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The role of non-renewable energy consumption in economic growth and carbon emission: Evidence from oil producing economies in Africa

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ABSTRACT

Non-renewable energy consumption facilitates the production of output but it is also a major source of carbon emission, leading to a dilemma in policy priority between economic growth and pollution reduction. The study therefore investigates the role of non-renewable energy in economic growth and carbon emissions among the top oil producing economies in Africa during 1980–2015. After accounting for nonlinearity and structural break in unit root and cointegration analysis, the paper adopted non-linear autoregressive distributed lag (NARDL) technique.

The study reveals evidence of asymmetric effect of per capita consumption of both petroleum and natural gas consumption on economic growth and carbon emission per capita in all the selected countries except Algeria. In Nigeria, although positive change in the non-renewable energy consumption retards growth, it reduces emission. In the case of Gabon, increase in the consumption of these energy products promotes growth and enhances environmental quality. Consumption of these energy types has negligible impact on environmental pollution in Egypt as it enhances economic growth. While positive change in the non-renewable energy consumption contributes to economic growth in Angola, the effect on carbon emission is mixed across time and energy type. In addition, the influence of negative change in petroleum and natural gas consumption is similar to those observed for positive change in Egypt and Nigeria. It is therefore imperative for policymakers in oil producing economies (in Africa) to explore avenues to invest in, and promote, carbon-reducing technology in production processes in their quest for economic growth if they must continue to increase the consumption of their abundant resources-petroleum and natural gas.

1. Introduction

The quest for stable economic growth and sustained environmental quality is fast becoming a topical issue among governments, international institutions and other stakeholders interested in sustainable development. This follows the realization that increased use of energy, especially from carbon related sources, in the production of economic growth is associated with rising level of carbon emission which is harmful to the environment and human health. Developing countries view constraints on carbon intensive energy as detrimental to their efforts towards economic expansion, thereby recommending the need for industrial economies to increase finance of programs to mitigate global warming largely caused by their industrial activities [1,2]. Consequently, the 1997 Kyoto protocol took a giant step by committing industrialized economies to drastically reduce their emissions of greenhouse gases [3]. Since, the growth of world economy is increasingly dependent on carbon intensive energy, reducing energy consumption or shortage of energy supply has serious implication for income.

In oil producing developing economies, where petroleum and natural gas production and consumption are major drivers of economic growth, controlling the level of CO2 emissions may be challenging as it may ultimately retard economic growth [4]. For instance, the average consumption of natural gas among Algeria, Angola, Egypt, Gabon and Nigeria grew from about 107.9 billion cubic feet in 1980 to about 327 billion cubic feet and 759.5 billion cubic feet in 2000 and 2015

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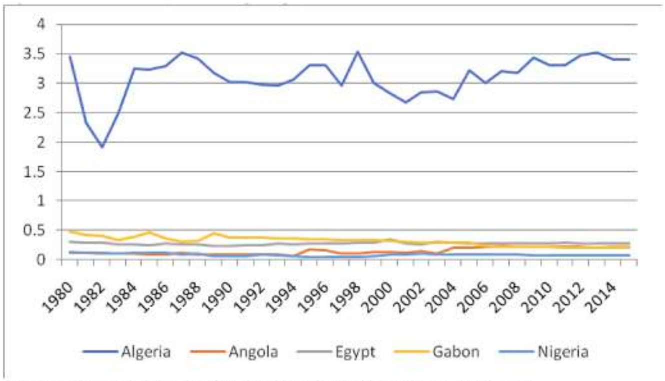
respectively. This suggests that the average consumption of natural gas in 2015 among these countries represents an increase of about 604% and 133% from their 1990 and 2000 values respectively. Similarly, the consumption of petroleum products among these countries rose from an average of 116.4 thousand barrels per day in 1980 and 213.2 thousand barrels per day in 2000 to about 339.2 thousand barrels per day in 2015, representing an increase of about 191% and 59% over their 1980 and 2000 values respectively. This corresponds to a 15% increase in average GDP per capita over the period 1990–2015 among these economies and about 144% rise in average carbon emission.

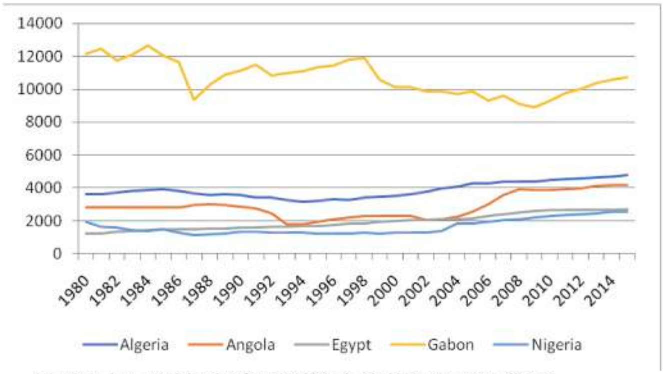
External shocks such as oil price and production quotas trigger structural change in the production and consumption of oil and its products, and produce asymmetric response of growth and associated environmental pollution, the implication of which may differ from country to country. Thus, trends of non-renewable energy (petroleum and natural gas) consumption, economic growth and carbon emissions among top oil producing economies in Africa appear to follow dissimilar pattern over the period 1980–2015. Generally, CO2 emissions across these economies remained highly unstable during 1980–2015, with Algeria being the leading emitter of carbon (measured in per capita terms) among the selected countries for all the years (Fig. 1). In recent years, Gabon and Nigeria experienced noticeable downward trend in carbon emission per capita, falling from a high emission per capita of about 0.48 metric tons and 0.14 metric tons respectively in 1980 to their lowest value of about −0.20 metric tons and 0.07 metric tons respectively in 2013. On the contrary, carbon emission per capita has been on the increase in Angola over the same period. While Algeria is observed to record the highest carbon emission per capita among the countries throughout the period 1980–2015, Nigeria remained the cleanest for most of the same period.

Furthermore, except for the case of Gabon, real GDP per capita rose gently in all the countries beginning from early 2000s after initial decline for most of the preceding period. Interestingly, Gabon, whose carbon emission per capita fell remarkably over the years, appears to be the richest economy in terms of real income per capita among the selected oil producers in Africa, even though it deteriorated in recent years (Fig. 2). Across all the countries, the consumption of natural gas per capita has been rising over the years (Fig. 3). This is most noticeable in Egypt, where natural gas consumption per capita rose from about 692 billion cubic feet in 1980 to about 21,908 billion cubic feet in 2012. In the case of Nigeria, consumption of natural gas experienced an upward but unstable trend for most part of the period between 1980 and mid 2000s, although major shock was witnessed between 2008 and 2011. Among the selected countries, per capita natural gas consumption seems to be lowest in Angola and closely followed by Nigeria and Gabon for almost all the years under consideration. Similarly, as revealed in Fig. 4, petroleum consumption per capita rose among oil producing economies in Africa. Obviously, Angola and Nigeria are the least consumers of petroleum (in per capita terms) among these economies. Except in Gabon (and to some extent Nigeria), where per capita petroleum consumption declined over the period under consideration, rising trends are observed for Gabon being the leading consumer of petroleum resources (in per capita terms) followed by Egypt and Algeria in that order.



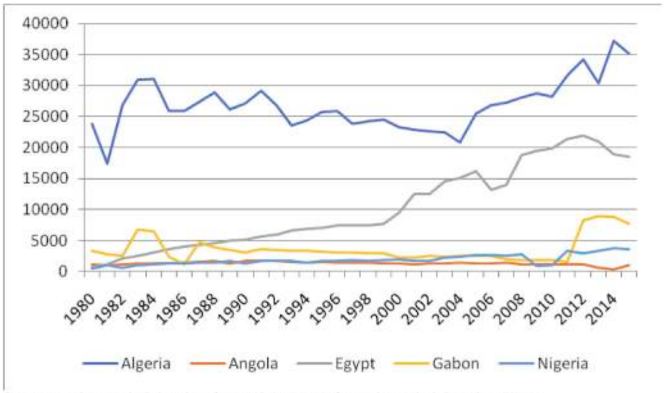
Source: Author; underlying data from World Bank, World Development Indicators

Fig. 1. CO2 emissions (metric tons per capita).



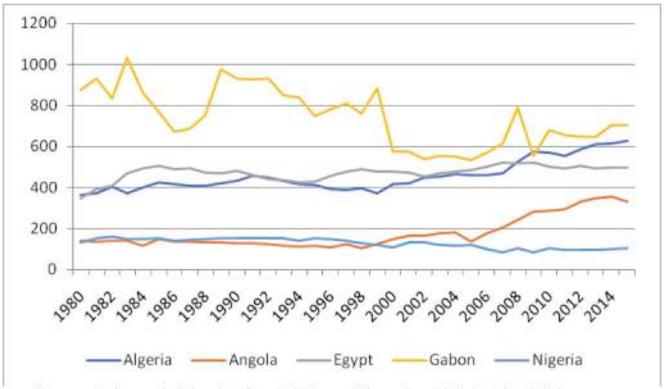
Source: Author; underlying data from World Bank, World Development Indicators

Fig. 2. GDP per capita (constant 2010 US$).



Source: Author; underlying data from US Energy Information Administration (EIA)

Fig. 3. Natural Gas Consumption (Billion Cubic Feet per capita).



Source: Author; underlying data from US Energy Information Administration (EIA)

Fig. 4. Total Petroleum Consumption per capita (Litres).

It therefore appears that the consumption of these non-renewable energy types promotes income per capita but contributes to higher carbon emissions. This raises some pertinent questions: to what extent do petroleum and natural gas consumption contribute to economic growth and carbon emissions in these economies? Should policy focus more on growth than reducing carbon emissions (or vice versa) that arise from the consumption of these resources? These questions therefore call for an empirical investigation of the role of petroleum and natural gas consumption in economic growth and carbon emission among African oil producing economies towards achieving sustainable growth (the twin objectives of sustained economic growth and reduction in CO2 emissions).

The motivations for this study stem from some important gaps observed in the literature. First, most related studies such as Hanif [5] focused on aggregate energy (fossil fuel) consumption. However, any effect of fossil fuel on either economic growth or carbon emission may be driven by consumption of specific fossil fuel energy such as petroleum or natural gas. Such aggregate analysis may confound the effect of specific fossil fuel which is important for policy analysis and prescription. Other studies on specific non-renewable energy types either focus on carbon emissions [1] or economic growth [65] and [6]. Therefore, this study examines the effect of specific fossil fuel (petroleum and natural gas) on growth and carbon emission. Second, given the role of non-renewable natural resources in economic growth of oil producing countries in Africa, very limited studies exist in this regard. Besides, the few studies that focused on African countries either consider biomass (renewable) energy consumption or total non-renewable (or total fossil fuel) energy consumption, while ignoring the role of petroleum and natural gas in economic growth and carbon emission.[1] Third, despite the possibility of asymmetries in the energy-growth-emission links, very few studies have been done in this respect. These few studies have been conducted at aggregate (total) energy level, while none has been done for specific energy type. This study therefore focuses on investigating the role of non-renewable energy consumption (petroleum and natural gas) on economic growth and carbon emission among the top oil producers in Africa during 1980-2015[2], considering not only the role of asymmetries but also that of structural change (break) so as to enrich policy analysis and prescription. It also accounts for the possible influence of financial development, trade openness, urbanisation and carbon intensity on the link among non-renewable energy consumption, economic growth and carbon emission so as to make our results robust.[3]

Findings from the study show that both petroleum and natural gas consumption have asymmetric effect on economic growth and carbon emission in all the selected countries except Algeria. Also, the responses of economic growth and carbon emissions to positive and negative changes in the consumption of either of these energy types vary across countries. The rest of this paper is structured such that section 2.0 provides the literature review, while section 3.0 discusses the theory and methodology of the study. Section 4 presents the empirical results, and section 5 summarises the paper, including policy implications.

2. Literature review

The literature is vast on the relationship between energy consumption and CO2 emissions, and between energy consumption and economic growth. However, as identified by Adewuyi and Awodumi [7] in a comprehensive literature survey, studies that capture the link among these variables are limited and still developing. As summarised in Table 1, studies are categorised into three: those linking (1) energy consumption and CO2 emissions, (2) energy consumption and economic growth, and (3) energy consumption, CO2 emissions and economic growth.

2.1. Studies on the link between energy consumption and CO2 emissions

Among the studies on the energy consumption-carbon emission link, there is overwhelming focus on total energy (including total renewable and total non-renewable energy), with high level of consensus on the positive effect on carbon emission. For instance, Jalil and Feridun [9] investigated the long-run impact of financial development, economic growth and energy consumption on environmental pollution in China during 1953–2006. Their autoregressive distributed lag (ARDL) bounds test results revealed that total energy consumption had positive effect on environmental pollution. Using similar technique, Acaravci and Ozturk [12], Jayanthakumaran et al. [10], Ozturk and Acaravci [11] and Shahbaz et al. [4] confirmed this finding for Europe, China (and India), Turkey and Indonesia respectively. This finding is consistent with Hossain [8], where VECM Granger causality and GMM results also indicated mixed results for the role of urbanization among 9 newly industrialized countries (NIC). Bélaïd and Youssef [17] and Alola et al., [15] demonstrated that the positive effect of energy consumption on environmental pollution remain valid when total energy is decomposed into total renewable and non-renewable energy for the case of 16-EU countries and Algeria respectively. In addition, most of these studies provided a role for financial development and trade openness as evident in Shahbaz et al. [4] who confirmed that these factors have reducing influence on carbon emission. In contrast, Jalil and Feridun [9] provided evidence of significant contribution of financial development to reduction in environmental pollution, but they equally reported positive influence of trade openness. Although, this finding is largely supported by Ozturk and Acaravci [11], they found no role for financial development. Hossain [8] and Jayanthakumaran et al. [10] however,argued that the contribution of trade openness to environmental quality is negligible.

