation by 2025 [14].

Moreover, decarbonization portends some negative economic consequences for many African countries. Specifically, South Africa heavily relies on coals and fossil fuels for energy generation, while Nigeria, Egypt, Algeria, and Libya depend heavily on fossil fuels. Therefore, some basic initiatives for promoting energy utilization efficiency to ensure attainment of the global decarbonization agenda is imperative. This calls for a clearer understanding of the effect of initiatives for the promotion of energy utilization efficiency on emission of GHGs among top GHG emitters in Africa. Although there is a growing body of studies on the energy-GDP nexus in various regions of the world [15–19], only few studies have focused specifically on the top GHG emitters in Africa.

More importantly, this study demonstrates significant uniqueness by providing some policy relevant analyses on the linkages between some indicators of energy utilization efficiency and three distinct indicators of environmental quality, which are total emission of GHG (kt of CO_2 equivalent), CO_2 emissions (kt), and per capita CO_2 (metric ton per capita) in Africa's top five emitters. Specifically, the introduction of alternative energy sources and technological innovations to facilitate reduction in energy consumption and gradual offset of people's dependence on coals and fossil fuels has been a welcomed but very challenging development initiative. In the remaining parts of this paper, literature review, methodology, results and discussion and conclusion are presented in the given order.

Literature review

Energy is one of the primary drivers of economic growth in developed and developing countries. It is also the primary source of GHG emissions. Therefore, initiatives to promote efficiency in energy utilization is a major step towards reduction of GHG emissions [20]. Energy efficiency connotes usage of less than usual energy in the production of goods and delivery of services. The gains from energy efficiency can include environmental conservation through lesser emission of GHGs, less utilization of fossil fuel, and economic competitiveness due to reduction in production cost of goods and services [21]. Therefore, there is now a growing interest among scholars on studies that explore the impacts of energy utilization efficiency on the promotion of global decarbonization initiatives.

Applied econometric modelling has dominated the strand of studies on the relationships between energy efficiency and air pollution abatement. However, some other studies chose the non-parametric approach such as life cycle analysis [22], scenario-based analysis [23], and simulation [24]. It had been unanimously found that reduction of GHG emissions results from energy efficiency. Parametrically, some indicators of energy utilization efficiency had been constructed in literature. These include CO_2 emissions per dollar equivalent of GDP (carbon intensity), CO_2 intensity (kg per kg equivalent energy use), per capita CO_2, and percentage increase in renewable energy utilization (Global Leaders for Tomorrow Environment Task Force [25]TF] of World Economic Forum, 2005; [26]). These indicators define the compliance of current economic activities to the trajectory requirements of environmental sustainability as emphasized in the seventh Sustainable Development Goal (SDG).

In some empirical analyses, the effects of some indicators of energy efficiency on GHG emissions had been analysed. Although Brookes [27] reported that promotion of energy efficiency significantly influenced economic growth, its impact on decarbonization was not significant. Using data from Turkey, Say and Yücel [28] found an association between total energy consumption and GHG emissions using a regression analysis. Although a very high coefficient of determination was reported, inability to subject the variables to stationarity and cointegration tests could have significantly biased the results. Using the 1960–2007 data for China, Zhang and Cheng [29] estimated some robust multivariate econometric models using the Granger causality method. They reported a long run unidirectional Granger causality that proceeded from GDP to energy consumption and from energy consumption to GHG emissions.

Ahmed and Long [30] tested the presence of Environmental Kuznets Curve (EKC) in Pakistan and concluded that energy utilization and growth of GDP promoted emission of GHGs in Pakistan. Özbuğday and Erbas [31] used a common correlated effects (CCE) estimator that shows consistency in the presence of heterogeneity and contemporaneous panel correlation to analyse the long-run effect of energy utilization efficiency on emission of CO_2. It was found that CO_2 emissions reduced with replacement of non-renewable energy by renewable energy. Heryadi and Hartono [32] concluded that utilization of renewable energy and energy efficiency had negative impact on GHG emissions.

Intensity of energy utilization was the indicator of energy efficiency used in some studies. Dong et al. [33], Krozer [34], and Li [35] found that reduction in the intensity of energy utilization will reduce emission of CO_2. Zhou et al. [36] also found that using the Vector Error Correction Model (VECM), energy efficiency reduced emission of GHGs in China. Liobikienė and Butkus [37] concluded the existence of complex relationship between economic activities and environmental degradation. It was found that while energy efficiency reduced GHG emissions in the agricultural and industrial sectors, the effect of renewable energy was declining. Several other studies have symmetrically corroborated the negative impact of energy efficiency on GHG emissions [38,39], while some used trend analysis [40,41].

