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Article

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Energy Reports

Provided in Cooperation with:

Elsevier

Suggested Citation: Ehigiamusoe, Kizito Uyi (2020) : A disaggregated approach to analyzing the effect of electricity on carbon emissions: Evidence from African countries, Energy Reports, ISSN 2352-4847, Elsevier, Amsterdam, Vol. 6, pp. 1286-1296, <https://doi.org/10.1016/j.egy.2020.04.039>

This Version is available at:

<https://hdl.handle.net/10419/244120>

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A disaggregated approach to analyzing the effect of electricity on carbon emissions: Evidence from African countries

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ARTICLE INFO

Article history:

Received 27 August 2019

Received in revised form 23 April 2020

Accepted 30 April 2020

Available online xxxx

JEL classification:

Q53

Q56

O44

Keywords:

Carbon emissions

Electricity consumption

Electricity generation

Renewable electricity output

Sustainable development

African countries

ABSTRACT

This paper investigates the effects of electricity consumption and generation on carbon emissions in 25 African countries for the 1980–2016 period. Specifically, it examines the effects of diverse electricity sources (e.g. hydro, oil, natural gas, coal) and renewable electricity output on carbon emissions. It employs estimation techniques that are appropriate for cointegrated panels such as Dynamic Ordinary Least Squares (DOLS), Fully Modified Ordinary Least Squares (FMOLS) and Augmented Mean Group (AMG). The panel cointegration tests reveal a cointegration relationship between the variables. The estimation results show that electricity consumption has a detrimental effect on carbon emissions, while renewable electricity output mitigates carbon emissions in African countries. Moreover, electricity generation from oil, natural gas and coal have detrimental effects on carbon emissions while electricity generation from hydro alleviates carbon emissions. This implies that electricity consumption and generation are significant determinants of carbon emissions in African countries, hence efforts to abate carbon emissions should incorporate them in order to achieve sustainable development.

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1. Introduction

The importance of energy in fostering economic growth and development of any country cannot be overemphasized. The theoretical and empirical literature posited that energy consumption enhances the growth of economic activities (Narayan and Smyth, 2008). This implies that a higher level of economic development can be achieved with a higher level of energy consumption. However, energy consumption could take place at the expense of carbon emissions which worsen environmental degradation. Infact, carbon emissions are considered as one of the main causes of climate change and global warming, issues that have occupied global discourse in recent decades. It is necessary to control climate change and global warming because of their detrimental effects on the ecosystem and human existence. Consequently, several scholars have devoted considerable attention to unveil the main determinants of carbon emissions. Although other views exist, most of the empirical outcomes revealed that energy consumption is deleterious to carbon emissions (Acaravci and Ozturk, 2012; Ehigiamusoe and Lean, 2019; Ehigiamusoe et al., 2020, 2019). Nevertheless, the empirical literature provided evidences that non-renewable energy consumption aggravates carbon emissions, while renewable energy consumption has a mitigating effect (see Dogan and Seker, 2016a).

One aspect of energy that has not received a considerable attention (especially in developing countries) is the nexus between electricity generation/consumption and carbon emissions, albeit evidences abound that electricity consumption enhances economic growth (Khan et al., 2018). The previous empirical outcomes on the effect of electricity consumption on carbon emissions are mixed, with some studies reporting a detrimental effect (e.g. Al-mulali and Che Sab, 2018; Lean and Smyth, 2010a; Salahuddin et al., 2015) while other studies documented a mitigating or insignificant effect (e.g. Belaid and Youssef, 2017; Belaid and Zrelli, 2019; Cowan et al., 2014). Moreover, Belaid and Youssef (2017) noted that renewable electricity consumption enhances environmental quality in Algeria, while Cowan et al. (2014) revealed absence of any causal relationship from electricity consumption to carbon emissions in Brazil, Russia, China and South Africa. The differences in the empirical results of previous studies could be attributed to failure to account for some economic and econometric issues such as heterogeneity and cross-sectional dependence. Dogan and Aslan (2017) posited that one main criticism of the extant studies on energy-growth-environment nexus is the use of panel empirical methodologies that do not consider heterogeneity and cross-sectional dependence across countries, which may engender forecasting errors. In developing countries, the effect of renewable electricity output on carbon emissions has not received adequate attention.

Besides, some empirical studies indicated that electricity generation has a significant influence on economic growth (Altıntaş

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and Kum, 2013; Lean and Smyth, 2010b). While enhancing economic growth, electricity generation could also worsen carbon emissions. Basically, electricity can be generated from various sources such as hydro, oil, natural gas and coal. Each of these sources of electricity could have different effects on carbon emissions. Nevertheless, Shahbaz et al. (2013) provided evidence that coal consumption worsens carbon emissions in South Africa while Solarin and Lean (2016) showed that natural gas consumption intensifies carbon emissions in China and India. However, the effects of electricity generation from various sources (e.g. hydro, oil, natural gas and coal) on carbon emissions in African countries have not been thoroughly explored. An insight into the effects of electricity consumption and generation on carbon emissions is fundamental for policy formulation.

This study focuses on African countries because the empirical literature on the effects of electricity consumption and generation on carbon emissions is very scanty. Moreover, the high degree of carbon emissions constitutes a grave concern to policymakers in the region. The level of carbon emissions increased from 62.8% in 1980, reached 65.7% in 1993, and then declined to 51.4% in 2014.¹ Essentially, carbon emissions from electricity and heat production increased from 39.8% in 1980, reached 59.2% in 2001, and then marginally declined to 54.5% in 2014. More precisely, since 1987, carbon emissions from electricity and heat production constitutes more than 50% of the total carbon emissions in the region. Moreover, electricity consumption increased from 445.3 kWh per capita in 1980, reached 556.3 kWh per capita in 1997, and then declined to 480.3 kWh per capita in 2014. The electricity generation from coal increased from 62.8% in 1980, reached 65.7% in 1993, and then declined to 51.4% in 2014. During the period, though electricity generation from hydro was about 21%, electricity generation from natural gas increased from 1.9% to 8.5%; electricity generation from oil increased from 2.3% to 4.2%, and renewable electricity output increased from 19.4% to 26.3%. These data indicate that some of the variables moved in the same direction (albeit with varying degree) during the period. This throws up the questions: Do variations in electricity consumption and generation cause variations in carbon emissions in Africa?