It is possible that energy types contribute differently to carbon emission, which makes it imperative to isolate their individual effects for policy purpose. To this end, employing ARDL-ECM, FMOLS, DOLS, panel Granger causality approaches, Shahbaz et al. [1] and Chen et al. [16] analysed the effect of coal consumption on carbon emission in South Africa and China respectively and found that the consumption of this energy type worsened environmental quality. They further provided evidence that trade openness and financial development are critical factors in improving environmental quality. Ma et al. [51] employed the extended Kaya identity with the logarithmic mean Divisia index (LMDI) decomposition method to show that reduction in energy intensity promoted environmental quality. Utilizing total fossil fuel energy consumption, Hanif [5] and Hanif et al., [13] considered the case of East Asia and the Pacific, and 25 developing Asian economies respectively. Based on GMM estimates, they discovered significant contribution of this energy type to CO2 emission. However, ARDL estimates of Hdom [14] could not establish any significant influence of fossil fuel electricity consumption on carbon emission in 8 South American countries. Among these studies, it still remains unclear what role the specific energy types plays in carbon emission in countries that are relatively abundant in these resources. In particular, while natural gas and petroleum products continue to represent major sources of carbon emission, consumption of these products are hardly considered in the energy-carbon emission literature. In addition, most of these studies neglected the role of economic growth in the energy-emission nexus.

2.2. Studies on the link between energy consumption and economic growth

On the link between energy consumption and economic growth, studies focussing on aggregate energy indicated support for the positive impact of the later on the former irrespective of the methods of analysis as evident in Lee and Chang [3], Lee et al. (2008), Warr and Ayres [18] and [20], for the case of Asia, OECD countries, US and BRIC respectively. When total renewable energy is considered, Fang [21] and Apergis and Payne [24], reported similar result using OLS for the case of China and

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[1] See few studies on African countries that consider biomass (renewable) energy consumption [26,50] and those on total non-renewable (or total fossil fuel) energy consumption [17,37,46].

[2] The period 1980–2015 was selected based on data availability at the time of our analysis.

[3] See Refs. [1,4,8–11,64] and [51].

Table 1
Summary of literature.

S/N	Author & Year	Country (s) & scope	Energy Variable	Estimation technique	Impact on Carbon Emissions or Economic Growth
Energy Consumption and Carbon Emissions					
1	Hossain [8]	Brazil, China, India, Malaysia, Mexico, Philippines, South Africa, Thailand and Turkey (1971–2007)	Total energy	VECM Granger causality and GMM	Positive both in the long-run and short-run
2	Jalil and Feridun [9]	China (1953–2006)	Total energy	ARDL	Positive in the long-run
3	Jayanthakumaran et al. [10]	China and India (1971–2007)	Total energy	ARDL and ECM	Positive both in the long-run and short-run
4	Shahbaz et al. [1]	South Africa (1965–2008)	Coal	ARDL and ECM	Positive both in the long-run and short-run
5	Ozturk and Acaravci [11]	Turkey (1960–2007)	Total energy	ARDL and ECM-Granger causality	Positive both in the long-run and short-run
6	Shahbaz et al. [4]	Indonesia (1975–2011)	Total energy	ARDL and VECM-Granger causality	Positive both in the long-run and short-run
7	Hanif [5]	East Asia and the Pacific (1990–2014)	Total fossil fuel energy	System GMM	Positive
8	Acaravci and Ozturk [12]	Europe (1960–2005)	Total energy	ARDL	Positive
9	Hanif et al., [13]	25 developing Asian economies (1990 2015)	Fossil Fuels Energy	2-step GMM	Positive
10	Hdom [14]	8 South American countries (1980–2010)	fossil fuel electricity	ARDL	No significant effect
11	Alola et al., [15]	16-EU Countries (1997–2014)	Total RE and NRE	PMG-ARDL	NRE has positive effect
12	Chen et al. [16]	China (1995–2012)	Coal and non-fossil fuel energy	FMOLS, DOLS and Panel Granger causality	NRE positive effect
13	Bélaïd and Youssef [17]	Algeria (1980–2012)	Total RE and NRE Energy	ARDL; VECM Granger causality	NEC has positive effect
Energy Consumption and Economic Growth					
14	Lee and Chang [3]	16 Asian countries (1971–2002)	Total energy	Panel-based error correction models (FMOLS &causality)	Positive
15	Lee et al. (2008)	OECD countries (1960–2001)	Total energy	Panel-based error correction models (FMOLS& causality)	Positive
16	Warr and Ayres [18]	US (1946–2000)	Total energy	Granger causality and VECM	Positive
17	Apergis and Payne [19]	15 emerging market economies (1980–2006)	Coal	FMOLS and Panel causality	Negative
18	Pao and Tsai [20]	BRIC (1980–2007)	Total energy	Grey prediction and VECM	Positive
19	Fang [21]	China (1978–2008)	Renewables	OLS	Positive
20	Ozturk and Acaranci [22]	11 MENA countries (1971–2006)	Electric power	ARDL bound testing approach	No relationship between EL & Y
21	Apergis and Payne [23]	16 emerging economies (1990–2007)	Total RE and NRE electricity	Panel Granger causality	Bidirectional causality between NRE and growth
22	Apergis and Payne [24],	6 Central American countries (1980–2006)	Total renewable electricity	The heterogeneous panel co-integration and FMOLS	Positive
23	Al-mulali et al. [25]	18 LAC (1990–2011)	Total RE and NRE	Panel dynamic OLS (DOLS)	Positive
24	Caraiani et al. [6]	Emerging European countries (1980–2013)	Coal, gas, oil and renewables	VECM	Positive
25	Ozturk and Bilgili [26],	51 Sub-Sahara African Countries (1980–2009)	Biomass	Dynamic panel OLS	Positive
26	Wolde-Rufael [65]	6 coal consuming countries (1965–2005)	Coal	VAR- Granger causality	mixed results across countries
27	Razmi et al., [27]	Iran (1990–2014)	RE; combustible renewable and waste	ARDL	No long-run effect: Positive effect of renewables in the short-run
28	Ozcan and Ozturk [28]	17 emerging countries (1990–2016)	Total RE (electricity)	The bootstrap panel causality test	No significant effect
29	Aydin [29]	26 OECD countries (1980–2015)	Total RE and NRE	Panel Frequency Causality	Bidirectional causality between NEC and growth
30	Luqman et al., [30]	Pakistan (1990–2016)	RE and Nuclear	NARDL	Positive and negative shocks of RE; Nuclear have positive effect
31	Afonso et al., [31]	28 countries (1995–2013)	Total RE and NRE	ARDL (PMG and MG)	NRE has positive effect
32	Tuna and Tuna [32]	5ASEAN countries (1980–2015)	Total RE and NRE	Hacker and Hatemi-J (2006) and Hatemi-j (2012) tests	Mixed results across countries
33	Tugcu and Topcu [33],	G7 countries (1980–2014)	Total RE and NRE	NARDL and Granger-Causality	mixed results across countries
34	Destek and Aslan [34]	17 emerging economies (1980–2012)	Total RE and NRE	Panel Granger-Causality	mixed results across countries
35	Alper and Oguz [35]	8 EU member countries (1990–2009)	Combustible RE and waste	Asymmetric causality test and ARDL	Positive effect
36	Dogan [36]	Turkey (1988–2012)	Total RE and NRE	ARDL and VECM Granger causality	Positive effect of NRE
37	Adams et al., [37]	30 SSA countries (1980–2012)	Total RE and NRE	FMOLS and DOLS	Positive effect of NRE
38	Kahia et al., [38]	13 MENA Net Oil Exporting Countries (1980–2012)	Total RE and NRE	FMOLS and Panel granger causality	Bidirectional causality between NRE and growth
39	Kahia et al., [39]		Total RE and NRE	FMOLS and Panel granger causality	

(*continued on next page*)

Table 1 (*continued*)

S/N	Author & Year	Country (s) & scope	Energy Variable	Estimation technique	Impact on Carbon Emissions or Economic Growth
		11 MENA Net Oil Importing Countries (1980–2012)			Bidirectional causality between NRE and growth
40	Park and Yoo [40]	Malaysia (1965–2011)	Oil	ECM Granger causality	Oil causes growth
41	Bildirici and Bakirtas [41]	BRICTS (1980–2011)	Oil, natural gas and coal	ARDL	Oil causes growth, mixed results for natural gas and coal
42	Lei et al. [42]	Biggest coal consuming countries (2000–2010)	Coal	Panel causality	Mixed results
43	Bloch et al., [43]	China (1965–2013)	Coal and Oil	ARDL and VECM Granger causality	Positive effect of oil and coal
44	Bhattacharya et al., [44]	China (1978–2010)	Coal	ARDL and Toda-Yamamoto Granger-Causality	Coal causes growth
Energy Consumption, Carbon emission and Economic Growth					
45	Ito [45]	42 developed countries (2002–2011)	Total REC and fossil fuel	GMM; PMG	Fossil fuel has positive on CO2 and negative on growth
46	Mensah et al., [46]	22 African countries (1990–2015)	Total Fossil fuel energy	PMG panel ARDL	Positive effect on growth and CO2
47	Kang et al. [47]	India (1965–2015)	Coal and hydroelectricity	T-Varying Bayesian VAR; T-Y Granger-Causality	Coal causes CO2 and growth
48	Akadiri et al., [48]	EU-28 countries (1995–2015)	Total RE	FMOLS, ARDL (PMG, MG and DFE) and panel causality	Positive effect on growth; Causes CO2
49	Boontome et al., [49]	Thailand (1971–2013)	Total RE and NRE	ECM- Granger-Causality	Positive effect of NRE on CO2; no effect on growth
50	Adewuyi and Awodumi [50]	11 ECOWAS countries (1980–2010)	Biomass	3SLS	Mixed results across countries (growth and CO2)

Note: (N)ARDL= (Non-linear) Autoregressive distributed lag model; OLS=Ordinary least squares; VECM= Vector Error Correction Model; FMOLS= Fully modified OLS; 3SLS = three stage least squares; SSA = Sub-Saharan African.

FMOLS for 6 Central American countries respectively. In contrast, ARDL results of Razmi et al., [27] could not establish significant long-run effect of renewable energy on economic growth in Iran, though positive short-run impact is reported. This finding is corroborated by Ozcan and Ozturk [28] for renewable electricity in emerging countries using the bootstrap panel causality.

Studies also paid considerable attention to the role of aggregate non-renewable (and renewable) energy in economic growth. For instance, Afonso et al., [31] and [36] adopted ARDL technique and its variants to show that non-renewable energy significantly promoted economic growth in Turkey and 28 countries respectively. In Latin America and Sub-Saharan Africa (SSA), Al-Mulali et al. [25] and Adams et al., [37] respectively provided evidence to support the growth effect of non-renewable energy consumption using FMOLS, DOLS and VECM Granger causality. The result for SSA is also confirmed for biomass energy in SSA by Ozturk and Bilgili [26], in a dynamic panel OLS analysis. Further estimates of Al-Mulali et al. [25] and Afonso et al., [31] showed strong indication of increasing effect of trade openness and export respectively on economic growth.

Evidence is provided using various causality analysis to show that non-renewable energy Granger causes economic growth. These studies include Aydin [29], Kahia et al., [38] and Kahia et al., [39] which were conducted for OECD countries, MENA net oil exporting countries and MENA net oil importing countries respectively. Similar findings are also reported for emerging economies by Apergis and Payne [23] and Destek and Aslan [34]. Against common findings in the literature, Ozturk and Acaranci [22] argued that electric power consumption does not have significant influence on economic growth in MENA countries based on the estimates of ARDL bound testing approach.

A few studies concentrate on specific non-renewable energy such as oil, natural gas and coal with high level of support for their significant role in driving economic growth. For instance, using ARDL and VECM Granger causality approaches to explore the case of China, Bloch et al., [43] found that oil and coal had positive effect on growth, with similar results observed for oil, gas, coal and renewables among emerging European countries by Caraiani et al. [6]. Moreover, Park and Yoo [40] and Bhattacharya et al., [44] found that oil Granger caused growth in Malaysia and coal Granger caused growth in China, while mixed results were noticed for coal by [65] and Lei et al., [42] for the biggest coal consuming countries. Also, although, ARDL approach of Bildirici and Bakirtas [41] suggested that oil Granger caused growth among BRICTS economies, mixed results are reported for natural gas and coal. Contrarily, Apergis and Payne [19] found that coal consumption hindered economic growth in emerging market economies using FMOLS and Panel causality methods. Financial development has been identified to play positive role in economic growth of China [52], middle income countries [53] and developing, emerging and advanced economies [54]. In contrast, panel data analysis of 13 EU countries conducted by [55] revealed negative long-run effect of financial depth on real output, with similar findings reported by Hao et al. [56] for 29 Chinese provinces using impulse response function. Asteriou and Spannos [57] however found that financial development promoted economic growth before crisis (but not after the crisis) among 26 EU economies.