Sarkodie and Strezov [17] focused on the top global GHG emitters - China, India, Iran, Indonesia and South Africa – and found that using the 1982–2016 data, GHG emissions were significantly influenced by energy consumption. Moreover, they confirmed the presence of EKC for China and Indonesia, and a U-shape relationship was found for India and South Africa. Akram et al. [42] used the panel ordinary least squares and fixed-effect panel quantile regression (PQR) to analyse the effects of renewable energy, energy efficiency, and some other variables on carbon emissions in 66 developing economies using the data covering 1990–2014. The results showed that carbon emissions reduced by energy efficiency across all the quantiles.

Awodumi and Adewuyi [16] focused on oil producing countries in Africa and analysed the effect of non-renewable energy on economic growth and GHG emissions with dataset covering the 1980–2015 periods. The non-linear autoregressive distributed lag (NARDL) was used. The results emphasized that except in Algeria, there were asymmetric impacts of per capita petroleum and natural gas consumption on economic growth and per capita GHG emissions. More specifically, consumption of non-renewable energy promoted growth in Gabon, Egypt and Angola, and reduce GHG emissions in Nigeria and Gabon.

Mahapatra and Irfan [43] examined the asymmetric shock transmission of energy efficiency to emission of GHGs in selected developed and developing countries for the 1990–2017 period. The nonlinear Panel ARDL model was used, and the results showed a heterogenous long-run asymmetric response of CO_2 emission by energy efficiency. The results further indicated a long-run reduction in emission of GHGs due to positive energy-related shocks. Ali et al. [15] also found that in South Africa, a NARDL analysis of the determinants of environmental quality showed that in the renewable energy consumption improved environmental quality in the short and long run, while positive oil price shock promoted environmental degradation. However, positive gold price shock promoted environmental quality.

Shaari et al. [44] used the panel ARDL model to analyse the effects of economic growth and renewable energy consumption on CO_2 emissions in some countries that were classified by per capita income for the 1990–2017 periods. It was found that renewable energy reduced CO_2 emissions in the long run, while population and economic growth rates promoted emissions. The short run parameters indicated an environmental degrading impact of economic growth, while population growth and renewable energy utilization enhanced environmental quality. Sidker et al. [18] used the panel ARDL approach to analyse the determinants of CO_2 emissions in 23 developing economies across the world. The results indicated that in the long-run, CO_2 emissions increased with increase in industrialization, urbanization, economic growth and energy use. There was adjustment to long run equilibrium distortion at 0.19 %.

Jahanger et al. [45] analysed the effects of renewable energy and technology on carbon emissions in top ten manufacturing countries in the world. The results showed a significant positive contribution of the manufacturing sector to greenhouse gas emissions, but an interaction of energy efficiency with the manufacturing sector reduced emissions. Wang et al. [19] used the decoupling approach to build an inventory of energy-related CO_2 emissions for 19 countries in Africa. It was found that for most African countries, there has been progressive growth in CO_2 emissions, although South Africa and Tanzania had reversed the trend. Population and

Table 1
Selected variables and descriptive statistics.

Variable	Mean	Std dev	Minimum	Maximum	N
Total emission of GHG (kt of CO_2 equivalent)	251,408.2	127,269.4	70,056.86	555,409.3	155
CO_2 emissions (kt)	152,584.3	116,380.5	26,342.3	448,298.1	155
Per capita CO_2 (metric ton per capita)	4.222229	3.056828	.491376	9.985813	155
Adjusted savings: particulate emission damage (current US$)	2.29e+09	3.52e+09	8.65e+07	1.53e+10	155
Per Capita GDP (current US $)	4025.27	3046.005	494.1292	15,765.42	155
Renewable energy consumption (%)	21.49052	32.17909	.06	88.68	155
CO_2 intensity (kg per kg of oil equivalent energy use)	2.406893	.7574867	.6664634	3.341033	125
Electric power transmission and distribution losses (% of output)	18.32685	12.3474	5.865399	69.69601	125
Electric power consumption (kWh per capita)	1756.436	1534.493	74.14613	4766.652	125
Energy use (kg of oil equivalent per capita)	4,371,692	6,818,902	0	2.27e+07	155

economic activities were the major drivers of CO_2 emissions, while energy intensity reduced them, Although the adopted methodology is new and robust for sectoral aggregation of emissions, the major limitation was the utilization of constant emission factor for every type of fossil fuel.