The specific objectives of this paper include (i) To determine the impact of electricity consumption on carbon emissions in African countries. (ii) To investigate the impact of renewable electricity output on carbon emissions in African countries. (iii) To examine the impact of electricity generation from various sources (e.g. hydro, oil, natural gas, coal) on carbon emissions in African countries. In this regard, this study differs from previous empirical studies in African region that mainly focus on the nexus between aggregate energy consumption and carbon emissions, thereby neglecting the impact of electricity consumption on carbon emissions. Moreover, previous studies also neglected the nexus between electricity generation and carbon emission, an issue that could aid policy formulations. By investigating the impact of the various sources of electricity generation (renewable and non-renewable) on carbon emissions, this study differs from previous empirical studies, and provides insights that could inform policy decisions-making on ways of mitigating the environmental impact of electricity generation in African region. Therefore, the study makes some contributions to the extant literature. First, it epitomizes a novel idea by examining the effects of both electricity consumption and generation on carbon emissions within a single framework. Although some empirical studies have investigated the impact of electricity consumption on carbon emissions in other countries or regions (Lean and Smyth, 2010a for ASEAN countries; Al-mulali and Che Sab, 2018

for Middle East countries, and Salahuddin et al., 2015 for Gulf Cooperation Council countries), the issue has not been thoroughly explored in African countries. Hence, an insight into the effect of electricity consumption on carbon emissions in African countries is fundamental for formulating policies to address the menace of carbon emissions in the continent.

Secondly, while several studies have examined the impact of renewable energy consumption on carbon emissions (Dogan and Seker, 2016a), there is a scanty literature on the impact of renewable electricity on carbon emissions. The only notable study (to the best of our knowledge) is Belaid and Youssef (2017) for Algeria. But our study differs because it focuses on the effect of renewable electricity output on carbon emissions in developing countries. Third, though Lean and Smyth (2010b) and Altıntaş and Kum (2013) reported a causality relationship between electricity generation and economic growth in Malaysia and Turkey respectively, the impact of different sources of electricity (e.g. hydro, oil, natural gas, coal) on carbon emissions has not been given adequate attention in the empirical literature. It is necessary to provide insight into this issue so that policymakers should be aware of the sources of electricity that intensify or mitigate carbon emissions.

Finally, given that there are several contributors to carbon emissions (e.g. electricity and heat production; gaseous, liquid and solid fuel consumption; manufacturing industries and construction; transport; residential building, commercial and public services), this study also examines the main contributors to carbon emissions from electricity and heat production (as a percentage of total carbon emissions). Hence, we use carbon emissions from electricity and heat production as our dependent variable in a separate regression. Our empirical outcomes are robust for policy formulations since we employed several panel unit root tests, cointegration tests and estimation techniques that can address various econometric issues such as integration, cointegration, heterogeneity, and cross-sectional dependence.

Besides this introduction, the remaining parts of the paper is divided into five sections. Section 2 reviews the related literature while Section 3 contains the methodology and data. Section 4 presents the empirical results, while the discussions and policy implications of the findings are contained in Section 5. The final section presents some concluding remarks.

2. Literature review

2.1. Electricity consumption, economic growth and carbon emissions

2.1.1. Developed countries

One strand of literature emphasized the fundamental role of electricity consumption in accelerating economic growth. For instance, Acaravci and Ozturk (2012) investigated the effect of electricity consumption on economic growth in Turkey, and reported both short-run and long-run causality from electricity consumption to economic growth. The empirical outcomes support the growth hypothesis, which posits that energy consumption has a direct impact on economic growth. Conversely, some studies have provided empirical evidences to support the conservation hypothesis (the assertion that energy consumption is driven by economic growth). Salahuddin and Alam (2015) examined the impact of electricity consumption on economic growth in Australia, and showed that economic growth stimulates long run electricity consumption, thereby supporting the conservation hypothesis. Furuoka (2017) also examined the impact of electricity consumption (renewable and non-renewable) on economic development in 3 European countries (Estonia, Latvia and Lithuania), and found no evidence that electricity consumption stimulates economic development. Rather, they found evidence to

¹ All the data were obtained from World Development Indicators (2018) of the World Bank.

support the conservation hypothesis (i.e. economic development causes greater utilization of renewable electricity).

Besides, the impact of renewable and non-renewable energy consumption on economic growth have been investigated by some researchers. [Apergis and Payne \(2010b\)](#) examined the impact of renewable energy consumption on economic growth in a panel of 20 OECD countries, and revealed that renewable energy consumption has a positive impact on economic growth. They also showed a bidirectional causal relationship between renewable energy consumption and economic growth. In a related study, [Aydin \(2019\)](#) provided empirical evidences to support the feedback hypothesis between economic growth and electricity consumption (renewable and non-renewable) in 26 OECD countries. [Khan \(2019a\)](#) explored the interplay between electricity generations and emissions with emphasis on renewable versus fossil fuel dominated electricity systems, and identified peak carbon-intensive hours. The study provided evidence to design the requisite demand-side management strategies necessary for lessening the GHG emissions.

2.1.2. Developing countries

In developing countries, the relationship between electricity consumption, economic growth and carbon emissions had received the attention of scholars. [Khan et al. \(2018\)](#) examined the effect of electricity consumption on economic growth in Kazakhstan, and reported a significant positive growth-enhancing effect. Moreover, [Apergis and Payne \(2011\)](#) investigated the impact of renewable and non-renewable electricity consumption on economic growth in 16 emerging market economies. The estimation results showed that non-renewable electricity consumption has a positive and significant impact on economic growth, while the impact of renewable electricity consumption is statistically insignificant. Nevertheless, the Granger causality test provided evidence to support a long-run bidirectional causality between electricity consumption (renewable and non-renewable) and economic growth, thereby supporting the feedback hypothesis.

At the extreme, some empirical studies have provided evidences to support the neutrality hypothesis which emphasized an insignificant relationship between energy consumption and economic growth. [Ozturk and Acaravci \(2011\)](#) investigated the impact of electricity consumption on economic growth in 11 MENA countries, and found insignificant relationship between the variables. Similarly, [Cowan et al. \(2014\)](#) examined the relationship between electricity consumption, economic growth and carbon emissions in BRICS (i.e. Brazil, Russia, India, China and South Africa). The study supported the neutrality hypothesis for Brazil, India and China, suggesting that electricity consumption and economic growth have no significant relationship. However, the study supported the feedback hypothesis for Russia, and the conservation hypothesis for South Africa. Moreover, [Al-mulali et al. \(2014\)](#) showed that both renewable and non-renewable electricity consumption are significant determinants of economic growth in 18 Latin American countries albeit the impact of renewable electricity consumption is stronger.