Furthermore, studies that considered the role of asymmetries in the link between energy and growth largely concentrate on total renewable and non-renewable energy with results that are largely mixed across countries. These studies have been conducted for the EU [35], G7 countries [33], ASEAN countries [32] and Pakistan [30]. Despite the increasing dominance of refined petroleum products in the energy mix of developing countries in driving economic growth, the literature is still very limited in this respect.

2.3. *Studies on the link among energy consumption, CO2 emissions and economic growth*

Studies that focused on all three variables are quite few and largely interested in either aggregate renewable or aggregate non-renewable energy or both with results that vary across countries and methodologies adopted. For instance, Akadiri et al., [48] employed a combination of FMOLS, panel ARDL and causality approaches for 28 EU countries and submitted that total renewable energy promoted economic growth but aggravated carbon emission. Thus, the use of renewable energy may imply a dilemma between growth and environmental quality. However, no consensus has been reached among studies that focused on total non-renewable (and fossil fuel) energy. Boontome et al., [49] used ECM Granger Causality technique to demonstrate that consumption of non-renewable energy increased carbon emission but had negligible impact on economic growth of Thailand, while Ito [45] discovered that fossil fuel consumption increased CO2 emission but retarded economic growth in developed economies, according to GMM and pooled mean group estimates. While Mensah et al. [46] and Kang et al. [47] provided evidence that total fossil fuel (African countries) and coal (India) consumption contributed positively to growth but raised the level of CO2 emission, Adewuyi and Awodumi [50] showed that results are mixed among ECOWAS member countries.

Among these studies, no role is provided for asymmetries and structural changes especially in energy consumption, which are common features in most economies. Again, the role of petroleum product and natural gas in growth and emission remains a gap in the energy-growth-emission literature. Studies on the impact of energy consumption on economic growth are mainly multi-country analysis. Moreover, the only study that focused on Africa considered total energy consumption and ignored the specific role of petroleum and natural gas in economic growth while studies that captured the role of these energy types in economic growth, and incorporate environmental concerns is still missing in the literature. Given the role of petroleum and natural gas in the economies of African oil producers, this study fills the identified gaps by disaggregating non-renewable energy consumption into these two sources while examining their effects on economic growth as well as CO2 emission, and also accounting for asymmetries and structural break.

3. Theoretical framework and methodology

3.1. Theoretical framework

The Solow growth model emphasized the role of physical labour and capital accumulation in the production of national output, with no specific role given to technical progress and natural resources. However, the modern economy has shown an overwhelming reliance on natural resources (energy) in production and transportation activities as equipment and machinery, brought about by improved technology, are powered by energy. This is evident in the increasing growth rates recorded in most economies of the world, especially the newly industrialising economies. This study therefore adopts the new growth theory which internalizes technology into production functions [58]. Thus, facilitating production and economic growth requires the deployment of critical inputs of capital and labour as well as energy [50,59]. Other factors that can influence economic growth include economic stability, trade openness and the level of financial development.

As the level of economic activities rises, demand for energy tends to rise, especially in countries with abundant energy resources, which further propels growth by facilitating the functioning of the primary inputs (labour and capital). However, the resulting higher level of carbon emissions is detrimental to growth. Production processes may also be augmented by energy-saving and carbon-efficient techniques which may reduce energy use as well as mitigating the associated adverse effect on the environment, and hence enhance human health and productivity. Further, the effect of economic growth (engendered by the rising level of economic activities) on carbon emission has been summarised in the EKC[4] hypothesis [10]. The hypothesis suggests that CO2 emission increases at lower income levels, but declines as income rises beyond certain higher levels. Also, the level of urbanisation has direct impact on the level of carbon emissions [60] just as trade openness influences the level of carbon emission due to the level of carbon embedded in exports and imports. The response of economic growth to positive change in non-renewable energy consumption may differ from response to negative change, with the attending implications for environmental quality.

3.2. Methodology

3.2.1. Model specification and Estimation technique

For the effect of energy consumption on economic growth, this study follows the model specification of Lee and Chang [3]; using the new growth theory which sets real GDP (Y) as a function of real capital stock (KS), physical labour (L) and energy consumption (E):

$$\mathrm{Y} = \mathrm{f}(\mathrm{KS},\ \mathrm{L},\ \mathrm{E}) \tag{1}$$

This equation can be rewritten using the Cobb Douglas production function as:

$$\mathrm{Y_t} = \mathrm{AK}^{\alpha t}\mathrm{L}^{\beta t}\mathrm{E}^{\theta t}, \quad \textit{such that}\ \ \alpha+\beta+\theta=1 \tag{2a}$$

where α, β and θ refers to the coefficient elasticities of capital, labour and energy consumption respectively. Expressing the variables in equation (2a) in per capita terms, we have the following

$$\mathrm{y_t} = \mathrm{Ak}^{\alpha t}\mathrm{e}^{\theta t} \tag{2b}$$

Adding some control variables, such as financial development (FD), and trade openness (TO), which influence the efficiency of the production technology (A) to equation (2b), and log linearising the equation yield

$$\mathrm{Iny_t} = \alpha_0 + \alpha_1\mathrm{In}(\mathrm{e_t}) + \alpha_2\mathrm{In}(\mathrm{k_t}) + \alpha_3\mathrm{In}(\mathrm{FD_t}) + \alpha_4\mathrm{In}(\mathrm{TO_t}) + \mu_t \tag{3}$$

where $i = 1, \ldots, N$ represents the country and $t = 1, \ldots, T$ represents the time period. *y* is the real GDP per capita (GDPC), *k (PCAP)* and *e (ECP)* means capital per head and energy use per capita respectively while other variables are as specified earlier. Also, μ_t is the residual term, and *In* represents natural logarithm. The energy consumption per capita will be broken down into per capita petroleum (PET) and natural gas consumption (GAS).

In specific terms, the effect of renewable energy consumption on economic growth is examined using the following econometrics model:

$$\mathrm{GDPC_t} = \alpha_0+\alpha_1\mathrm{PET_t}+\alpha_2\mathrm{GAS_t}+\alpha_3\mathrm{PCAP_t} + \alpha_4\mathrm{FD_t} + \alpha_4\mathrm{TO_t}+\mu_t \tag{4}$$

In order to analyse the role of non-renewable energy consumption (PET and GAS) in carbon emission, we specified equation (5) in line with the Environmental Kuznets Curve- EKC equation) which was applied by previous studies such as Jayanthakumaran et al. [10] where the production of CO2 emissions in China and India depends on most of the variables in equation (4). Following Jayanthakumaran et al. [10]; we have

$$\mathrm{CO2} = \mathrm{f}(\mathrm{y},\ \mathrm{y}^2,\ \mathrm{e},\ \mathrm{t}) \tag{5}$$

where *CO2* is per capita CO2 emissions, *y* indicates per capita real income, y^2 is the square of per capita real income, *TO* stands for trade openness while *e* measures per capita energy consumption. This specification is modified to accommodate the role of technology *(A)* captured by carbon intensity of energy *(CINT)*. Also, urbanisation *(URB)* is included while renewable (petroleum and natural gas) energy replaces total energy consumption.

$$\mathrm{CO2} = \mathrm{f}(\mathrm{y},\ \mathrm{y}^2,\ \mathrm{e},\ \mathrm{TO},\ \mathrm{A},\ \mathrm{URB}) \tag{6}$$

The econometric form of the model is specified as;

$$\begin{aligned}\mathrm{CO2PC_t} = {} & \theta_0 + \theta_1\mathrm{PET_t} + \theta_2\mathrm{GAS_t} + \theta_3\mathrm{GDPC_t} + \theta_4\mathrm{GDPC_t^2} \\ & + \theta_5\mathrm{FD_t} + \theta_6\mathrm{CINT_t} + \theta_7\mathrm{URB_t} + \theta_8\mathrm{TO_t} + \pi_t\end{aligned} \tag{7}$$

where $\mu_t, \pi_t =$ White noise disturbance term.

Following the possibility of asymmetries in the response of economic growth and carbon emission to positive and negative changes in non-renewable energy consumption (natural gas and petroleum), this study adopts the non-linear autoregressive distributed lag (NARDL) bound testing approach to empirically analyse the functional forms above. It also accounts for the possible influence of structural break in the consumption of these energy types on growth and CO2 emission. The technique shows the long run relationships and dynamic interactions among the variables of interest. It estimates the co-integrating

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[4] Environmental Kuznet Curve.

relationship after determining the optimal lag order of the model while accommodating regressors that are stationary at either levels, I (0), or first difference, I (1). Moreover, long run and short run parameters of the models can be simultaneously estimated [61].

Hence, the linear autoregressive distributed lag (ARDL) specification without asymmetry and structural break effects in short-run and long-run is written as[5]:

$$\begin{aligned}\Delta GDPC_t = \alpha_1 + \ & \theta_1 GDPC_{t-1} + \theta_2 PET_{tt} + \theta_3 GAS_t + \theta_4 PCAP_t + \theta_5 FD \\ & + \theta_6 TO_t + \sum_{i=0}^{m}\beta_i \Delta GDPC_{t-i} + \sum_{i=0}^{m}\beta_i \Delta PET_{t-i} + \sum_{i=0}^{m}\beta_i \Delta GAS_{t-i} \\ & + \sum_{i=0}^{m}\beta_i \Delta PCAP_{t-i} + \sum_{i=0}^{m}\beta_i \Delta FD_{t-i} + \sum_{i=0}^{m}\beta_i \Delta TO_{t-i} + \pi_{1t}\end{aligned} \tag{8}$$

$$\Delta GAS_t^{+} = \sum_{j=1}^{t}\Delta GAS_j^{+} = \sum_{j=1}^{t}\max(\Delta GAS_j, 0) \text{ and}$$
$$\Delta GAS_t^{-} = \sum_{j=1}^{t}\Delta GAS_j^{-} = \sum_{j=1}^{t}\min(\Delta GAS_j, 0) \tag{10a}$$

Similarly,

$$\Delta PET_t^{+} = \sum_{j=1}^{t}\Delta PET_j^{+} = \sum_{j=1}^{t}\max(\Delta PET_j, 0) \text{ and}$$
$$\Delta PET_t^{-} = \sum_{j=1}^{t}\Delta PET_j^{-} = \sum_{j=1}^{t}\min(\Delta PET_j, 0) \tag{10b}$$

Thus, the non-linear ARDL model can be specified for economic growth and carbon emission as follows:

$$\begin{aligned}\Delta GDPC_t = \alpha + \theta_1 GDPC_{t-1} + \theta_2^{+} GAS_{t-1}^{+} + \theta_3^{-} GAS_{t-1}^{-} + \theta_4^{+} PET_{t-1}^{+} \\ + \theta_5^{-} PET_{t-1}^{-} + \theta_6 Z_t + \sum_{i=1}^{n}\rho_i \Delta GDPC_{t-i} + \\ \sum_{i=0}^{m}(\beta_i^{+}\Delta GAS_{t-i}^{+} + \beta_i^{-}\Delta GAS_{t-i}^{-}) + \sum_{i=0}^{m}(\beta_i^{+}\Delta PET_{t-i}^{+} + \beta_i^{-}\Delta PET_{t-i}^{-}) + \sum_{i=0}^{m}\beta_i \Delta Z_{t-i} + \pi_{1t}\end{aligned} \tag{11a}$$

$$\begin{aligned}\Delta CO2PC_t = \alpha + \theta_1 CO2PC_{t-1} + \theta_2^{+} GAS_{t-1}^{+} + \theta_3^{-} GAS_{t-1}^{-} + \theta_4^{+} PET_{t-1}^{+} + \theta_5^{-} PET_{t-1}^{-} + \theta_6 Z_t + \sum_{i=1}^{n}\rho_i \Delta CO2PC_{t-i} \\ + \sum_{i=0}^{m}(\beta_i^{+}\Delta GAS_{t-i}^{+} + \beta_i^{-}\Delta GAS_{t-i}^{-}) + \sum_{i=0}^{m}(\beta_i^{+}\Delta PET_{t-i}^{+} + \beta_i^{-}\Delta PET_{t-i}^{-}) + \sum_{i=0}^{m}\beta_i \Delta Z_{t-i} + \pi_{2t}\end{aligned} \tag{11b}$$

$$\begin{aligned}\Delta CO2PC_t = \alpha_1 + \ & \theta_1 CO2PC_{t-1} + \theta_2 PET_t + \theta_3 GAS_t + \theta_4 GDPC_t + \theta_5 GDPC_t^2 \\ & + \theta_6 FD_t + \theta_7 CINT_t + \theta_8 URB_t + \theta_9 TO_t + \sum_{i=0}^{m}\beta_i \Delta CO2PC_{t-i} \\ & + \sum_{i=0}^{m}\beta_i \Delta PET_{t-i} + \sum_{i=0}^{m}\beta_i \Delta GAS_{t-i} + \sum_{i=0}^{m}\beta_i \Delta GDPC_{t-i} + \sum_{i=0}^{m}\beta_i \Delta GDPC_{t-1}^2 \\ & + \sum_{i=0}^{m}\beta_i \Delta FD_{t-i} + \sum_{i=0}^{m}\beta_i \Delta CINT_{t-i} + \sum_{i=0}^{m}\beta_i \Delta URB_{t-i} + \sum_{i=0}^{m}\beta_i \Delta TO_{t-i} + \pi_{2t}\end{aligned} \tag{9}$$

The study also specifies non-linear ARDL (NARDL) models developed by Shin et al. (2014), which accommodates the potential long-run and short-run asymmetric effects. Natural gas (and petroleum) consumption per capita are first decomposed into positive, ΔGAS_t^{+} (ΔPET_t^{+}), and negative, ΔGAS_t^{-} (ΔPET_t^{-}), partial sums for increases and decreases respectively such that:

where θ^{+} and θ^{-} capture the short-run asymmetry, while β^{+} and β^{-} capture the long-run, with the subscript (+) and (−) referring to the positive and negative partial sum decomposition. Z represents all other explanatory variables as contained in equations (8) and (9), including structural break dummies. Long-run coefficients with respect to the negative and positive changes in the natural gas (and petroleum) consumption per capita can be computed as - θ_2^{+}/θ_1 and - θ_2^{-}/θ_1 respectively. Wald test can be performed on the null hypothesis of long-run symmetry ($-\theta_2^{+}/\theta_1 = -\theta_2^{-}/\theta_1$) for the two energy types. In the short-run, asymmetric response of economic growth and CO2 per capita to positive and negative changes in the consumption of these energy types is captured by the parameters β_i^{+} and β_i^{-} respectively. Thus, the short-run symmetry can be tested using the Wald tests on null hypothesis of short-run symmetry such that $\beta_i^{+} = \beta_i^{-}$ for all $i = 0, \ldots, m$.