Methodology

Data sources

The data for this study were obtained from the WDI database [46]. The data were for Egypt, South Africa, Nigeria, Algeria, and Libya. The study covered the 1990–2020 periods. The selected variables and their units of presentation are presented in Table 1. The Table shows that for the five countries, average annual total emission of GHG was 251,408.2 kt of CO_2 equivalent. The average annual per capita emission of CO_2 was 152,584.3 kt, while the average annual per capita CO_2 was 4.22 tne. Average annual particulate emission damage was 2294,178,638 and average annual percentage renewable energy usage was 21.49.

Empirical model

Following Shaari et al. [44] and Sidker et al. [18], and Adeleye et al. [47], this study used the panel Auto-Regressive Distributed Lagged (ARDL) model. The estimated model is specified according to Adeleye et al. [47] as:

$$Y_{it} = \sum_{j=1}^{p} \alpha_i Y_{i,t-j} + \sum_{j=0}^{q} \beta_{ij} X_{i,t-j} + \theta_i + \epsilon_{it} \tag{1}$$

Y_{it} is the dependent variable, $X_{i,t}$ is a kx1 vector of independent variables that are I(0) or I(1), α_i is the coefficient of the lagged dependent variable, β_{ij} are the coefficients of the independent variables, θ_i is the unit specific fixed effect and ϵ_{it} is the error term.

The estimated Error Correction Model (ECM) ARDL is specified based on Adeleye et al. [47] as:

$$\Delta Y_{it} = \sum_{j=1}^{p-1} s_i \Delta Y_{i,t-j} + \sum_{j=0}^{qi1} k_{ij} \Delta X_{i,t-j} + \vartheta i ECT + \theta_i + \epsilon_{it} \tag{2}$$

ECT is error correction term $= Y_{it-1} - \gamma_i X_{it}$, ϑi is the group specific speed of adjustment coefficient ($\vartheta i < 0$), s_i and k_{ij} are the short run dynamic coefficients, γ_i is a vector of long run coefficients. The Y_{it} and X_{it} are presented in Table 1. Table 1 shows the nature of the indicators of energy efficiency that were included in the model which are: renewable energy consumption (%); CO_2 intensity (kg per kg of oil equivalent energy use); electricity power transmission and distribution losses (% of output); electricity power consumption (kWh per capita) and energy use (kg of oil equivalent per capita). The other variables which were added to avoid any specification error are particulate emission damage (current US$) and per capita GDP.

Results of data analysis

Tests for unit root

The results of the tests for unit root are presented in Table 2. The results showed that except CO_2 intensity, all the variables were not stationary at level. However, they were all stationary at first difference. This implies that the variables were either I(0) or I(1). This is the basic requirement for using ARDL model.

Table 2
Results of the tests for stationarity.

Dependent variables	Z-t-tilde-bar		Stationarity Level;
	Level Data	1st Difference	
Total emission of GHG (kt of CO_2 equivalent)	0.1951	−6.070***	I(1)
CO_2 emissions (kt)	0.0125	−5.815***	I(1)
Per capita CO_2 (metric ton per capita)	0.2690	−5.946***	I(1)
Adjusted savings: particulate emission damage (current US$)	−1.2433	−6.2460***	I(1)
Per Capita GDP (current US $)	−0.7741	−5.6506***	I(1)
Renewable energy consumption (%)	−0.8698	−6.2226***	I(1)
CO_2 intensity (kg per kg of oil equivalent energy use)	−1.8801**	−6.0525***	I(0)
Electric power transmission and distribution losses (% of output)	−1.6321	−6.5248***	I(1)
Electric power consumption (kWh per capita)	0.7499	−5.2457***	I(1)
Energy use (kg of oil equivalent per capita)	0.5302	−6.5494***	I(1)

Note:.
** statistically significant at 5 % level.
*** statistically significant at 1 % level.

Results of Hausman test and estimated panel ARDL regression

The Hausman tests were conducted on the mean group (MG), pooled mean group (PMG), and dynamic fixed effect (DFE) models. The results were unanimously in favour of PMG estimator. Therefore, the PMG estimator was used in this study. The results in Table 3 show the short-run and long-run parameters of the pooled regression. Table 3 shows that the long run parameters of renewable energy are statistically significant ($p < 0.01$) with negative and positive signs in the total GHG and CO_2 emissions models, respectively. The results showed that in the long run, a 1 % increase in the renewable energy will reduce total GHG emissions by 0.3958 % but increase CO_2 emissions by 0.0780 %.