Apart from its impact on economic growth, electricity consumption has the capacity to influence carbon emissions, albeit the impact could be positive or negative. [Lean and Smyth \(2010a\)](#) investigated the impact of electricity consumption on carbon emissions in 5 ASEAN countries, and reported that electricity consumption exacerbates carbon emissions. [Al-mulali and Che Sab \(2018\)](#) revealed that electricity consumption and GDP have detrimental effects on carbon emissions in 12 Middle Eastern countries. [Salahuddin et al. \(2015\)](#) also revealed that electricity consumption has a deleterious effect on carbon emissions in 6 Gulf Cooperation Council Countries. [Salahuddin et al. \(2018\)](#) investigated the impact of electricity consumption on carbon

emissions in Kuwait. They reported that electricity consumption has both short-run and long-run detrimental effect on carbon emissions. Conversely, [Cowan et al. \(2014\)](#) showed that electricity consumption Granger causes carbon emissions in India, but there is no causal relation from electricity consumption to carbon emissions in Brazil, Russia, China and South Africa.

In African region, the impact of electricity consumption on economic growth or carbon emissions has not received much attention. Rather, the previous studies have focused on the impact of energy consumption on economic growth or carbon emissions. For instance, [Rafindadi \(2016\)](#) examined the relationship between economic growth, energy consumption and carbon emissions in Nigeria, and showed that economic growth diminishes energy demand, but intensifies carbon emissions. [Kohler \(2013\)](#) examined the relationship between energy consumption, carbon emissions and income in South Africa, and reported a bidirectional causal relationship between energy consumption and carbon emissions. [Shahbaz et al. \(2015\)](#) analyzed the trivariate relationship between energy intensity, economic growth and carbon emissions in 13 African countries. Evidence from the study revealed a unidirectional relationship from energy intensity to economic growth, and a bidirectional causality between economic growth and carbon emissions. Similarly, [Esso and Keho \(2016\)](#) examined the nexus between energy consumption, economic growth and carbon emissions in 12 African countries, and showed that energy consumption and growth Granger cause carbon emissions in 6 countries; while carbon emissions Granger cause economic growth in 3 countries in the long-run. The study also reported a short-run causal relationship from energy consumption to economic growth in 2 countries and the reverse causality in one country.

Moreover, [Chakamera and Alagidede \(2018\)](#) analyzed the nexus between electricity (consumption, transmission and distributional losses), economic growth and carbon emissions in 18 African countries, and showed that coal (solid fuel sources) is the main contributor to the high level of electricity-related carbon emissions. The study showed that renewable and non-renewable electricity consumption have different effects on carbon emissions. [Belaid and Youssef \(2017\)](#) investigated the effects of renewable and non-renewable electricity on carbon emissions in Algeria. They found that renewable electricity consumption has a beneficial effect on carbon emissions while non-renewable electricity consumption has a detrimental effect on carbon emissions. In a related study, [Belaid and Zrelli \(2019\)](#) reported that non-renewable electricity consumption diminishes environmental quality, while renewable electricity consumption improves environmental quality in 9 Mediterranean countries.

2.2. Electricity generation, economic growth and carbon emissions

2.2.1. Developed countries

Empirical literature emphasized the role of electricity generation in accelerating economic growth, albeit other views exist. For instance, [Altintas and Kum \(2013\)](#) investigated the impact of electricity generation on economic growth in Turkey and reported that electricity generation has a significant impact on economic growth. However, [Marques et al. \(2014\)](#) found no evidence of any causal relationship from renewable electricity generation to economic growth in Greece, albeit the study indicated that economic growth Granger causes renewable electricity generation. In a related study, [Marques et al. \(2016\)](#) examined the relationship between electricity generation, economic growth and carbon emissions in France, and reported that nuclear electricity accelerates economic growth while renewable electricity impedes growth. The study also indicated that nuclear electricity abates carbon emissions, albeit substitution effect exists among

the electricity sources. Al-mulali et al. (2015) revealed that renewable electricity generation from combustible renewables and waste, hydroelectricity, and nuclear power have negative long-run impact on carbon emissions, while the renewable electricity generation from solar power and wind power have no significant effect on carbon emissions in 23 European countries.

2.2.2. Developing countries

Lean and Smyth (2010b) examined the causal relationship between electricity generation and economic growth in Malaysia, and revealed a causal relation from economic growth to electricity generation. Atems and Hotaling (2018) investigated the nexus between electricity generation (renewable and non-renewable) and economic growth in a panel of 174 countries, and revealed that both renewable and non-renewable electricity generation have positive effects on economic growth. The study added that electricity transmissions and distribution losses have negative effects on economic growth. Mohiuddin et al. (2016) investigated the impact of electricity generation on carbon emissions in Pakistan, and showed a long-run relationship from electricity generation from coal, natural gas, and oil to carbon emissions. Hdom (2019) investigated the impact of electricity generation from fossil and renewable sources on carbon emissions in a panel of 8 South American countries. Evidence from the study showed that renewable electricity has a negative effect on carbon emissions while the effect of fossil electricity is insignificant.

Moreover, Khan (2019b) examined the economic, social and environmental dimensions of expansion in power generation in Bangladesh, and revealed that the economic impact dominates the sustainability measures, compared to the social and environmental dimensions. The study argued that energy policies should be designed to attain a balance among the three indicators with a view to ensuring a sustainable future electricity generation system. Yan et al. (2019) analyzed the nexus between thermal electricity generation and carbon emissions in a framework that also accounted for economic activity in China. Evidence from the study showed that economic activity, electricity demand and energy use aggravate carbon emissions, whereas technology, energy mix, energy efficiency and electricity efficiency have the opposite effect. Liddle and Sadorsky (2017) investigated the impact of electricity generation (from non-fossil fuels) on carbon emissions in a panel of 93 countries, and reported that non-fossil fuel electricity generation diminishes carbon emissions. When the panel was split into OECD and non-OECD countries, the impact was larger in the latter.