If both null hypotheses of long-run and short-run asymmetry are not rejected, then, the NARDL models collapse to the linear ARDL (equations (8) and (9)). However, if the long-run symmetry is not rejected, equations (11a) and (11b) reduces to:

$$\begin{aligned}\Delta GDPC_t = \alpha + \theta_1 GDP_{t-1} + \theta_2 GAS_{t-1} + \theta_3 PET_{t-1} + \theta_4 Z_t \\ + \sum_{i=1}^{n}\rho_i \Delta GDPC_{t-i} + \sum_{i=0}^{m}(\beta_i^{+}\Delta GAS_{t-i}^{+} + \beta_i^{-}\Delta GAS_{t-i}^{-}) \\ + \sum_{i=0}^{m}(\beta_i^{+}\Delta PET_{t-i}^{+} + \beta_i^{-}\Delta PET_{t-i}^{-}) + \sum_{i=0}^{m}\beta_i \Delta Z_{t-i} + \pi_{1t}\end{aligned} \tag{12a}$$

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[5] All variables are expressed in their natural logarithms.

Table 2

Variable description and data sources.

Variable	Description	Measurement	Data Sources
GDPC	Gross domestic product (GDP) per capita	GDP per capita (constant 2010 US$)	World Development Indicators
GDPC2	Square of gross domestic product (GDP) per capita	Square of GDP per capita (constant 2010 US$)	Computed based on data from World Development Indicators
PET	Petroleum consumption per capita	Total petroleum consumption per capita (Litres)	Computed based on data from US Energy Information Administration
GAS	Natural gas consumption per capita	Natural gas consumption per capita (cubic feet)	Computed based on data from US Energy Information Administration
CO2PC	Carbon emission per capita	CO2 Emissions per capita (kilograms)	Computed based on data from World Development Indicators
PCAP	Physical capital stock per head	Gross fixed capital formation per head (constant 2010 US$)	Computed based on data from World Development Indicators
FD	Financial development	Domestic credit to private sector (% of GDP)	World Development Indicators
TO	Trade openness	Exports of goods and services + imports of goods and services as a % of GDP	World Development Indicators
URB	Urbanisation	Population in urban agglomerations of more than 1 million (% of total population)	World Development Indicators
CINT	Carbon intensity of energy	CO2 intensity (kg per kg of oil equivalent energy use)	World Development Indicators

Source: Author's compilation

$$\Delta CO2PC_t = \alpha + \theta_1 CO2PC_{t-1} + \theta_2 GAS_{t-1} + \theta_3 PET_{t-1} + \theta_4 Z_t + \sum_{i=1}^{n} \rho_i \Delta CO2PC_{t-i} + \sum_{i=0}^{m} (\beta_i^+ \Delta GAS_{t-i}^+ + \beta_i^- \Delta GAS_{t-i}^-) + \sum_{i=0}^{m} (\beta_i^+ \Delta PET_{t-i}^+ + \beta_i^- \Delta PET_{t-i}^-) + \sum_{i=0}^{m} \beta_i \Delta Z_{t-i} + \pi_{2t} \tag{12b}$$

This shows that asymmetry only occurs in the short-run. Similarly, if the short-run symmetry is not rejected, equations (11a) and (11b) reduces to:

$$\Delta CO2PC_t = \alpha + \theta_1 CO2PC_{t-1} + \theta_2^+ GAS_{t-1}^+ + \theta_3^- GAS_{t-1}^- + \theta_4^+ PET_{t-1}^+ + \theta_5^- PET_{t-1}^- + \theta_6 Z_t + \sum_{i=1}^{n} \rho_i \Delta CO2PC_{t-i} + \sum_{i=0}^{m} \beta_i \Delta GAS_{t-i} + \sum_{i=0}^{m} \beta_i \Delta PET_{t-i} + \sum_{i=0}^{m} \beta_i \Delta Z_{t-i} + \pi_{1t} \tag{13}$$

This shows that asymmetry only occurs in the long-run.

3.2.2. Data and variable description

Data utilized for this study cover the period 1980–2015 due to data availability constraint across all the selected countries. The data were obtained from two sources: World Bank, World Development Indicators (WDI, online) and US Energy Information Administration (EIA). The variables used for estimations are described in Table 2.

4. Empirical results and discussions

4.1. Preliminary analysis

Table 3 presents the summary statistics with the mean, maximum and minimum values, as well as the standard deviation of the variables used for the analysis. The statistics reveal that Algeria had the highest mean of carbon emission per capita (CO2PC-8.03) with minimum and maximum of 7.55 and 8.17 respectively. Gabon had the lowest average carbon emission per capita of about 2.57 ranging from 2.34 to 2.87. Average GDP per capita (GDPC) was higher in Gabon (9.27) than any other selected country with minimum of 9.09 and maximum of 9.45. Nigeria also had the least average GDP per capita (7.37) which ranges from 7.04 to 7.84. On average and in per capita terms, Algeria was the leading consumer of natural gas (GAS) among the top oil producers in Africa with a mean of about 10.19, ranging from 9.76 to 10.53 while Gabon was the leading consumer of petroleum products (PET) with a mean of 6.59, and minimum and maximum of 6.28 and 6.94 respectively. Interestingly, on average, Gabon, which recorded the highest GDP per capita, consumed the most of petroleum products in per capita terms, although its natural gas consumption was about midway among the top oil producers in Africa.

As shown by the standard deviation, volatility was highest in Angola for CO2 per capita (0.48), and GDP per capita (0.32), Egypt for dry natural gas (0.85) and Angola for petroleum (0.39). Conversely, Algeria was the least volatile economy in terms of carbon emission per capita (0.13) and natural gas consumption per capita (0.15), while Gabon and Egypt were least volatile in terms of GDP per capita (0.10) and for petroleum consumption (0.08) respectively.

Due to the possibility of asymmetry and structural change in natural gas and petroleum consumption per capita, traditional unit root tests,

Table 3
Summary of statistics.

		CINT	CO2PC	FD	GAS	GDPC2	GDPC	PCAP	PET	TO	URB
Algeria	Mean	5.83	8.03	2.88	10.19	68.12	8.25	3.35	6.11	4.03	1.95
	Maximum	6.39	8.17	4.24	10.53	71.83	8.48	3.64	6.44	4.34	2.13
	Minimum	5.51	7.55	1.36	9.76	64.97	8.06	3.03	5.89	3.49	1.88
	Std. Dev.	0.17	0.13	0.97	0.15	2.02	0.12	0.17	0.16	0.20	0.06
Angola	Mean	4.94	6.63	–	7.17	62.98	7.93	2.85	5.13	4.82	3.00
	Maximum	5.45	7.29	–	7.46	69.46	8.33	7.94	5.87	7.94	3.30
	Minimum	4.11	5.73	–	5.82	56.27	7.50	1.35	4.64	3.91	2.55
	Std. Dev.	0.40	0.48	–	0.32	4.25	0.27	1.04	0.39	0.65	0.24
Egypt	Mean	5.62	7.47	3.51	8.94	56.79	7.53	3.02	6.15	3.92	3.19
	Maximum	5.85	7.86	4.01	9.99	62.47	7.90	3.54	6.25	4.41	3.25
	Minimum	5.46	6.95	2.58	6.54	50.42	7.10	2.53	5.85	3.55	3.12
	Std. Dev.	0.07	0.28	0.33	0.85	3.75	0.25	0.24	0.08	0.22	0.05
Gabon	Mean	5.73	2.57	8.36	8.06	86.00	9.27	3.31	6.59	4.50	–
	Maximum	6.18	2.87	9.12	9.10	89.24	9.45	3.83	6.94	4.79	–
	Minimum	5.30	2.34	7.95	7.07	82.69	9.09	2.98	6.28	4.30	–
	Std. Dev.	0.26	0.14	0.36	0.49	1.80	0.10	0.21	0.19	0.11	–
Nigeria	Mean	4.41	6.38	3.80	7.46	54.43	7.37	2.48	4.84	3.87	2.54
	Maximum	4.94	6.83	4.07	8.23	61.52	7.84	3.56	5.08	4.40	2.74
	Minimum	3.81	5.73	3.40	6.25	49.63	7.04	1.70	4.43	3.07	2.21
	Std. Dev.	0.31	0.30	0.22	0.46	3.89	0.26	0.46	0.19	0.37	0.15

Source: Author; Data from WDI and US Energy Information Administration (EIA)

non-linear unit root tests, and unit root test with structural break were conducted. For traditional unit root tests, KPSS and Phillips-Perron (PP) unit root tests were performed to determine the stationarity property of the series to provide for more reliable decision and the results are presented in Table 4. Unlike PP, KPSS tests the null hypothesis of no unit root based on linear regression [62]. The results show that all the variables are stationary either at level I (0) or at first difference I (1). Also, based on ADF unit root test with structural break (Table 5), all the variables are either I (0) or I (1). Moreover, the results of KSS [63] non-linear unit root test are presented in Table 6 and also suggest that the variables are either stationary at levelI (0) or at first difference I (1). Thus, the ARDL approach is adopted in this study.

The results of the ARDL-bounds test for each model with and without structural break and asymmetry are presented in Table 7. In the models for carbon emissions without asymmetry and structural break for Algeria and Nigeria, as well as similar models for economic growth for Egypt and Gabon, the F-statistics is higher than the upper bound critical value at 1%. In the case of carbon emission model for Gabon, the F-statistics is higher than the upper bound critical value at 5% while it is higher than the upper bound critical value at 10% for other models. Therefore, null hypothesis of no co-integration is rejected and long-run co-integration relationship is established among the variables in these models. For economic growth models for Angola and Nigeria, as well as carbon emission model for Egypt, the F-statistics fall within the critical values either at 1% or 5% suggesting inconclusive decision.

In the models with asymmetry and structural break, the F-statistics is higher than the upper bound critical value at 1% in most of the countries and 5% in others implying that the null hypothesis of no co-integration is rejected. Thus, long-run co-integration relationship exists among the variables. Therefore, the importance of accounting for asymmetry and structural break is underscored by these results.

4.2. The impact of non-renewable energy on economic growth and CO2 emission

4.2.1. Impact of non-renewable energy on economic growth

Following the evidence of non-linear cointegration in the presence of structural break for all countries, the study proceeds to estimate non-linear ARDL models accounting for structural break in petroleum and natural gas consumption. Results of the asymmetric impact of the consumption of these non-renewable energy products on economic growth and carbon emission per capita are presented in Tables 8 and 9.

From the estimates of economic growth models reported in Table 8, the null hypotheses of long-run and short-run symmetry are not rejected at conventional significance levels for both energy types only in the case of Algeria. This implies that increases and decreases in the consumption of these energy types had symmetric effects on real GDP per capita in the country. For this country, long-run impact of natural gas consumption per capita on GDP per capita is significant positive in Algeria with elasticity of 1.17 while petroleum consumption per capita produced insignificant effect.

For other countries, the asymmetric effects of the energy types on economic growth vary by time horizon and type of energy. For instance, for natural gas consumption per capita, while the null hypothesis of symmetry is not rejected in the long-run and short-run for Nigeria, the hypothesis is not rejected only in the long-run for the case of Egypt and in the short-run for Gabon. For petroleum consumption per capita, the symmetry hypothesis could not be rejected in the short-run for Angola, Egypt and Gabon, while the hypothesis is not rejected in the long-run for Gabon and Nigeria.

Long-run results indicate that both positive and negative changes in natural gas consumption per capita had significant (negative) effect on real GDP per capita only in Gabon.[6] Thus, 1.0% increase in natural gas consumption per capita reduced economic growth by about 8.50%, as a similar reduction in the consumption of this energy contributed to improvement in economic growth by 9% in this country. Long-run estimates further show that the effect of both positive and negative changes in petroleum consumption per capita on GDP per capita is significant (negative) in Angola and Egypt, and significant positive in Nigeria. The results suggest that 1.0% fall in petroleum consumption per capita raised GDP per capita by about 1.34% and 1.14% in Angola and Egypt respectively but reduced GDP per capita in Nigeria by about 3.19%. While a similar 1.0% increase in petroleum consumption per capita led to a decline in GDP per capita by about 1.22% and 1.16% in Angola and Egypt respectively, it raised GDP per capita in Nigeria by 3.15%. While structural break in natural gas consumption per capita had long-run significant positive influence on economic growth in Egypt and Nigeria, such break in petroleum consumption per capita produced similar effect on economic growth in Angola and Egypt. Long-run results further show that physical capital significantly contributed to increase in GDP per capita in Angola and Egypt, while financial development is

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[6] As indicated in the methodology section, long-run coefficients with respect to the negative and positive changes in the natural gas (and petroleum) consumption per capita can be computed as $-\theta_2^+/\theta_1$ and $-\theta_2^-/\theta_1$ respectively.