In Table 4, the parameters of renewable energy utilization were positive and statistically significant ($p < 0.05$) in South Africa for total GHG emission and CO_2 emissions. These results indicated that in the short run, a 1 % increase in renewable energy utilization will increase total GHG emission and CO_2 emissions by 0.0331 % and 0.0355 %, respectively. Similar result was obtained for Libya, where a 1 % increase in renewable energy utilization significantly increase ($p < 0.01$) total GHG emissions by 0.3457 % in the short run. However, in Nigeria, renewable energy utilization significantly reduced ($p < 0.01$) CO_2 emissions and CO_2 emissions per capita. These results showed that in the short run, a 1 % increase in the utilization of renewable energy will reduce CO_2 emissions and CO_2 emissions per capita by 2.7435 % and 2.2238 %, respectively.

The world leaders have been advised to embrace utilization of energy from renewable sources as a way of combatting climate change and other problems that are associated with GHG emissions [48]. This follows Intergovernmental Panel on Climate Change (IPCC) [49] report which highlighted crucial role of renewable energies to ensure drastic reduction in the GHG emissions [50]. The results showed some rays of hope for Africa's reduction of GHG emissions, given that the long-run parameter for total GHG emissions is with negative sign. At the country level, however, only Nigeria reported negative association between renewable energy utilization of some indicators of carbon emissions. This finding is in tandem with findings of some researchers such as Adeleye et al. [47], Yuaningsih et al. [51], Abbasi et al. [52], Mehmood et al. [53], Nguyen and Kakinaka [54] and Bölük and Mert [55]. Similarly, Karimi et al. [56] found that utilization of renewable energy will increase economic growth in Iran.

Table 3 shows that the long run CO_2 intensity (kg of CO_2 per kg of oil equivalent) parameters are all with positive sign and statistically significant ($p < 0.01$). These parameters imply that in the long run, a 1 % increase in CO_2 intensity will lead to 0.8792 %, 1.8197 % and 0.6982 % increase in total GHG emissions, CO_2 emissions and CO_2 emissions per capita, respectively. Table 4 further shows the short run parameters of CO_2 intensity. The results showed that in the short run, a 1 % increase in CO_2 intensity will increase Egypt's total GHG emissions and CO_2 emissions by 0.4651 % and 0.8226 %, respectively. Similar results were found for South Africa where in the short run, a 1 % increase in CO_2 intensity will significantly increase ($p < 0.01$) total GHG emissions and CO_2 emissions by 0.7282 % and 0.9656 %, respectively. In Nigeria, in the short run, a 1 % increase in CO_2 intensity will significantly increase ($p < 0.01$) total GHG emissions. Also, in Libya, a 1 % increase in CO_2 intensity will in the short run significantly increase ($p < 0.05$) CO_2 emissions and CO_2 emissions per capita by 0.4741 % and 0.5954 %, respectively. However, the results showed that in Libya, a 1 % increase in CO_2 intensity will reduce total GHG emission by 0.3126 % and will reduce CO_2 emissions in Algeria by 0.3341 %.

The results overwhelmingly connote the positive association between CO_2 intensity and GHG emissions. These findings are in accordance with the findings by some authors such as Abbasi et al. [57] who reported a positive association between CO_2 emission per capita and CO_2 intensity in Turkey. Other scholars with similar findings are Chang et al. [58] who reported that CO_2 emissions had negligible effect on CO_2 emissions. Kirikkaleli et al. [59] found that in the long run, there existed a significant relationship between

Table 3
Pooled mean group estimators for the five countries.