In African countries, the impact of electricity generation on economic growth or carbon emissions has not been thoroughly explored. The only notable study (to the best of our knowledge) is Kwakwa and Alhassan (2018) who examined the impact of electricity generation on carbon emissions in Ghana. The study reported that electricity generation from hydro has a significant negative impact on carbon emissions while electricity generation from fossil energy has a significant positive effect on carbon emissions.

The review above indicates absence of consensus among researchers on the impact of electricity consumption and generation on carbon emissions (and economic growth), which throws open the need to conduct more research to determine the link between the variables, especially in developing countries. The differences in the empirical outcomes of previous studies could be due to differences in empirical strategies, methodologies, data, period, countries/regions as well as failure to account for some economic and econometric issues such as heterogeneity, endogeneity and cross-sectional dependence. It is obvious that the impact of the various components of electricity generation on carbon emissions has not received adequate attention of scholars. This study intends to fill this gap by using disaggregated approach to analyze the impact of electricity on carbon emissions in African countries.

3. Methodology and data

3.1. Model specification

This study employs the following model to examine the effect of electricity consumption on carbon emissions in line with the empirical literature (Lean and Smyth, 2010a; Salahuddin et al., 2015):

$$CO2_{it} = \alpha_0 + \alpha_1 GDP_{it} + \alpha_2 GDP_{it}^2 + \alpha_3 ELEC_{it} + \mu_{it} \quad (1)$$

where $CO2$ = carbon dioxide emissions (measured in metric ton per capita), GDP = real GDP per capita (in 2010 constant USD), GDP^2 = squared of real GDP per capita, $ELEC$ = electricity consumption (kWh per capita), μ_{it} = independent and identically distributed error term, i = country index, t = time index.

Moreover, we substitute renewable electricity output for electricity consumption in order to examine the effect of renewable electricity output on carbon emissions specified as follows (Belaid and Youssef, 2017):

$$CO2_{it} = \alpha_0 + \alpha_1 GDP_{it} + \alpha_2 GDP_{it}^2 + \alpha_3 RENEW_{it} + \mu_{it} \quad (2)$$

where $RENEW$ = renewable electricity output (as a percentage of total electricity output).

To determine the effects of the diverse electricity sources on carbon emissions, we substitute each of the electricity sources in the models² as follows (Hdom, 2019):

$$CO2_{it} = \alpha_0 + \alpha_1 GDP_{it} + \alpha_2 GDP_{it}^2 + \alpha_3 HYDRO_{it} + \mu_{it} \quad (3)$$

$$CO2_{it} = \alpha_0 + \alpha_1 GDP_{it} + \alpha_2 GDP_{it}^2 + \alpha_3 OIL_{it} + \mu_{it} \quad (4)$$

$$CO2_{it} = \alpha_0 + \alpha_1 GDP_{it} + \alpha_2 GDP_{it}^2 + \alpha_3 GAS_{it} + \mu_{it} \quad (5)$$

$$CO2_{it} = \alpha_0 + \alpha_1 GDP_{it} + \alpha_2 GDP_{it}^2 + \alpha_3 COAL_{it} + \mu_{it} \quad (6)$$

where $HYDRO$ = electricity generation from hydro (as a percentage of total), OIL = electricity generation from oil (as a percentage of total), GAS = electricity generation from natural gas (as a percentage of total), $COAL$ = electricity generation from coal (as a percentage of total). All the variables are transformed into natural logarithm before econometric analysis.

3.2. Estimation techniques

The empirical strategies employed in this study proceeds as follows: First, we determine the order of integration of the variables in the model with different panel unit root tests proposed by Breitung (2000), Levin et al. (2002), Im et al. (2003) and Pesaran (2007). These tests allow us to account for individuals and common unit root processes as well as cross-sectional dependence. Second, we investigate the cointegration relationships between the variables using the panel cointegration tests proposed by Pedroni (1999) and Johansen–Fisher (Maddala and Wu, 1999). The Pedroni cointegration test enables us to account for country size and heterogeneity which permit multiple regressors of the cointegration vector to vary across various panel sections.

Third, we employ estimation technique which is appropriate for cointegrated panels namely the Fully Modified Ordinary Least Squares (FMOLS) proposed by Pedroni (2000). For robustness checks, we use the Dynamic Ordinary Least Squares (DOLS) developed by Stock and Watson (1993) and the Augmented Mean Group (AMG) proposed by Eberhardt and Bond (2009). The DOLS provides better results for panels that have cointegration relationships since the conventional OLS is inappropriate for cointegrated

² We also made attempt to include all the electricity sources in a single model, albeit we do not give much attention to the empirical outcomes since different countries have different sources of electricity.

panels because it will produce spurious results. However, the FMOLS is superior to both the OLS and DOLS because it can account for cross sectional heterogeneity, serial correlation and addresses potential endogeneity. It provides consistent estimates even in small sample, and allows the country-specific fixed effects to be heterogeneous in estimating long-run relationships (Pedroni, 2000).

Furthermore, Pesaran (2006) argued that parameters estimates could be considerably bias, and their sizes distorted, if cross-sectional dependence is overlooked. Consequently, we use the AMG which is robust in the presence of cross-sectional dependence and endogeneity, and has the advantage of allowing for heterogeneous slope coefficients across countries. Finally, we determine causal relationship between the variables using the Error Correction Model (ECM) procedure. Unlike the other Granger causality techniques, the ECM approach produces robust results in both small and large samples, as well as reveals both short-run and long-run causal relationships. By distinguishing between the short-run and long-run causal relationships, it provides viable options for policy formulations.

3.3. Data

This study uses panel data of 25 African countries for the 1980–2016 period. These countries include Algeria, Angola, Benin, Botswana, Cameroon, Cote D'Ivoire, Democratic Republic of Congo, Republic of Congo, Egypt, Ethiopia, Gabon, Ghana, Kenya, Libya, Mauritius, Morocco, Mozambique, Nigeria, Senegal, South Africa, Tanzania, Togo, Tunisia, Zambia, Zimbabwe. The data were obtained from the [World Development Indicators \(2018\)](#) of the World Bank. Our original intention was to include all the African countries in our sample, but our scope was limited by unavailability of data on electricity consumption and generation in some African countries. Even at that, only 23 countries in our sample have data on renewable electricity output and hydroelectric, 14 countries source electricity from oil, and 8 countries source electricity from coal.