Table 4
Traditional unit root test.

	Kwiatkowski-Phillips-Schmidt-Shin (KPSS)		Phillips-Perron (PP)		Decision
	Level	1st Difference	Level	1st Difference	
ALGERIA					
CO2PC	0.2842	0.2997	−3.2856**	−6.9379*	I (0)
GDPC	0.4289***	0.2748	−0.0973	−3.1839**	I (1)
GDPC2	0.4313***	0.2788	−0.0701	−3.1740**	I (1)
PET	0.5729**	0.1754	−0.0273	−6.0079*	I (1)
GAS	0.2694	0.4232***	−2.1339	−8.1185*	I (1)
CINT	0.6722**	0.2823	−4.1625*	−9.6254*	I (1)
FD	0.3280	0.1885	−1.4655	−4.8184*	I (1)
PCAP	0.1942	0.2585	−1.7184	−4.9230*	I (1)
TO	0.4626**	0.1778	−1.6562	−4.2250*	I (1)
URB	0.6253**	0.3951***	−5.6189*	−2.0505	I (0)
ANGOLA					
CO2PC	0.5718**	0.2393	−1.1286	−11.6560*	I (1)
GDPC	0.2787	0.2258	−0.7302	−2.9960**	I (1)
GDPC2	0.2833	0.2317	−0.6938	−2.9559**	I (1)
PET	0.5233**	0.3498***	0.2178	−5.7865*	I (1)
GAS	0.4006***	0.5000**	−27132***	−3.5512*	I (1)
CINT	0.5741**	0.1899	−1.5717	−12.6916*	I (1)
PCAP	0.1147	0.3118	−3.9023*	−18.8054*	I (0)
TO	0.1338	0.1134	−4.0491*	−11.0154*	I (0)
URB	0.6989**	0.4824**	−5.4098*	−0.5625	I (0)
EGYPT					
CO2PC	0.6958**	0.0780	−1.3894	−7.8991*	I (1)
GDPC	0.7085**	0.0981	−1.0172	−3.6980*	I (1)
GDPC2	0.7070**	0.0840	−0.8441	−3.6547*	I (1)
PET	0.4989**	0.2138	−4.1020*	−4.4673*	I (1)
GAS	0.7050**	0.5043**	−4.5147*	−4.0154*	I (0)
CINT	0.1817	0.1358	−3.2145**	−9.0976*	I (0)
FD	0.3231	0.3768***	−2.9257**	−6.0356*	I (0)
PCAP	0.6836**	0.1228	−0.9269	−4.3371*	I (1)
TO	0.2197	0.0802	−2.0605	−4.9860*	I (1)
URB	0.6510**	0.1708	−0.7592	−3.1852**	I (1)
GABON					
CO2PC	0.6873**	0.5000**	−2.6868***	−7.9056*	I (0)
GDPC	0.5608**	0.1656	−2.0072	−6.0660*	I (1)
GDPC2	0.5618**	0.1657	−2.0072	−6.0660*	I (1)
PET	0.5274**	0.1423	−2.3815	−8.5972*	I (1)
GAS	0.1262	0.4355***	−2.7633***	−9.6306*	I (0)
CINT	0.6713**	0.1807	−1.0385	−9.5623*	I (1)
FD	0.3565***	0.1564	−1.8171	−5.9891*	I (1)
PCAP	0.2126	0.0398	−2.8966**	−7.6635*	I (0)
TO	0.3234	0.1564	−2.4716	−8.2824*	I (1)
NIGERIA					
CO2PC	0.1722	0.2186	−2.2437	−5.9593*	I (1)
GDPC	0.4398***	0.5792**	−0.3635	−4.8389*	I (1)
GDPC2	0.4425***	0.5893**	−0.3179	−4.8583*	I (1)
PET	0.6096**	0.1444	−0.9976	−8.9308*	I (1)
GAS	0.7311**	0.1995	−2.9773**	−12.5104*	I (1)
CINT	0.2402	0.2481	−2.2351	−6.1457*	I (1)
FD	0.1679	0.4723**	−2.4722	−9.1599*	I (1)
PCAP	0.3546***	0.3882***	−2.5428	−5.0362*	I (1)
TO	0.2087	0.1821	−1.5011	−7.2273*	I (1)
URB	0.7033**	0.6349**	−7.1939*	−3.5705*	I (0)

Note: *,** and *** indicate that the variable is stationary at 1%, 5% and 10% respectively. I(0) represents stationarity at level while I(1) denotes stationarity at first difference.
Source: Author; Data from WDI and US Energy Information Administration (EIA)

Table 5
ADF unit root tests with structural breaks.

Variables	Break Date	t-statistics	Break Date	t-statistics	Decision
		Level		First difference	
Algeria					
CINT	1998	−6.16*	2005	−5.69*	I (0)
CO2PC	2004	−3.54	2005	−6.30*	I (1)
FD	2014	−1.27	1997	−5.23*	I (1)
GAS	2010	−3.63	1993	−8.47*	I (1)
GDPC2	2001	−2.30	1994	−4.24***	I (1)
GDPC	2001	−2.30	1994	−4.25***	I (1)
PCAP	2008	−2.60	2009	−7.78*	I (1)
PET	2007	−3.07	1999	−6.66*	I (1)
TO	1998	−3.23	2002	−4.99*	I (1)
URB	1999	−7.48*	2014	−2.12*	I (0)
Angola					
CINT	2003	−5.17*	1997	−8.97*	I (0)
CO2PC	2003	−5.21*	1997	−9.17*	I (0)
GAS	2011	−4.59**	1994	−7.44*	I (0)
GDPC2	2002	−3.09	1993	−5.96*	I (1)
GPC	2002	−3.08	1993	−6.13*	I (1)
PCAP	1995	−11.39*	1995	−11.61*	I (0)
PET	2005	−3.11	2005	−8.68*	I (1)
TO	1995	−11.61*	1995	−11.70*	I (0)
URB	2007	−9.32*	2007	−4.21***	I (0)
Egypt					
CINT	2000	−4.6580**	2003	−8.3929*	I (0)
CO2PC	1994	−2.8323	2009	−8.1118*	I (1)
FD	1992	−4.8172**	2004	−7.5647*	I (0)
GAS	1999	−7.9788*	2003	−5.7409*	I (0)
GDPC2	2004	−4.1862	2002	−4.8637*	I (1)
GPC	2005	−2.0918	2003	−4.8124**	I (1)
PCAP	1992	−3.0774	1998	−4.4318*	I (1)
PET	1995	−5.0962*	1994	−4.7753**	I (0)
TO	1992	−4.8488**	2008	−5.3298*	I (0)
URB	1999	−4.7709**	2008	−2.2585	I (0)
Gabon					
CINT	2005	−3.1782	2006	−6.5890*	I (1)
CO2PC	1999	−2.9918	2008	−7.6932*	I (1)
FD	1992	−2.4781	1994	−6.4516*	I (1)
GAS	2011	−5.5250*	2011	−10.1536*	I (0)
GDPC2	1998	−3.4236	2009	−6.2904*	I (1)
GDPC	1998	−3.4184	2009	−6.3079*	I (1)
PCAP	1998	−3.1904	1998	−7.9275*	I (1)
PET	1999	−4.5796**	2008	−8.8657*	I (0)
TO	2014	−4.9040*	1994	−9.1837*	I (0)
Nigeria					
CINT	2002	−4.6195**	1995	−6.4687*	I (0)
CO2PC	1995	−2.3910	1995	−6.3257*	I (1)
FD	2006	−4.3880**	2010	−5.9049*	I (0)
GAS	2002	−5.1884*	2011	−9.7024*	I (0)
GDPC2	2003	−5.2347*	2004	−7.2277*	I (0)
GDPC	2003	−5.2530*	2004	−7.1070*	I (0)
PCAP	2007	−3.8960	2003	−6.2961*	I (1)
PET	2002	−3.5687	2007	−9.9379*	I (1)
TO	2011	−2.4606	2014	−7.2188*	I (1)
URB	1992	−2.2176	2007	−8.0378*	I (1)

Source: Author; Data from WDI and US Energy Information Administration (EIA) **Note:** *,** and *** indicate that the variable is stationary at 1%, 5% and 10% respectively. I(0) represents stationarity at level while I(1) denotes stationarity at first difference.

found to promote economic growth only in Algeria. However, either financial development or trade openness had significant reducing effect on growth in Egypt, Nigeria and Angola.

In the short-run, both positive and negative changes in natural gas consumption per capita exerted significant negative influence on GDP per capita only in Angola and Nigeria while the effect of similar changes in petroleum consumption per capita is only significant (positive) in Angola. Hence, 1.0% reduction in natural gas consumption improved economic growth by about 0.08% and 0.12% in Angola and Nigeria while 1.0% rise in the consumption of this energy type led to a decline in economic growth by about the same percentage (0.08% and 0.12%) in these countries respectively. However, 1.0% fall (rise) in petroleum consumption per capita deteriorated (raised) economic growth by about 0.53% (0.51%) in Angola. Moreover, capital stock had positive effect on economic growth in Egypt while financial development promoted growth in Algeria and Egypt but retarded it in Nigeria. Trade openness had significant negative effect on growth in Angola and Gabon. Short-run influence of structural break in natural gas consumption per capita on economic growth is significant positive in Egypt and Gabon, but the impact of similar break in petroleum consumption per capita yielded

Table 6
Non-linear unit root test.

Variable	KSSa	KSSb	Decision
Algeria			
CINT	−1.5714 (6)*	−2.0514 (6)*	I (0)
CO2PC	0.4783 (6)*	−0.9902 (6)*	I (0)
FD	−1.1871 (1)*	−1.8832 (11)*	I (0)
GAS	0.8693 (3)*	−2.2356 (6)*	I (0)
GDPC2	1.9998 (11)	−0.5173 (2)*	I (0)
GDPC	1.9792 (11)	−0.5720 (2)*	I (0)
PCAP	−0.2373 (2)*	−3.1544 (1)	I (0)
PET	1.7587 (3)*	−0.1927 (3)*	I (0)
TO	−0.0125 (11)*	−1.2714 (11)*	I (0)
URB	−3.7043 (11)	−0.2797 (9)*	I (0)
Angola			
CINT	1.3200 (11)	−2.6055 (3)*	I (0)
CO2PC	1.1525 (2)*	−1.7907 (2)*	I (0)
GAS	−1.0737*	−3.2903 (1)	I (0)
GDPC2	0.2282 (1)*	−2.1293 (1)*	I (0)
GDPC	0.3262 (1)*	−2.2234 (1)*	I (0)
PCAP	−2.9049 (1)	−3.5989 (1)	I (1)
PET	1.5861 (1)*	0.2362 (1)*	I (0)
TO	−1.3875 (1)*	−4.1988 (1)	I (0)
URB	−0.3219 (4)*	−1.8713 (1)*	I (0)
Egypt			
CINT	−0.2376 (1)*	−4.0409 (9)	I (0)
CO2PC	2.5579 (1)*	−1.1610 (1)*	I (0)
FD	0.2765 (6)*	−0.7918 (6)*	I (0)
GAS	1.6079 (2)*	−0.9723 (3)*	I (0)
GDPC2	0.8665 (11)*	−1.6120 (11)*	I (0)
GDPC	1.1890 (11)*	−1.5815 (11)*	I (0)
PCAP	−3.2509 (8)	−2.3230 (1)*	I (0)
PET	0.4762 (5)*	−4.7909 (1)	I (0)
TO	−1.1661 (8)*	−2.6260 (10)*	I (0)
URB	0.9223 (2)*	−1.7477 (2)*	I (0)
Gabon			
CINT	−0.9348 (7)*	−3.1555 (9)	I (0)
CO2PC	−1.2778 (11)*	−1.4298 (9)*	I (0)
FD	−0.6431 (10)*	−3.2731 (7)	I (0)
GAS	0.0389 (7)*	−1.6940 (7)*	I (0)
GDPC2	−1.3131 (11)*	−1.6075 (8)*	I (0)
GDPC	−1.2733 (11)*	−1.6153 (8)*	I (0)
PCAP	−0.5265 (10)*	−3.4198 (10)	I (0)
PET	−0.5912 (1)*	−1.2361 (1)*	I (0)
TO	−1.0249 (11)*	0.6031 (11)*	I (0)
Nigeria			
CINT	−0.0981 (9)*	−0.4973 (9)*	I (0)
CO2PC	0.0739 (9)*	−0.3788 (9)*	I (0)
FD	−0.7080 (3)*	−3.1191 (1)	I (0)
GAS	0.0779 (8)*	−1.9748 (1)*	I (0)
GDPC2	0.9954 (1)*	0.1595 (1)*	I (0)
GDPC	0.9608 (1)*	0.1031 (1)*	I (0)
PCAP	−0.4525 (4)*	−2.9634 (3)	I (0)
PET	−1.4430 (2)*	−0.9216 (8)*	I (0)
TO	−1.3655 (9)*	−1.6595 (10)*	I (0)
URB	3.4219 (11)*	2.0133 (11)*	I (0)

Note: (a) a = raw series; b = demeaned series. (b) Note: *indicate significance at 10% (c) Critical values: raw series (10% = −1.92) and demeaned series (10% = −2.66). I(0) represents stationarity at level while I(1) denotes stationarity at first difference.
Source: Author; Data from WDI and US Energy Information Administration (EIA)

the similar effect on economic growth only in Angola.