	Coefficient Total GHG Emissions (CO_2)	z-stat	Coefficient CO_2 Emission	z-stat	Coefficient CO_2 Per Capita Emission	z-stat
Long-run parameters						
Particulate emission damage	.3608***	10.87	.2200	1.64	.0346***	2.72
Per capita GDP	−0.2747***	−8.89	−0.2911**	−2.48	−0.0172	−1.49
Renewable energy	−0.3958***	−9.00	.0780***	3.36	−0.0222	−1.23
CO_2 intensity	.8792***	6.62	1.8197***	6.27	.6982***	21.88
Electricity power losses	−0.1682***	−10.68	−0.0600	−0.91	−0.0019	−0.47
Electricity consumption per capita	.3858***	11.82	.6665***	13.30	.0627***	4.51
Energy use	1.0804***	8.86	1.5731***	7.41	.8687***	48.22
Short-run parameters						
ECT	−0.2453	−1.13	−0.1685	−1.51	−0.4865	−1.85
D1.Particulate emission damage	−0.1080	−1.83	−0.0815	−0.92	−0.0562	−1.93
D1.Per capita GDP	0.0761	1.72	.0878	0.90	.0452	1.37
D1.Renewable energy	.0311	0.31	−0.5648	−1.04	−0.4576	−1.04
D1.CO_2 intensity	0.2841	1.66	.4145	1.76	.3536	1.64
D1.Electricity power losses	.0670	1.10	.0238	1.81	.0133	1.54
D1.Electricity consumption per capita	.0375	0.56	−0.0872	−1.57	−0.0334	−0.61
D1.Energy use	.5606***	4.61	.6886***	3.20	.4831	1.76
Constant	−0.4578	−1.06	−0.5877	−1.54	−1.4100*	−1.83

Note:.
*** Statistically significant at 1 % level.
** Statistically significant at 5 % level.

Table 4
Country level short-run parameters for the PMG model.

Short-run parameters Egypt	Coefficient Total GHG Emissions (CO_2)	z-stat	Coefficient CO_2 Emission	z-stat	Coefficient CO_2 Per Capita Emission	z-stat
ECT	0.0169	0.75	0.0241	1.55	−1.4454***	−7.92
D1.Particulate emission damage	−0.0073	−0.10	0.1053**	2.47	−0.0084	−0.25
D1.Per Capita GDP	0.0144	0.24	−0.0748**	−2.04	−0.0219	−0.83
D1.Renewable energy	0.0496	0.99	−0.0077	−0.26	−0.0123	−0.52
D1.CO_2 intensity	0.4651***	4.20	0.8226***	12.26	−0.2570	−1.77
D1.Electricity power losses	0.0006	0.05	−0.0013	−0.18	0.0042	0.86
D1.Electricity consumption per cap	0.0127	0.13	0.0410	0.69	0.0543	1.04
D1.Energy use	0.6291***	10.10	0.9275***	22.13	−0.3783**	−2.31
Constant	0.0303	1.11	0.0870*	1.67	−4.2230***	−7.19
South Africa						
ECT	−0.0545***	−3.50	−0.0044	−0.60	0.0048	1.42
D1.Particulate emission damage	0.0187	0.65	0.0117	0.50	−0.0073***	−3.13
D1.Per Capita GDP	−0.0214	−0.78	−0.0138	−0.62	0.0068***	3.03
D1.Renewable energy	0.0331**	1.98	0.0355***	2.89	0.0023	1.79
D1.CO_2 intensity	0.7282***	30.93	0.9650***	46.92	1.0058***	302.65
D1.Electricity power losses	−0.0031	−0.42	0.0008	0.12	0.0006	1.02
D1.Electricity consumption per cap	0.0222	1.01	0.0116	0.62	−0.0020	−1.03
D1.Energy use	0.7487***	27.81	0.9726***	45.23	1.0046***	286.44
Constant	−0.0790*	−1.90	−0.0114	−0.39	0.0138	1.45
Nigeria						
ECT	−0.0335	−1.73	−0.0619	−1.43	−0.0382	−0.69
D1.Particulate emission damage	−0.0628**	−2.28	−0.0449	−0.97	−0.0572	−1.24
D1.Per capita GDP	0.0345**	2.32	0.0307	1.24	0.0307	1.22
D1.Renewable energy	−0.2963	−0.63	−2.7435***	−3.38	−2.2238***	−2.80
D1.CO_2 intensity	0.2534**	2.35	0.1450	0.65	0.3346*	1.89
D1.Electricity power losses	0.0188	1.23	0.0257	1.02	0.0156	0.64
D1.Electricity consumption per cap	−0.1481***	−2.90	−0.2373***	−2.86	−0.2476***	−2.92
D1.Energy use	0.8691***	3.03	0.9858**	2.11	1.0698**	2.22
Constant	0.0035	0.17	−0.1262	−1.01	−0.1174	−0.72
Libya						
ECT	−1.1123***	−12.18	−0.2199***	−2.94	−0.3688***	−3.59
D1.Particulate emission damage	−0.2898***	−5.94	−0.0625	−0.65	−0.0422	−0.48
D1.Per capita GDP	0.1316***	5.38	0.0273	0.47	0.0410	0.75
D1.Renewable energy	0.3457***	7.69	−0.0962	−1.00	−0.0524	−0.56
D1.CO_2 intensity	−0.3126***	−2.93	0.4741**	2.43	0.5954***	3.45
D1.Electricity power losses	0.3099***	8.75	0.0223	0.31	0.0002	0.00
D1.Electricity consumption per cap	0.2678***	2.97	−0.0560	−0.28	−0.0051	−0.03
D1.Energy use	0.2938	1.80	0.7065***	4.20	0.6080***	3.74
Constant	−2.1804***	−3.05	−0.9792**	−2.18	−1.0344***	−3.56
Algeria						
ECT	−0.0432*	−1.73	−0.5801***	−7.67	−0.5851***	−4.18
D1.Particulate emission damage	−0.1987	−0.86	−0.4174***	−3.11	−0.1659	−0.91
D1.Per capita GDP	0.2213	1.04	0.4695***	3.54	0.1694	1.02
D1.Renewable energy	0.0232	1.15	−0.0119	−1.06	−0.0018	−0.11
D1.CO_2 intensity	0.2863	1.59	−0.3341**	−2.49	0.0893	0.57
D1.Electricity power losses	0.0089	0.20	0.0715***	3.04	0.0460	1.29
D1.Electricity consumption per cap	0.0328	0.25	−0.1950**	−2.24	0.0333	0.31
D1.Energy use	0.2625	1.95	−0.1495	−1.04	0.1113	0.67
Constant	−0.0635	−1.35	−1.9087***	−2.64	−1.6893***	−4.06