4. Empirical results

4.1. Descriptive statistics and correlation analysis

The descriptive statistics presented in [Table A.1](#) shows wide variations and dispersions among the variables. For instance, the average carbon emissions, real GDP per capita and electricity consumption were 1.6 metric ton per capita, USD2678.6 and 705.5 kWh per capita respectively. Their respective standard deviations were 2.34, 2814 and 973.9 suggesting wide spread of the data around the means. The average renewable electricity output was 46.6% of the total electricity output, with a standard deviation of 38.4%. The sources of electricity indicate that hydro, oil, natural gas and coal constitute 44.7%, 21.4%, 19.5% and 12.72% of the total electricity sources respectively, the data are quite dispersed around their means. The lower panel of [Table A.1](#) containing the correlation analysis of the variables reveals that all the variables have positive relationship with carbon emissions, except renewable electricity output and hydroelectricity. Moreover, [Fig. 1](#) shows that real GDP per capita and electricity consumption increased steadily during the period, while [Fig. 2](#) indicates that the percentage of non-renewable electricity (in total electricity) rose steadily compared to renewable electricity during the period. [Figs. 3](#) and [4](#) show that total carbon emissions and the carbon emissions from electricity and heat production (as a percentage of total) increased during the period. The trends suggest that the variables may have some relationships.

Table 1

Panel unit root tests.

Variables	LLC	IPS	Breitung	Pesaran
CO2	−2.633***	−1.495	−3.627***	−0.044
GDP	−0.040	3.427	2.183	0.817
ELEC	−2.906**	1.437	−0.957	−0.552
RENEW	−2.460***	−1.864	−4.136***	1.153
HYDRO	−3.900***	−3.177***	−2.351	−5.026***
OIL	−1.996	−1.688	−3.436***	−3.742***
GAS	0.953	−1.628	−0.910	0.724
COAL	−2.504***	−0.426	−0.342	−0.872
ΔCO2	−16.215***	−19.859***	−10.958***	−16.582***
ΔGDP	−7.584***	−11.161***	−7.540***	−9.898***
ΔELEC	−13.747***	−17.271***	−8.138***	−12.862***
ΔRENEW	−12.744***	−14.120***	−8.379***	−16.087***
ΔHYDRO	−12.915***	−19.088***	−9.995***	−15.406***
ΔOIL	−18.020***	−17.787***	13.152***	14.188***
ΔGAS	−0.791	−10.752***	−6.062***	−6.812***
ΔCOAL	−3.408***	−6.991***	−6.073***	−5.665***

Notes: ***, ** and * indicate statistically significant at 1%, 5% and 10%, respectively. Δ = first differenced notation, LLC = [Levin, Lin and Chu \(2002\)](#) test, IPS = [Im et al. \(2003\)](#) test, Breitung = [Breitung \(2000\)](#) test, Pesaran = [Pesaran \(2007\)](#) test.

4.2. Panel unit root tests

The panel unit root results reported in [Table 1](#) indicates that all the variables are integrated of order one at 1% significant level. Therefore, it is necessary to examine the cointegration relationship between the variables.

4.3. Panel cointegration tests

The results of the panel cointegration tests reported in [Table 2](#) indicate that the variables have cointegration relationships in all the models, albeit that of model 6 is relatively weak. Thus, Pedroni and Johansen–Fisher panel cointegration tests found similar results. Hence, we reject the null hypothesis of no cointegration in favor of the alternative hypothesis.

4.4. Long-run estimation

The FMOLS estimation results presented in [Table 3](#) show that real GDP per capita enters with a positive and significant coefficient while the coefficient of real GDP per capita squared is negative and significant. Hence, the EKC hypothesis is supported in African countries. This implies that at the early stage of economic growth, one percent increase in real GDP per capita will increase carbon emissions by 2.305 percentage points. But after a certain threshold level of economic growth, a further increase in real GDP per capita will decrease carbon emissions in African countries. This finding is consistent with [Apergis and Payne \(2010a\)](#), [Ehigiamusoe \(2020a\)](#) and [Ozturk and Acaravci \(2013\)](#) who reported a valid EKC hypothesis in Commonwealth of independent states, ASEAN, and Turkey respectively. Second, the results show that the coefficient of electricity consumption is positive and significant, indicating that electricity consumption has a deleterious effect on carbon emissions in African countries. This implies that electricity consumption has taken place at the expense of carbon emissions in African countries. This finding is consistent with [Lean and Smyth \(2010a\)](#) and [Al-mulali and Che Sab \(2018\)](#) who revealed that electricity consumption and GDP have detrimental effects on carbon emissions in 5 ASEAN and 12 Middle Eastern countries, respectively.

Third, the results also show that renewable electricity output enters with a negative coefficient (albeit insignificant at conventional level), suggesting that renewable electricity output does

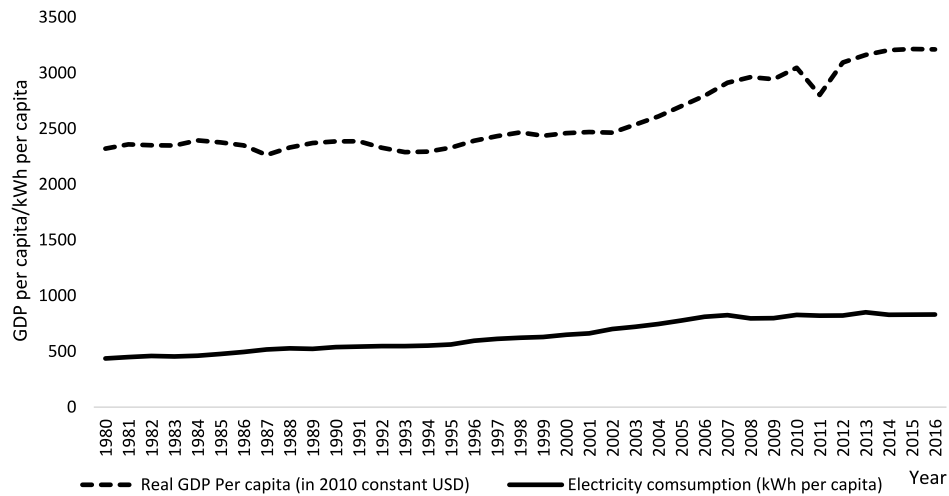


Fig. 1. Trends in real GDP per capita and electricity consumption in Africa.