The speed of adjustment of economic growth to long run equilibrium as indicated by the error correction term varies from about 20% in Egypt to 99% in Algeria. Moreover, the diagnostic statistics suggest that the error is normally distributed, with absence of error autocorrelation and absence of functional misspecification in all countries, as suggested by the Jacque Bera (JB), Breusch–Godfrey (BG) serial correlation LM and Ramsey RESET test statistics respectively. Also, the ARCH heteroscedasticity test statistics indicate that the variances of the error terms do not differ across observations. The CUSUM and CUSUM square, reported in appendix A, shows that all estimated models are stable.

4.3. Impact of non-renewable energy on CO2 emission

The non-linear ARDL estimates of carbon emission per capita models are reported in Table 9. The null hypothesis of symmetry in the long-run is rejected for both energy types only in the case of Nigeria, suggesting that positive and negative changes in the consumption of these energy types had asymmetrical long-run impact on carbon emission per capita in the country. Moreover, while asymmetry is confirmed in the short-run for both energy types in Angola, Gabon and Nigeria, evidence of this asymmetry is only found for petroleum consumption per capita in Egypt. Thus, in Algeria, no evidence of asymmetry is found both in the long-run and in the short-run while the influence of both energy types on carbon emission is insignificant in both time horizons.

Further, long-run results indicate that increase and decrease in natural gas consumption per capita had significant positive impact on carbon emission per capita in Angola but their effects on this emission is significant negative in Gabon. Specifically, 1.0% decrease (increase) in natural gas consumption per capita reduced (escalated) carbon emission per capita by 0.06% (0.01%) in Angola. Conversely, 1.0% decline (rise) in natural gas consumption per capita raised (reduced) carbon emission per capita by about 13.08% (13.23%) in Gabon. In Nigeria, while negative change in natural gas consumption per capita produced significant reducing effect on carbon emission, the impact of a positive change in the consumption of this energy type is negligible. Thus, 1.0% decrease in natural gas consumption per capita contributed about 1.05% to the decline in the level of carbon emission per capita in the country.

For petroleum consumption per capita, the effect of both positive and negative changes on carbon emission per capita is significant negative in Angola in the long-run as 1.0% reduction (increase) in the consumption of this energy type yielded 1.34% (1.22%) increase (fall) in carbon emission per capita. In Nigeria, only positive change in petroleum consumption per capita produced long-run significant (positive) impact on carbon emission with 1.0% rise in the consumption of petroleum product per capita associated with 11.12% rise in carbon emission per capita. Results further confirm the existence of EKC hypothesis in Angola and Nigeria but inverted-KC in Gabon in the long-run. Long-run influence of structural break in natural gas consumption per capita is significant positive in Angola and negative in Gabon, while similar break in petroleum consumption per capita produced significant effects in Algeria (negative) and Angola (positive). Moreover, the impact of urbanization is found to be significant negative in Algeria and Angola while carbon emission per capita exhibited long-run significant positive response to carbon intensity in Algeria, Angola and Egypt, which underscores the important role of carbon-reducing technologies in promoting environmental quality in these economies.

In the short-run, negative and positive changes in natural gas consumption per capita generated significant adjustments in carbon emission per capita in all countries, except Nigeria. For instance, 1.0% reduction in natural gas consumption per capita escalated carbon emission per capita by 0.64% in Algeria and 0.01% in Egypt, but reduced the emission by 0.06% and 0.11% Angola and Gabon respectively. Also, 1.0% increase in per capita consumption of natural gas led to a rise in the level of carbon emission by 0.63% and 0.05% in Algeria and Angola respectively, but reduced the emission by 0.01% in Egypt and 0.48% in Gabon.[7] In terms of petroleum consumption per capita, negative and positive changes exerted short-run significant effect on carbon emission per capita in all the countries except Algeria. Thus, 1.0% decrease in petroleum consumption per capita raised carbon

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[7] Short-run effect of the negative and positive changes in natural gas consumption per capita and petroleum consumption per capita on carbon emission per capita is the sum of their short-run coefficients.

Table 7
ARDL bounds test for Co-integration relationship.

Country	Model	F-Statistics	K	90% level		95% level		99% level	
				I (0)	I (1)	I (0)	I (1)	I (0)	I (1)
Without Asymmetry and Structural Break									
Algeria	Economic Growth	3.79	6	2.53	3.59	2.87	4	3.6	4.9
	Carbon Emission	6.29	7	2.03	3.13	2.32	3.5	2.96	4.26
Angola	Economic Growth	2.68	5	1.81	2.93	2.14	3.34	2.82	4.21
	Carbon Emission	3.05	7	1.7	2.83	1.97	3.18	2.54	3.91
Egypt	Economic Growth	4.78	6	2.12	3.23	2.45	3.61	3.15	4.43
	Carbon Emission	2.42	6	2.12	3.23	2.45	3.61	3.15	4.43
Gabon	Economic Growth	6.67	6	2.12	3.23	2.45	3.61	3.15	4.43
	Carbon Emission	3.53	6	1.75	2.87	2.04	3.24	2.66	4.05
Nigeria	Economic Growth	3.02	6	2.53	3.59	2.87	4	3.6	4.9
	Carbon Emission	6.55	7	2.03	3.13	2.32	3.5	2.96	4.26
With Asymmetry and Structural Break									
Algeria	Economic Growth	4.05	10	2.07	3.16	2.33	3.46	2.84	4.1
	Carbon Emission	4.97	10	1.6	2.72	1.82	2.99	2.26	3.6
Angola	Economic Growth	6.15	9	1.88	2.99	2.14	3.3	2.65	3.97
	Carbon Emission	3.32	10	1.6	2.72	1.82	2.99	2.26	3.6
Egypt	Economic Growth	3.04	9	1.63	2.75	1.86	3.05	2.37	3.68
	Carbon Emission	3.44	9	1.63	2.75	1.86	3.05	2.37	3.68
Gabon	Economic Growth	11.22	10	1.83	2.94	2.06	3.24	2.54	3.86
	Carbon Emission	9.70	9	1.88	2.99	2.14	3.3	2.65	3.97
Nigeria	Economic Growth	4.75	9	1.88	2.99	2.14	3.3	2.65	3.97
	Carbon Emission	8.20	9	2.16	3.24	2.43	3.56	2.97	4.24

Source: Author's computation

emission per capita by about 0.10%, 0.63%, 1.42% and 1.50% in Angola, Egypt, Gabon and Nigeria respectively. However, a positive change in this energy type by 1.0% led to about 0.10%, 0.63%, 1.41% and 1.44% reduction in carbon emission in these countries respectively. In the short-run, the EKC hypothesis is valid in all countries, except Egypt. Short-run impact of structural break in natural gas consumption per capita on carbon mission per capita is only confirmed in Gabon (negative) while structural break in petroleum consumption per capita is found to produce similar effect only in Algeria. Also, carbon emission per capita responded positively to carbon intensity in Algeria, Angola and Egypt. For urbanization and trade openness, the response of carbon emission per capita is negative in Angola and Nigeria respectively.

The error correction terms suggest that a deviation from the long-run equilibrium level of CO2 emissions per capita in 1 year is corrected the following year with varying adjustment speed across the selected countries, ranging from 43% in Nigeria to 97% in Algeria. Diagnostic statistics confirm that the estimated models are valid and reliable. For instance, the Jacque Bera (JB), Breusch–Godfrey (BG) serial correlation LM and ARCH heteroscedasticity test statistics indicate normality of the residuals, absence of error autocorrelation and homoscedasticity of the errors respectively. Also, the Ramsey RESET test statistics show that the models are well specified. As reported in appendix B, CUSUM and CUSUM square tests confirm the stability of all estimated models.

4.4. What impact of non-renewable energy is observed?

No asymmetric effect of natural gas and petroleum consumption per capita on economic growth is observed in Algeria in both time dimensions. Positive changes in natural gas consumption per capita engendered long-run economic growth only in Gabon, while similar changes in petroleum consumption per capita promoted growth only in Angola and Egypt. This corroborates the findings of Luqman et al. [30] in the case of Pakistan's renewable and nuclear energy. Negative changes in the consumption of both energy types are discovered to either retard long-run growth or exert negligible impact in all selected countries, except Nigeria where such changes in petroleum consumption per capita enhanced long-run growth, which is partially in line with the asymmetric causality results of Tuna and Tuna [32] for Indonesia. In the short-run, positive changes in the per capita consumption of these products either hindered growth or exhibited insignificant influence. Only decrease in natural gas consumption promoted economic growth, especially in Angola and Nigeria, which is in line with Luqman et al. [30] for renewable energy.

As in economic growth models, no evidence of asymmetry is observed in the carbon emission models only in Algeria both in the long-run and short-run. In the long-run, increases in either natural gas consumption per capita or petroleum consumption per capita raised the level of carbon emission per capita in Angola and Gabon but reduced it in Nigeria. However, a decrease in the consumption of these energy types did not pose significant influence on this emission in all the countries, except Angola. In the short-run, while positive changes in natural gas consumption per capita showed mixed results across selected countries, similar changes in petroleum consumption per capita yielded significant reducing impact on carbon emission in Gabon and Nigeria but negligible effect in other countries. Negative changes in natural gas consumption per capita reduced CO2 emission in Angola and Gabon, while carbon emissions escalated in Gabon and Nigeria with similar changes in petroleum consumption per capita. Table 10 summarises the major results from the linear and non-linear ARDL estimates.

Overall, while petroleum consumption per capita positively and significantly impacted income per capita in Angola and Egypt, their impact on carbon emission per capita is negligible. These findings are consistent when positive and negative changes in petroleum consumption per capita are considered, especially in the long-run. Similar

Table 8

Non-linear ARDL estimates for economic growth.

Variable	Algeria	Angola	Egypt	Gabon	Nigeria
Long-run					
GDPC(-1)	0.64 (0.13)*	0.64 (0.17)*	0.80 (0.09)*	0.02 (0.20)	0.54 (0.12)*
GAS	1.17 (0.15)*	–	–	–	–
PET	−0.01 (0.10)	–	–	–	–
GAS^{-}	–	−0.04 (0.14)	0.02 (0.08)	0.18 (0.05)**	−0.15 (0.15)
GAS^{+}	–	−0.004 (0.13)	0.02 (0.08)	0.17 (0.05)**	−0.14 (0.15)
PET^{-}	–	0.86 (0.26)*	0.91 (0.28)*	−0.10 (0.07)	−1.72 (0.76)**
PET^{+}	–	0.78 (0.23)*	0.93 (0.28)*	0.10 (0.07)	−1.70 (0.75)**
PCAP	−0.001 (0.04)	0.22 (0.07)*	0.50 (0.22)**	0.16 (0.08)	0.06 (0.12)
FD	1.01 (0.12)*	–	−0.53 (0.15)*	−0.23 (0.10)	−0.47 (0.20)**
TO	0.001 (0.03)	−0.54 (0.17)*	–	−0.48 (0.22)	–
GASSB	0.10 (0.06)	0.98 (0.60)	0.41 (0.13)*	0.04 (0.09)	0.61 (0.61)*
PETSB	−0.03 (0.03)	0.68 (0.26)**	0.20 (0.07)*	−0.15 (0.07)	0.21 (0.19)
C	−9.96 (7.91)	39.07 (15.47)**	–	20.16 (4.37)**	36.78 (19.27)***
TREND	0.02 (0.01)*	–	–	–	–
L^{-}_{G}	–	0.06	−0.03	−9.00**	0.28
L^{+}_{G}	–	0.01	−0.03	−8.50**	0.26
L^{-}_{P}	–	−1.34*	−1.14*	5.00	3.19**
L^{+}_{P}	–	−1.22*	−1.16*	−5.00	3.15**
Short-run					
GAS	1.17 (0.04)*	–	–	–	–
PET	−0.01 (-0.10)	–	–	–	–
GAS^{-}	–	−0.08 (0.04)***	0.004 (0.02)	−0.01 (0.02)	−0.12 (0.06)***
GAS^{-}(-1)	–	–	–	−0.04 (0.02)	–
GAS^{+}	–	−0.08 (0.04)***	0.004 (0.02)	−0.01 (0.02)	−0.12 (0.06)***
GAS^{+}(-1)	–	–	–	−0.03 (0.02)	–
PET^{-}	–	0.53 (0.16)*	0.06 (0.09)	0.04 (0.06)	−0.14 (0.21)
PET^{-}(-1)	–	–	–	−0.09 (0.05)	–
PET^{+}	–	0.51 (0.16)*	0.06 (0.09)	0.04 (0.04)	−0.14 (0.21)
PET^{+}(-1)	–	–	–	−0.09 (0.05)	–
PCAP	−0.001 (-0.04)	0.02 (0.13)	0.10 (0.02)*	0.05 (0.05)	−0.07 (0.07)
FD	1.01 (0.01)*	–	0.08 (0.03)*	0.01 (0.04)	−0.11 (0.06)***
FD (-1)	–	–	–	0.06 (0.03)	–
TO	0.001 (0.03)	−0.07 (0.04)***		−0.36 (0.09)**	–
GASSB	0.07 (0.06)	0.08 (0.09)	0.05 (0.01)*	0.10 (0.03)**	0.06 (0.07)
GASSB(-1)	–	–	–	0.14 (0.06)***	–
PETSB	−0.02 (0.02)	0.24 (0.05)*	0.01 (0.01)	−0.05 (-0.05)	0.01 (0.08)
PTSB(-1)	–	–	–	0.15 (0.04)**	–
TREND	0.02 (0.01)*	–	–	–	–
ECM(-1)	−0.99 (0.13)*	−0.36 (0.18)***	−0.20 (0.09)**	−0.98 (0.20)**	−0.46 (0.12)*
R-Square	0.99	0.99	0.99	0.99	0.98
Adj. R-Square	0.98	0.98	0.99	0.97	0.96
AIC	−5.11	−3.47	−6.50	−6.23	−2.98
SIC	−4.62	−2.66	−5.73	−4.87	−2.08
W_{LG}	0.30	4.55**	0.00001	0.01***	0.11
W_{SG}	2.62	9.74*	4.28**	5.23	1.04
W_{LP}	0.02	4.98**	9.51*	0.01	0.29
W_{SP}	2.66	0.45	0.68	1.53	7.27**
JB	0.28	0.63	1.08	1.44	0.42
BG	0.56	0.45 (1)	1.41 (1)	3.19 (1)	1.12 (1)
ARCH	0.03	1.45 (1)	0.21 (1)	0.20 (1)	0.04 (1)
R-RESET	0.42	2.81 (1)	0.02 (1)	0.75 (1)	0.13 (1)