Note:.
*** Statistically significant at 1 % level.
** Statistically significant at 5 % level.

consumption-based CO_2 emissions and carbon intensity of GDP. However, Inglesi-Lotz [60] non-parametrically concluded that CO_2 intensity reduced GHG emissions.

In addition, Table 3 shows that in the long run, a 1 % increase in electric power transmission losses significantly reduced ($p < 0.01$) total GHG emissions by 0.1682 %. However, Table 4 shows that in the short run, a 1 % increase in electricity power transmission losses significantly increased ($p < 0.01$) total GHG emission by 0.3099 % in Libya and increased CO_2 emissions by 0.0715 % in Algeria. Losses of generated power constitutes significant environmental damages due to inability to utilize such power for meaningful economic activities and the emissions that would be associated with its replacement [61]. Therefore, conservation of generated energy is synonymous with energy efficiency which will ultimately facilitate environmental conservation. The need to include electricity power losses in modelling CO_2 emissions had been emphasized by Wang et al. [62], although they could not implement this due to data paucity. The findings in this study are in alliance with the submission of Surana and Jordaan [63] who emphasized the contributions of electricity power losses to climate change. Molina-Martin et al. [64] highlighted the implications of electricity power losses for CO_2 concentration in the atmosphere and associated costs.

Table 3 further shows that the long run parameters of electricity consumption per capita are positive and significant ($p < 0.01$) for all indicators of carbon emissions. These results imply that in the long run, a 1 % increase in electricity consumption per capita will increase GHG emissions, CO_2 emissions, and CO_2 emissions per capita by 0.3858 %, 0.6665 % and 0.0627 %, respectively. Table 4 also shows the short run parameters for each of the five countries. It reveals that in the short run, a 1 % increase in electricity consumption per capita in Nigeria will significantly reduce ($p < 0.01$) total GHG emissions, CO_2 emissions, and CO_2 emissions per capita by 0.1481 %, 0.2373 %, and 0.2476 %, respectively. Similarly, the result for Algeria shows that a 1 % increase in electricity consumption per capita will significantly reduce ($p < 0.05$) CO_2 emissions by 0.1950 %. The result for total GHG emissions for Libya however has different implication, since the parameter is with positive sign and statistically significant ($p < 0.01$). This implies that a 1 % increase in the amount of electricity consumption per capita will increase total GHG emissions by 0.2678 %.

Energy consumption is a major driver of CO_2 emissions in many countries due to burning of coals [65–67]. This is very peculiar for South Africa, which generates significant amount of total electricity from coals. More importantly, electricity utilization is also synonymous with industrialization [68,69], which will generate some emissions of CO_2 and other associated gasses depending on the spectrum of adopted production technology. The findings in this study are in consonance with those of Ali et al. [70] and Ma et al. [71] who observed positive association between electricity consumption and emission of GHGs.