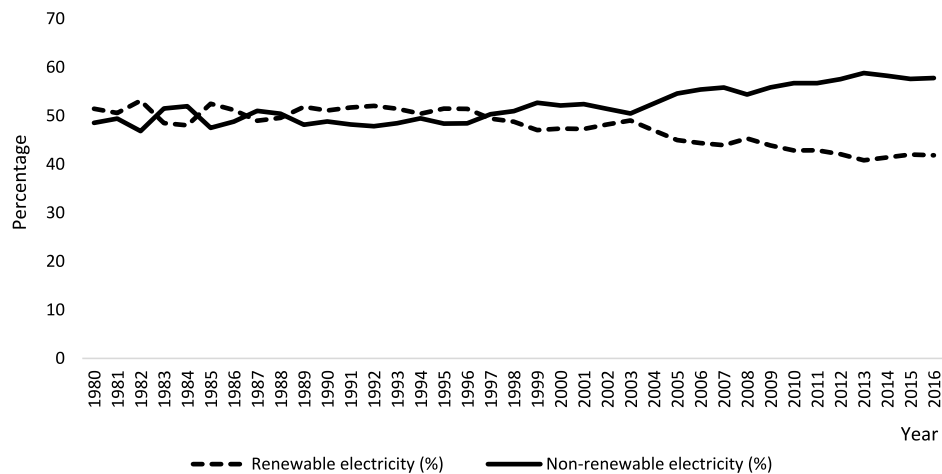


Fig. 2. Trends in renewable and non-renewable electricity in Africa.

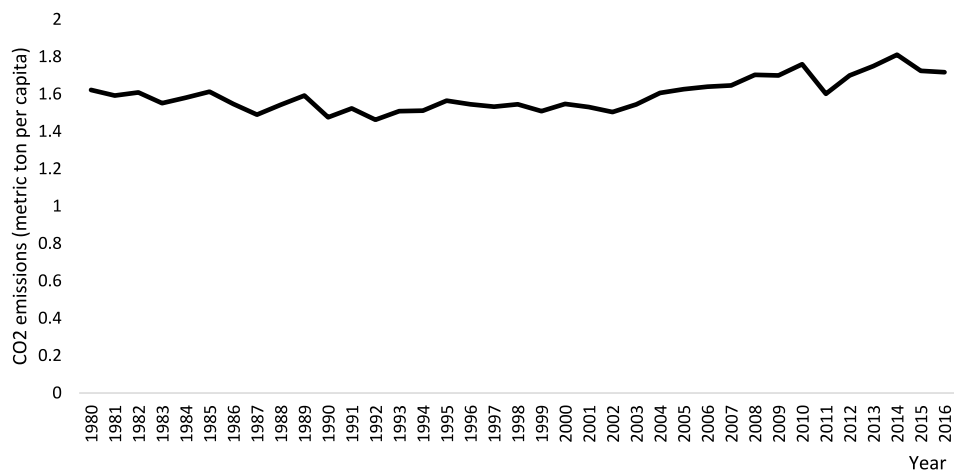


Fig. 3. Trends in carbon emissions in Africa.

not aggravate carbon emissions. [Belaid and Youssef \(2017\)](#) revealed that renewable electricity consumption enhances environmental quality in Algeria. Fourth, the results show that the coefficient of electricity generation from hydro is negative and

significant while the coefficient of electricity generation from natural gas is positive and significant. Specifically, one percent increase in electricity generation from hydro will lessen carbon emissions by 0.085 percentage points while one percent

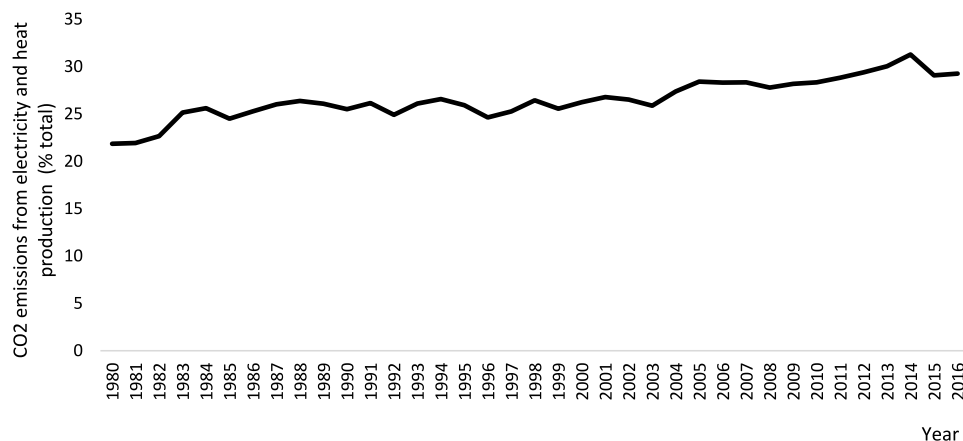


Fig. 4. Trends in carbon emissions from electricity and heat production in Africa.

Table 2
Results of panel cointegration tests.

	(1)	(2)	(3)	(4)	(5)	(6)
Pedroni tests						
Panel v-Statistic	0.390	−1.170	−1.227	−0.823	−1.123	−1.530
Panel rho-Statistic	−2.491***	−0.844	−2.321***	−2.036***	0.338	−0.157
Panel PP-Statistic	−6.083***	−4.008***	−5.359***	−4.828***	−1.377*	−0.758
Panel ADF-Statistic	−4.962***	−1.997**	−2.548***	−2.950***	0.001	0.785
Group rho-Statistic	−2.407***	−0.363	−1.336*	−1.455*	0.867	0.565
Group PP-Statistic	−7.887***	−5.636***	−6.666***	−6.347***	−4.272***	−1.815**
Group ADF-Statistic	−5.323***	−2.963***	−2.131***	−3.116***	−4.044***	−0.146
Johansen Fisher tests						
None	306.2***	318.6***	310.0***	308.5***	112.2***	133.5***
At most 1	134.0***	113.3***	101.1***	120.3***	68.10***	6.49***
At most 2	72.83**	66.74***	56.10	65.48*	53.36***	26.57**
At most 3	78.31***	84.92***	66.49**	68.36***	48.59***	9.343