Note: BG = Breusch–Godfrey serial correlation LM test; Ramsey = Ramsey RESET test: ARCH = ARCH heteroscedasticity; JB = Jacque Bera; AIC = Akaike info criterion; SIC = Schwarz criterion; W_{LG} = Wald test of long-run symmetry for natural gas consumption per capita; W_{SG} = Wald test of short-run symmetry for natural gas consumption per capita; W_{LP} = Wald test of long-run symmetry for petroleum consumption per capita; W_{SP} = Wald test of short-run symmetry for petroleum consumption per capita; L^{-}_{G} = long-run coefficient of asymmetric negative change in natural gas consumption per capita; L^{+}_{G} = long-run coefficient of asymmetric positive change in natural gas consumption per capita; L^{-}_{P} = long-run coefficient of asymmetric negative change in petroleum consumption per capita; L^{+}_{G} = long-run coefficient of asymmetric positive change in petroleum consumption per capita.

*, ** and *** represent significance levels at 1%, 5% and 10% respectively. Standard errors are in parenthesis.

Table 9
Non-linear ARDL Estimates for CO2 per capita.

Variable	Algeria	Angola	Egypt	Gabon	Nigeria
Long-run					
CO2PC(-1)	0.08 (0.18)	0.05 (0.15)	0.53 (0.25)***	0.08 (0.14)	0.57 (0.12)*
GAS	0.07 (0.06)	–	–	–	–
PET	0.09 (0.11)	–	–	–	–
GAS^-	–	0.04 (0.02)**	0.18 (0.14)	1.06 (0.26)*	−0.60 (0.32)***
GAS^+	–	0.05 (0.02)*	0.19 (0.14)	1.07 (0.26)*	−0.38 (0.2859)
PET^-	–	0.40 (0.05)*	−0.10 (0.57)	−0.21 (0.16)	−6.5506 (1.8322)
PET^+	–	0.39 (0.05)*	−0.06 (0.55)	−0.16 (0.15)	−6.34 (1.56)*
GDPC	−5.83 (11.80)	0.57 (0.20)**	−0.75 (0.86)	−183.45 (43.48)*	92.45 (35.16)*
GDPC2	0.39 (0.72)	−0.05 (0.01)*	0.08 (0.05)	9.88 (2.32)*	−6.44 (2.42)*
FD	–	–	–	0.03 (0.09)	–
TO	−0.02 (0.05)	–	–	–	0.43 (0.36)
CINT	0.64 (0.08)*	0.63 (0.12)*	1.34 (0.54)**	–	
URB	−1.38 (0.18)*	−0.22 (0.11)***	–	–	–
GASSB	−0.01 (0.06)	0.16(0.08)***	0.06 (0.09)	−1.34 (0.19)*	0.15 (0.37)
PETSB	−0.12 (0.07)*	0.31 (0.08)*	−0.12 (0.09)	−0.10 (-0.11)	–
C	27.36 (49.15)	–	–	852.91 (203.43)*	−291.53 (122.25)**
TREND	–	–	–	–	−0.04 (0.02)***
L^-_G	−0.24	0.06**	−0.03	−13.08*	1.05*
L^+_G	−0.24	0.01*	−0.03	−13.23*	0.67
L^-_P	0.94	−1.34*	−1.14	2.64	11.49
L^+_P	0.91	−1.22*	−1.16	1.98	11.12*
Short-run					
GAS	0.07 (0.06)	–	–	–	–
PET	0.08 (0.11)	–	–	–	–
GAS^-	–	0.05 (0.02)*	0.16 (0.12)	0.29 (0.08)**	0.10 (0.11)
GAS^-(-1)	–	0.01 (.0.001)*	−0.17 (0.07)**	−0.18 (0.08)***	–
GAS^+	–	0.05 (0.01)*	0.16 (0.12)	−0.31 (0.08)**	0.15 (0.11)
GAS^+(-1)	–	–	−0.17 (0.07)**	−0.17 (0.08)***	–
PET^-	–	−0.002 (0.05)	−0.10 (0.44)	−1.08 (0.23)*	−1.50 (0.42)*
PET^-(-1)	–	−0.10 (0.05)***	−0.53 (0.27)***	−0.34 (0.14)***	–
PET^+	–	0.01 (0.05)	−0.09 (0.44)	−1.06 (0.23)*	−1.44 (0.41)*
PET^+(-1)	–	−0.09 (0.05)***	−0.54 (0.27)***	−0.35 (0.14)***	–
GDPC	53.72 (23.88)**	0.64 (0.19)*	−0.41 (0.45)	151.82 (54.55)**	39.37 (13.14)*
GDPC(-1)	–	–	0.87 (0.46)***	399.87 (79.86)*	–
GDPC2	−3.28 (1.46)**	−0.04 (0.01)*	0.04 (0.04)	−8.22 (2.94)**	−2.78 (0.90)*
GDPC2(-1)	–	–	–	−21.54 (4.31)*	–
URB	–	−0.21 (0.10)***	–	–	–
TO	−0.02 (0.05)	–	–	–	−0.48 (0.11)*
FD	–	–	–	−0.06 (0.07)	–
FD (-1)	–	–	–	−0.05 (0.08)	–
CINT	0.77 (0.06)*	0.87 (0.04)*	0.88 (0.13)*	–	–
CINT (-1)	–	0.11 (0.03)*	−0.19 (0.11)	–	–
GASSB	−0.01 (0.06)	−0.04 (0.04)	0.04 (0.05)	−0.28 (0.10)**	0.23 (0.15)
GASSB(-1)	–	−0.15 (0.05)*	−0.12 (0.05)**	0.61 (0.14)*	
PETSB	−0.12 (0.07)***	0.04 (0.04)	−0.05 (0.04)	−0.16 (0.09)	0.06 (0.21)
PETSB(-1)	–	−0.07 (0.03)**	–	−0.45 (0.15)**	
TREND	−1.27 (0.35)*	–	–	–	−0.02 (0.01)
ECM(-1)	−0.92 (0.18)*	−0.95 (0.15)*	−0.47 (0.25)***	−0.92 (0.1441)*	−0.43 (0.12)*
R-Square	0.97	0.99	0.99	0.99	0.96
Adj. R-Square	0.95	0.99	0.99	0.98	0.91
AIC	−4.10	−5.98	−4.65	−4.08	−1.68
SIC	−3.57	−4.89	−3.56	−2.77	−0.78
W_{LG}	0.05	0.008	0.21	0.34	18.25*
W_{SG}	0.75	3.15***	1.33	0.83	53.70*
W_{LP}	0.004	0.12	2.43	0.40	11.65*
W_{SP}	1.14	8.31*	8.13*	11.11**	14.57*
JB	0.72	0.63	0.79	4.95***	0.54
BG	0.97	0.56	2.05 (1)	2.37	2.52
ARCH	2.25	1.08	0.95	1.45	0.60
R-RESET	0.25	1.61	0.001	1.04	0.63

Note: BG = Breusch–Godfrey serial correlation LM test; Ramsey = Ramsey RESET test: ARCH = Autoregressive conditional heteroscedasticity test; JB = Jacque Bera; AIC = Akaike info criterion; SIC = Schwarz criterion; W_{LG} = Wald test of long-run symmetry for natural gas consumption per capita; W_{SG} = Wald test of short-run symmetry for natural gas consumption per capita; W_{LP} = Wald test of long-run symmetry for petroleum consumption per capita; W_{SP} = Wald test of short-run symmetry for petroleum consumption per capita; L^-_G = long-run coefficient of asymmetric negative change in natural gas consumption per capita; L^+_G = long-run coefficient of asymmetric positive change in natural gas consumption per capita; L^-_P = long-run coefficient of asymmetric negative change in petroleum consumption per capita; L^+_G = long-run coefficient of asymmetric positive change in petroleum consumption per capita. *, ** and *** represent significance levels at 1%, 5% and 10% respectively. Standard errors are in parenthesis.

Table 10
Summary of non-linear ARDL estimates.

Country	Dependent Variable: GDPPC				Dependent Variable: CO2PC			
	Long-run		Short-run		Long-run		Short-run	
	Negative Shock	Positive Shock	Negative Shock	Positive Shock	Negative Shock	Positive Shock	Negative Shock	Positive Shock
Effect of Natural Gas Consumption per Capita								
Algeria	No effect	No effect	No effect	No effect	No effect	No effect	–	+
Angola	No effect	No effect	–	–	+	–	+	+
Egypt	No effect	No effect	No effect	No effect	No effect	No effect	No effect	No effect
Gabon	+	+	No effect	No effect	+	–	+	–
Nigeria	No effect	No effect	–	–	–	No effect	No effect	No effect
Effect of Petroleum Consumption per Capita								
Algeria	No effect	No effect	No effect	No effect	No effect	No effect	No effect	No effect
Angola	+	+	+	+	+	+	No effect	No effect
Egypt	+	+	No effect	No effect	No effect	No effect	No effect	No effect
Gabon	No effect	No effect	No effect	No effect	No effect	No effect	–	–
Nigeria	–	–	No effect	No effect	No effect	–	–	–

Source: Computed from Earlier Tables Note: + indicates positive effect; - indicates negative effect

findings are discovered for natural gas consumption per capita in Algeria, although the impact of petroleum consumption per capita is insignificant on both GDP per capita and carbon emission per capita. Also, natural gas consumption per capita did not influence economic growth and carbon emission per capita significantly in Egypt and Nigeria (short-run). In general, positive and negative changes in natural gas consumption per capita and petroleum consumption per capita influenced economic growth and carbon emission per capita differently across the selected countries both in the short-run and the long-run. Thus, as primary inputs are being complemented by petroleum and natural gas, changes in the consumption of these energy types have implications (enhance or retard) for economic growth. Also, increasing the use of these non-renewable energy types may reduce or trigger CO2 emissions among top oil producing economies in Africa. Thus, achieving higher growth and reducing CO2 emission is conditioned on the adoption of carbon-reducing (if non-renewable energy consumption must be increased) techniques of production across major economic activities as indicated by the positive impact of carbon intensity of energy on carbon emission per capita across the countries.

5. Summary, conclusion and policy implication

This study investigated the impact of per capita petroleum and natural gas consumption on economic growth and carbon emissions per capita among top oil producing economies in Africa during 1980–2015.[8] Accounting for non-linearity and structural break in unit root and cointegration analysis, the paper adopted non-linear autoregressive distributed lag (NARDL) method for comparative analysis of these countries (Algeria, Angola, Egypt, Gabon and Nigeria).

Generally, the study found that per capita consumption of both petroleum and natural gas consumption had asymmetric effect on economic growth and carbon emission per capita in all the selected countries except Algeria. Thus, response of economic growth and carbon emissions to positive and negative changes in the consumption of either of these energy types could be positive, negative or insignificant across the top oil producers in Africa. In the particular case of Nigeria, findings suggest that positive change in the non-renewable energy consumption retarded growth but reduced emission. In Gabon, increase in the consumption of the non-renewable energy promoted growth and enhanced environmental quality. In Egypt, the consumption of these energy types did not produce any significant effect on environmental pollution as it contributed to economic growth. In Angola, while positive change in the non-renewable energy consumption improved economic growth, the effect on carbon emission is mixed, depending on the energy type and time horizon. The effect of negative change in petroleum and natural gas consumption is similar to those observed for positive change, especially in Egypt and Nigeria.

In the use of energy resources towards economic growth, results revealed that their effects on carbon emission largely vary from country to country. Thus, reducing carbon emission in the face of rising consumption of these energy resources is premised on the use of carbon-reducing techniques. This implies that, while focussing on economic growth, it is important for oil producing countries in Africa not to ignore the associated environmental pollution arising from carbon emissions.