Table 3 shows that the long run parameters of energy use are statistically significant ($p < 0.01$) with positive sign. This reveals in the long run, a 1 % increase in energy use will increase total GHG emissions, CO_2 emissions, and CO_2 emissions per capita by 1.0804 %, 1.5731 % and 0.8687 %, respectively. Table 3 also reveals that the short-run parameters for CO_2 emissions show statistical significance ($p < 0.01$). These results imply that for all the countries, a 1 % increase in energy use will in the short run increase total GHG emission and CO_2 emissions by 0.5606 % and 0.6886 %, respectively.

Table 4 further reveals the short run parameters for the individual country, with most of the parameters being positive. The results reveal that in the short run, 1 % increase in energy use in Egypt will significantly increase ($p < 0.01$) total GHG emissions and CO_2 emissions by 0.6291 %, and 0.9275 %, respectively. However, the parameter for CO_2 emissions per capita has a negative sign. In South Africa, a 1 % increase in energy use will in the short run significantly increase ($p < 0.01$) total GHG emissions, CO_2 emissions, and CO_2 emissions per capita by 0.7487 %, 0.9726 %, and 1.0046 %, respectively. In Nigeria, a 1 % increase energy use will in the short run significantly increase ($p < 0.05$) total GHG emissions, CO_2 emissions, and CO_2 emissions per capita by 0.8691 %, 0.9858 % and 1.0098 %, respectively. In Libya, in the short run, a 1 % increase in energy use will significantly increase ($p < 0.01$) CO_2 emissions and CO_2 emissions per capita by 0.7065 % and 0.6080 %, respectively.

Energy use is a promoter of CO_2 emissions across the world. The metric of the indicator used in this study refers to the equivalent of kilogram of oil per capita. The findings have unanimously confirmed the positive association between energy use intensity and CO_2 emissions. The findings are in accordance with those of Chang et al. [72], and Liobikienė, G. and Butkus [73–75]. Similarly, Akdag and Yıldırım [76] analysed the effect of energy efficiency on GHG emissions in selected European countries. It was found that a long-term relationship existed between energy efficiency and an increase in energy utilization efficiency decreases GHG emissions.

The long-run parameters showed that the particulate emission damage parameters are with positive sign in all the results, although that for CO_2 emissions did not show statistical significance ($p > 0.05$). The results showed that in the long run, increase in particulate emission damage by 1 % will significantly increase ($p < 0.01$) total GHG emissions and CO_2 per capita emissions by 0.3608 % and 0.0346 %, respectively. Table 4 further shows the estimated short run parameters for each of the five countries. It reveals that a 1 % increase in particulate emission damages will in the short run significantly reduce ($p < 0.05$) total GHG emissions in Nigeria and Libya by 0.0628 % and 0.2898 %, respectively, while it will significantly reduce CO_2 emissions by 0.4174 % in Algeria and increase it in Egypt by 0.1053 %. Also, a 1 % increase in particulate emission damages will in the short run significantly reduce ($p < 0.01$) per capita CO_2 emissions by 0.0073 % in South Africa.

Emission damages are the real reflections of the economic cost of pollution within every country [77]. The spectrum of economic sectors affected by environmental pollution is alarming, covering tourism [78,79], human health, productivity of labour [80], housing quality and pricing [81], wages [82], human mobility [83,84]. The results of this study are shedding some lights on the short-and long-run notions of pollution abatement through the basic understanding of their associated economic, social, and humanitarian costs to the society [85].

Although the results overwhelmingly showed a negative emission impact of particulate damages in the short-run, there will be some positive impacts in the long-run. This underscores lack of sustainability and continuity in some approaches that had been utilized in addressing environmental problems. Specifically, many African countries only take the problem of environmental degradation seriously when some obvious catastrophic events had happened. Therefore, the findings are clearly emphasizing the need for a long-term sustainable planning and political will for the promotion of environmental quality.

Table 4 further shows that per capita GDP significantly ($p < 0.05$) and positively increased total GHG emissions in Nigeria and Libya. The results specifically showed that in the short run, a 1 % increase in per capita GDP will increase total GHG emissions by 0.0345 % and 0.1316 % in Nigeria and Libya, respectively. However, in Egypt, in the short run, a 1 % increase in per capita GDP will lead to 0.0748 % decrease in CO_2 emissions ($p < 0.05$), while it will result in 0.4695 % increase in Algeria ($p < 0.01$). The results for South Africa show that if per capita GDP increases by 1 %, the per capita CO_2 emissions will increase by 0.0068 % in the short run.