Notes: ***, ** and * indicate statistically significant at 1%, 5% and 10%, respectively, and a rejection of the null hypothesis of no cointegration. Johansen Fisher panel cointegration test are the Fisher statistics from trace test, while the Fisher statistics from max-eigen test are not presented for want of space but available upon request.

increase in electricity generation from natural gas will increase carbon emissions by 0.132 percentage points in African countries.³ These imply that electricity generation from hydro mitigates carbon emissions while electricity generation from natural gas aggravates carbon emissions. These findings are consistent with Kwakwa and Alhassan (2018) and Al-mulali et al. (2015) who revealed that an increase in electricity generation from hydro lessens carbon emission in Ghana and 23 European countries, respectively. Finally, the electricity generation from oil and coal enter with positive coefficients (albeit insignificant at conventional level) in African countries. In all the models, the coefficient of determination (R^2) shows that variations in the regressors explain a reasonable proportion of the variations in the dependent variable.

4.5. Robustness checks

This study conducts some checks to ascertain the robustness of the estimation results. First, we use alternative estimation

technique namely Dynamic Ordinary Least Squares (DOLS) technique. The results reported in Table A.2 are similar to the FMOLS results in terms of sign and significance of the coefficient (albeit the magnitude somewhat differ). The EKC hypothesis is supported, electricity consumption and electricity generation from natural gas have detrimental effects on carbon emissions, while electricity generation from hydro has a mitigating effect.

Second, we replace total carbon emissions with the carbon emissions from electricity and heat production. This enables us to precisely capture the effects of electricity consumption and generation on carbon emissions generated during electricity and heat production. The results reported in Table 4 show that electricity generation from oil, natural gas and coal aggravate carbon emissions (from electricity and heat production), while renewable electricity output and electricity generation from hydro mitigates it. Expectedly, electricity consumption has insignificant effect on carbon emissions (generated from electricity and heat production).⁴

³ We thank the anonymous reviewer for this comment. The negative sign of the coefficients on renewable electricity output and hydroelectricity reported in this paper is robust since our estimation technique can control potential endogeneity. Our empirical outcomes are consistent with some previous studies such as Belaid and Zrelli (2019) for 9 Mediterranean countries; Kwakwa and Alhassan (2018) for Ghana, and Al-mulali et al. (2015) for 23 European countries. Besides, the extant literature on energy-environment nexus shows that renewable energy consumption has a negative impact on environmental degradation while non-renewable energy consumption has a positive effect (see Danish et al., 2017; Dogan and Seker, 2016b; Jebli et al., 2016; Shafiei and Salim, 2014).

⁴ We thank the anonymous reviewer for this comment. The detrimental effect of electricity consumption on carbon emissions found in our study is robust to different estimation techniques (e.g. FMOLS, DOLS, AMG). The results reported in Table 4 were estimated using a different dependent variable (namely carbon emissions from electricity and heat generation). The insignificance of the coefficient of electricity consumption does not suggest that the previous results (reported in Table 3 and Table A.2) are fragile, but it implies that electricity consumption has detrimental effect on carbon emissions per capita but has insignificant effect on carbon emissions from electricity and heat generation. This is reasonable since the carbon emissions are generated during electricity and heat production.

Table 3
Results of FMOLS estimations.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)
GDP	2.305*** (0.396)	2.730*** (0.563)	2.057*** (0.454)	2.636*** (0.330)	5.142*** (0.489)	3.195*** (0.619)	5.094*** (1.060)
GDP ²	−0.096*** (0.027)	−0.131*** (0.040)	−0.069** (0.026)	−0.112*** (0.023)	−0.267*** (0.033)	−0.146*** (0.043)	−0.360*** (0.084)
ELEC	0.225*** (0.047)						
RENEW		−0.025 (0.024)					
HYDRO			−0.085*** (0.026)				−0.065 (0.068)
OIL				0.003 (0.007)			0.222*** (0.036)
GAS					0.132*** (0.016)		0.631*** (0.092)
COAL						0.002 (0.019)	−0.097 (0.046)
R ²	0.983	0.984	0.980	0.984	0.987	0.991	0.972

Notes: ***, ** and * indicate statistically significant at 1%, 5% and 10%, respectively, Standard errors in parenthesis. Dependent variable is carbon dioxide (CO₂) emissions.

Table 4
Robustness checks using alternative proxy for dependent variable: FMOLS estimations.

Variables	(1)	(2)	(3)	(4)	(5)	(6)
GDP	2.044** (0.947)	4.280*** (1.173)	0.416 (0.922)	1.763*** (0.571)	2.592*** (0.790)	0.063 (0.1175)
GDP ²	−0.090 (0.066)	−0.291*** (0.085)	0.013 (0.066)	−0.087** (0.040)	−0.147*** (0.053)	0.013 (0.082)
ELEC	−0.186 (0.112)					
RENEW		−0.337*** (0.051)				
HYDRO			−0.433*** (0.054)			
OIL				0.238*** (0.012)		
GAS					0.382*** (0.026)	
COAL						0.081** (0.036)
R-Squared	0.867	0.902	0.867	0.890	0.925	0.891

Notes: ***, ** and * indicate statistically significant at 1%, 5% and 10%, respectively, Standard errors in parenthesis. Dependent variable is carbon dioxide emissions from electricity and heat generation (as a percentage of total fuel combustion).

Third, in order to account for cross-sectional dependence and reveal the estimation results for individual-country, we use the Augmented Mean Group (AMG) which is also appropriate for a cointegrated panel. Prior to the AMG estimation, we use the general CD tests proposed by Pesaran (2004) to ascertain the existence of cross-sectional dependence among the variables in the panel. The results reported⁵ cannot reject the null hypothesis of no cross-sectional dependence among the variables in the panel. The AMG estimation results⁶ for individual-country reveal that electricity consumption has a detrimental effect on carbon emissions in Angola, Benin, Congo Republic, Ethiopia, Mauritius, Morocco, South Africa, Togo, Tunisia, Zambia and Zimbabwe, while the effect is tenuous in the remaining countries. Moreover, the result reveal that renewable electricity output has a mitigating effect on carbon emissions in Cameroon, Ghana, Kenya, Morocco, Tanzania, Zambia and Zimbabwe. Besides, there are evidences that electricity generation from hydro has a mitigating effect on carbon emissions, whereas electricity generation from oil, natural gas and coal have detrimental effects.