It is therefore imperative for policymakers in oil producing economies in Africa to explore avenues to invest in, and promote, carbon-reducing and energy-saving technology in production processes in their quest for economic growth if they must continue to increase the consumption of their abundant resources-petroleum and natural gas. Reward and sanction mechanisms should be designed to facilitate compliance with environmental regulations.

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Appendix

A. *Stability Diagnostics for GDP per Capita Models*

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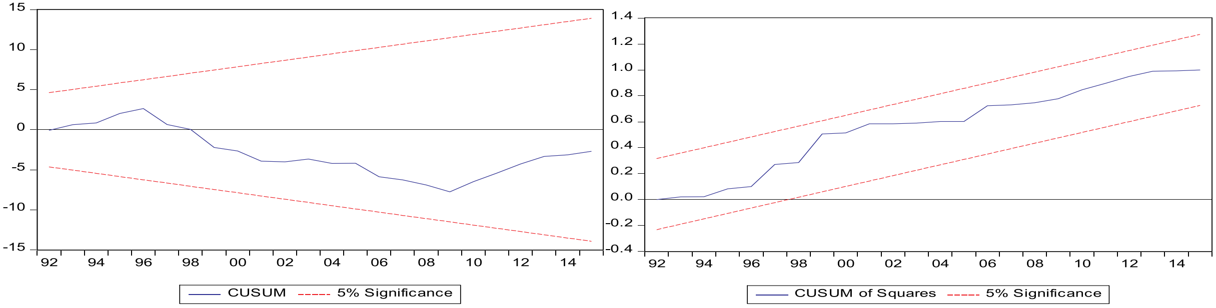
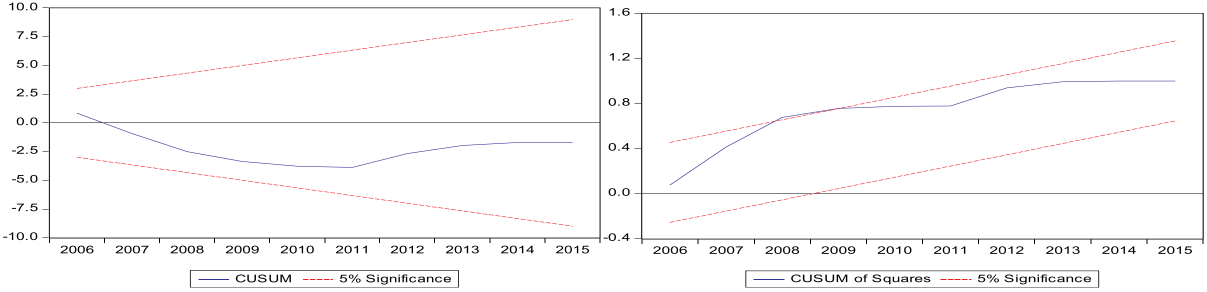
[8] The period 2016–2019 was not considered due to data availability issues across all the selected countries.

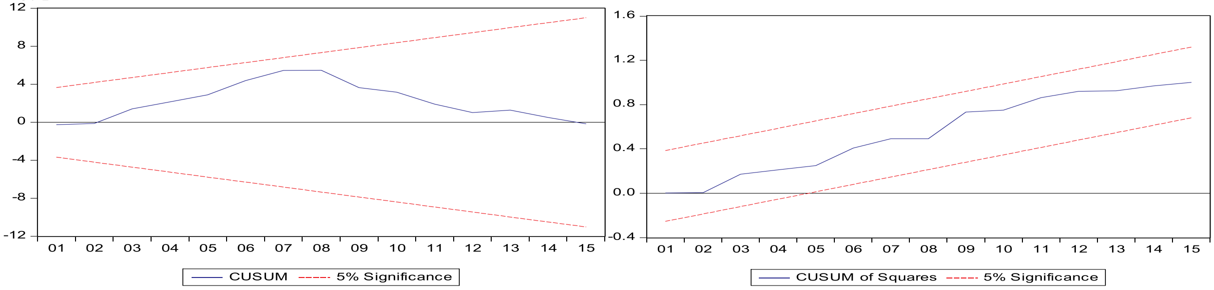
Algeria



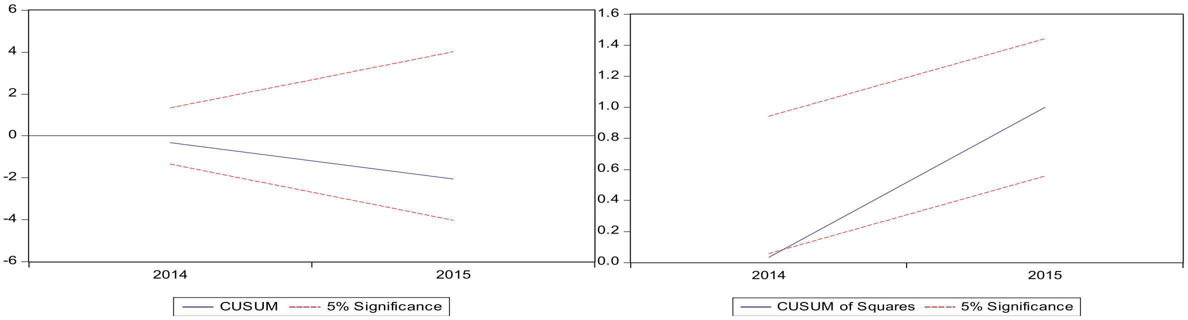
Angola



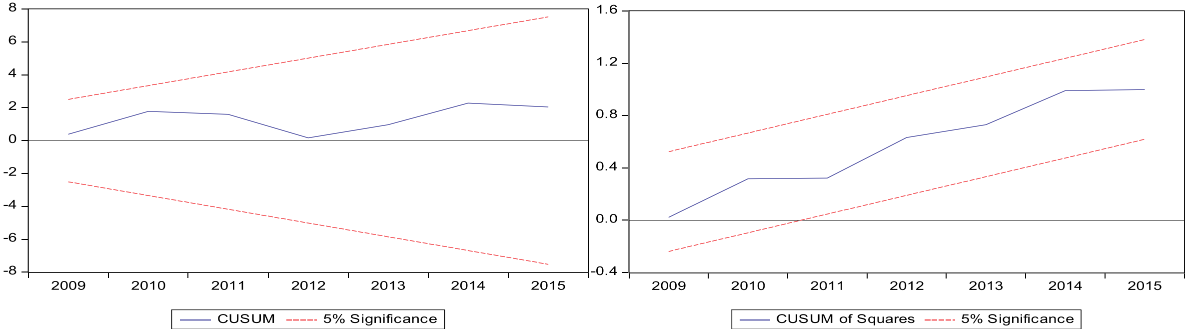
Egypt



Gabon

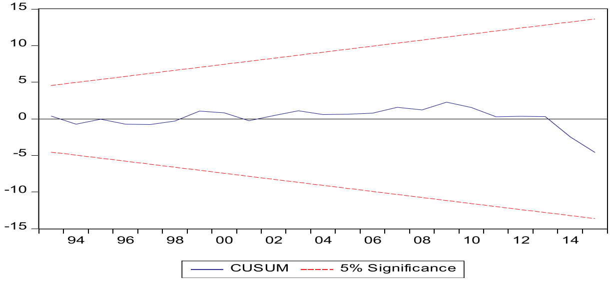


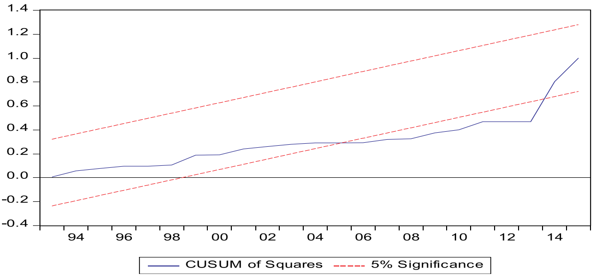
Nigeria



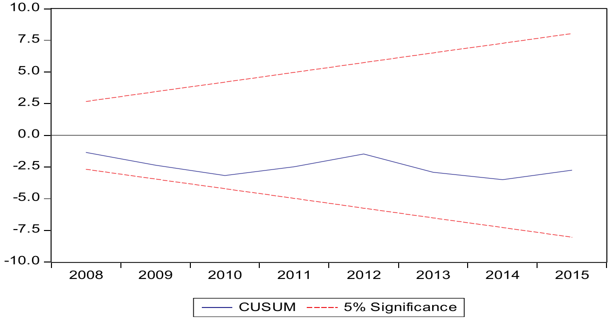
B. Stability Diagnostics for CO2 per Capita Models

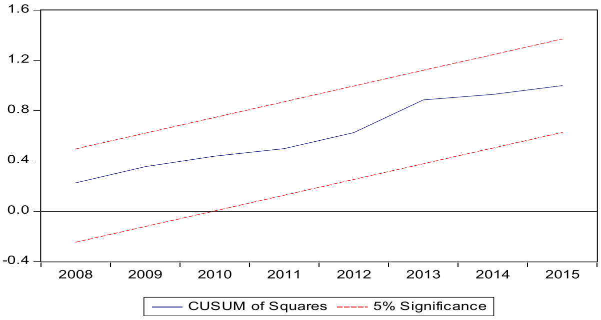
Algeria



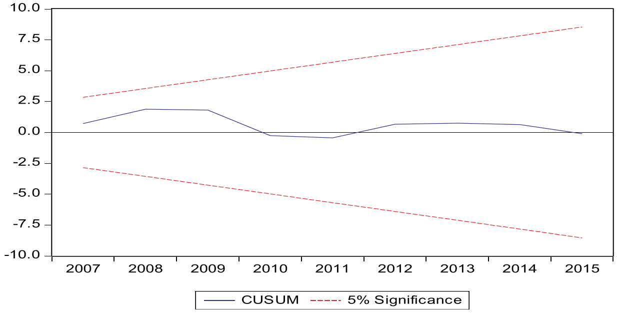


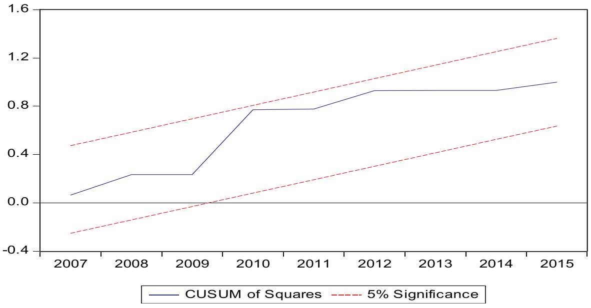
Angola



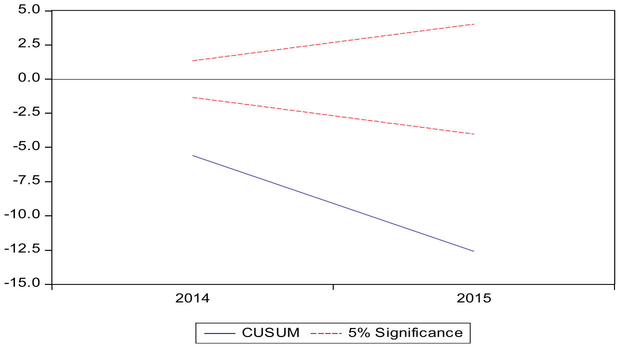


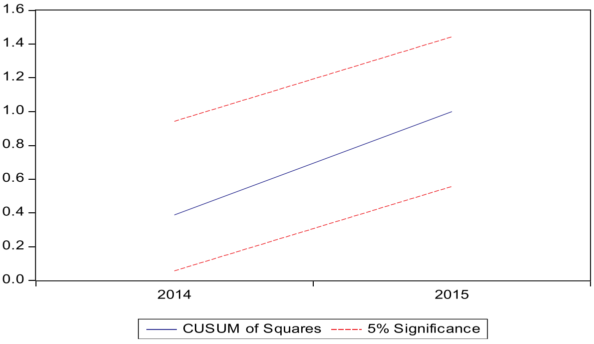
Egypt



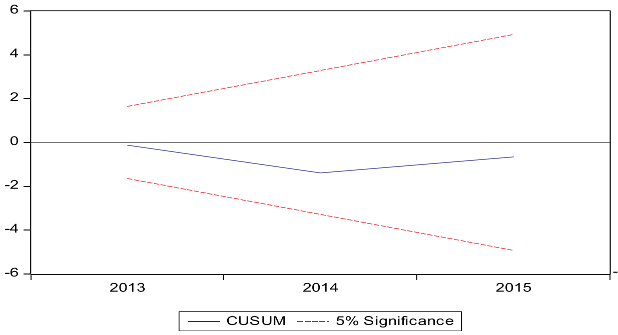


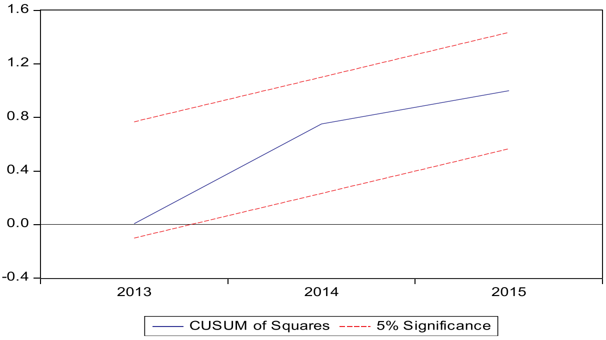
Gabon





Nigeria





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