Several studies have analyzed the effect of GDP on emission of GHGs with mixed results. Among the ones that found positive association between GDP and carbon emissions are Tucker [86] for 137 countries over a period of 21 years, Abdallh and Abugamos [87] for twenty MENA countries, Zoundi [88] for twenty African countries, Rahman [89] for eleven Asian countries, Ohlan [90] for India, Mohiuddin et al. [91] for Pakistan using data for the 1971–2013 periods, Wang and Li [92], Liu and Bae [93] for China, Granados and Spash [94] for the United States of America (USA), and those with negative association are Asumadu-Sarkodie and Owusu [95] for Rwanda using the data for 1965–2011 period, Adesina and Mwamba [96] for twenty four Africa countries, Dogan and

Inglesi-Lotz [97] for European countries, Yao et al. [98] for seventeen major developed and developing countries, and Kais and Sami [99] for a mix of countries across the world.

Table 4 shows the parameters of the error correction mechanisms for the short run models. The results showed that the error correction parameters in the total GHG emissions model for South Africa (−0.0545) and Libya (−1.1123) are significant ($p < 0.01$), while those for Nigeria (−0.0335) and Algeria (−0.0432) only showed statistical significance at the 10 % level. These results showed that a deviation from long run equilibrium in total GHG emissions will be corrected at the 5.45 %, 111.23 %, 3.35 % and 4.32 % adjustment speeds in South Africa, Libya, Nigeria, and Algeria, respectively. In the CO_2 emissions model, only the ECT parameter for Libya (−0.2199) and Algeria (−0.5801) were significant ($p < 0.01$), while those for Egypt (−1.4454), Libya (−0.3688) and Algeria (−0.5851) were significant in the CO_2 per capita model. These results showed that any deviations from the long-run equilibrium in the CO_2 model will be corrected at 21.99 % and 58.01 % adjustment speeds in Libya and Algeria, respectively. Also, deviations from long-run equilibrium in CO_2 per capita model will be corrected at 144.54 %, 36.88 % and 58.51 % adjustment speeds in Egypt, Libya and Algeria, respectively.

Conclusion

Reduction of carbon emission is a major development challenge the world currently faces. The twenty-first development agenda is primarily anchored on effective reduction of environmental pollution, along with its associated cost. Therefore, addressing emission of GHGs to forestall further climatic hazards is fundamentally projected in the Paris Agreement. Energy efficiency remains the core of all efforts to redress climatic hazards that have befallen the world with exorbitant economic costs. This study therefore contributes to the body of existing knowledge by utilizing some indicators of energy efficiency for modelling emission of total GHGs, CO_2 and CO_2 per capita with focus on the top five emitters in Africa. The results of data analyses have shown the contributions of energy utilization efficiency to different indicators of GHG emissions among top five emitters in Africa. The novelty of this study can be emphasized from inclusion of some vital variables like energy losses, energy use intensity, CO_2 intensity and utilization of renewable energies to capture indicators of energy efficiency. The implications of the results are quite remarkable for policy initiatives to facilitate compliance of African leaders with the Paris Agreement.

The results have shown that the adjustment speed to deviations from long run equilibrium differed. Therefore, each country would respond to emission destabilization with different speed and progress. This has some implications for policy stability and a proper understanding of some peculiar idiosyncratic shocks that can dismiss steady reduction of GHG emissions. Particulate emission damages will in the long run promote emission of GHGs, while they will reduce them in some countries in the long run. This implies that a comprehensive documentation of the cost of environmental degradation can propel some policy initiatives to offset the undesired short run trends through policy manipulation and intersectoral collaborations. The results further revealed the long run economic growth reducing impact on GHG emissions, while the short run presents a contrary result. This reemphasizes the need to adopt an environmentally benign growth process through adequate integration of sustainability notion in every frame of development initiatives. It also re-echoes the need for policy commitments and private-public partnership in facilitating adoption of renewable energies for energy utilization efficiency and environmental conservation.

In addition, efforts to reduce energy losses through proper coordination and investment will reduce the volume of GHG emissions and promote some levels of efficiency in energy utilization and CO_2 emission intensity.

List of abbreviations

CO_2	Carbon dioxide
DFE	Dynamic Fixed Effect
EKC	Environmental Kuznets Curve
GDP	Gross Domestic Product
GHG	Greenhouse Gas
MG	Mean Group
NDC	Nationally Determined Contribution
Panel ARDL	Panel Autoregressive Distributed Lag
PMG	Pooled Mean Group
WDI	World Development Indicators

Declaration of competing interest

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

Data availability

The data for this study are in public domains and will be made available upon request.

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