⁵ The estimation results are not presented for want of space, but available upon request.

⁶ The estimation results are not presented for want of space, but available upon request.

The findings of our paper are consistent with the theoretical and empirical literature which emphasize the mechanisms through which electricity consumption and generation influence carbon emissions (see Hdom, 2019). Electricity consumption intensifies carbon emissions in African countries because the region generates a considerable proportion of electricity from fossil fuels sources (see Fig. 2) while electricity generation from renewable sources is not uniformly distributed among the countries. Besides, there is no efficiency in the use of electricity for industrial, agricultural, domestic and public infrastructure purposes. African countries need to deactivate their highly polluting sources of electricity and begin to generate greater proportion of their electricity from renewable technologies. Hence, efficiency and the substitution of energy generation sources could mitigate carbon emissions in African countries.

4.6. Panel Granger causality

The results⁷ of the panel VECM Granger causality can be summarized as follows: (i) There is a joint long-run and short-run causality from real GDP and electricity consumption to carbon emissions, a finding which is consistent with Al-mulali and

⁷ The estimation results are not presented for want of space, but available upon request.

Che Sab (2018). (ii) There is a joint long-run and short-run causality from electricity consumption and carbon emissions to real GDP, a finding which is consistent with **Lean and Smyth (2010a)**. (iii) There is a joint short-run causality from the real GDP and carbon emissions to electricity consumption, a finding that agreed with **Salahuddin et al. (2015)**. (iv) There is a joint short-run causality from real GDP and renewable electricity output to carbon emissions. (v) There is a joint long-run and short-run causality from electricity generation from hydro and real GDP to carbon emissions. (vi) There is a joint long-run and short-run causality from electricity generation from oil and real GDP to carbon emissions. (vii) There is a joint short-run causality from electricity generation from natural gas and real GDP to carbon emissions. (viii) There is a joint long-run and short-run causality from electricity generation from coal and real GDP to carbon emissions. These findings are consistent with **Mohiuddin et al. (2016)** who reported long-run relationship from electricity generation from coal, natural gas, and oil to carbon emissions in Pakistan.

5. Discussion and policy implications

5.1. Discussion

The findings of this study can be summarized as follows: First, electricity consumption has a detrimental effect on carbon emissions in African countries. This implies that electricity consumption has taken place at the expense of carbon emissions. This finding is consistent with **Lean and Smyth (2010a)** for 5 ASEAN countries; **Al-mulali and Che Sab (2018)** for 12 Middle Eastern countries, **Ehigiamusoe (2020b)** for 31 African countries, and **Salahuddin et al. (2015)** for Gulf Cooperation Council countries. Second, this study reveals that renewable electricity output is negatively associated with carbon emissions in African countries. **Belaid and Youssef (2017)** revealed that renewable electricity consumption enhances environmental quality in Algeria. Consequently, African countries should give attention to building resources that would guarantee adequate supply of electricity by gradually increasing the proportion of renewable electricity output in the entire electricity supplies.

Third, this study also shows that electricity generation from oil, natural gas and coal exacerbate carbon emissions while electricity generation from hydro mitigate it. These findings are consistent with **Kwakwa and Alhassan (2018)** for Ghana. **Al-mulali et al. (2015)** for 23 European countries, and **Hdom (2019)** for 8 South American countries. Similarly, electricity generation from oil, natural gas and coal are the main contributors to carbon emissions (from electricity and heat production). **Bhattacharya et al. (2017)** reported a significant relationship between the coal sector and carbon emissions in India. Finally, this study also shows the countries where electricity consumption (renewable electricity output) is deleterious (beneficial) to carbon emissions and where it is not. Knowing where electricity consumption (renewable electricity output) is detrimental (beneficial) to carbon emissions and where it is not, is important for policy formulations.

5.2. Policy implications

The policy implication of this paper is that the increasing energy demand and use in African countries is aggravating carbon emissions. Hence, it may be necessary to adopt electricity consumption policies that do not exacerbate carbon emissions, albeit it may be challenging to pursue energy conservation policy. The countries should improve efficiency in electricity consumption; use carbon pricing, and provide the favorable regulatory framework to promote green growth and electricity pricing reform that will diminish the growth of electricity consumption.

There should be incentives for efficient utilization of electricity so that consumers can replace inefficient or high electricity-oriented appliances with efficient or low electricity-oriented products. It may be necessary to encourage technological development and innovation into low-carbon sources of electricity, investment into electricity expertise and the promotion of energy research that will guarantee output without compromising carbon emissions.

Furthermore, policies and programs that can lessen carbon emissions should be strongly pursued and made a vital agenda in the energy and environmental policies of African countries. To meet the growing energy demand, African countries should focus on the generation of electricity from renewable sources rather than fossil fuel sources (which aggravate carbon emissions). In African countries, it seems that renewable electricity is an efficient substitute for electricity from fossil fuel. Hence, African countries should pursue long-term effort at generating electricity from renewable sources.

In this regard, African countries should strive to increase the proportion of electricity generation from hydro and reduce electricity generation from oil, natural gas and coal in their quest to mitigate carbon emissions. They should boost their renewable electricity quotas in total electricity generation to provide improvement in the level of electricity efficiency and conservation. There should be massive investment in innovation in the renewable and clean electricity in order to tackle the trade-off between fossil fuel and carbon emissions. African countries should deactivate their high-emissions sources of electricity generation, and focus on electricity generation from renewable technologies with a view to diminishing carbon emissions.

6. Conclusion

This paper analyses the effect of electricity on carbon emissions in 25 African countries using a disaggregated approach. More precisely, it determines the effects of various sources of electricity (e.g. hydro, natural gas, oil, coal) and renewable electricity output on carbon emissions. It employs diverse panel unit root tests, cointegration tests and estimation techniques that can address various econometric issues such as integration, cointegration, heterogeneity, endogeneity and cross-sectional dependence. The long-run parameters were estimated using the Fully Modified Ordinary Least Squares (FMOLS), Dynamic Ordinary Least Squares (DOLS) and Augmented Mean Group (AMG), while the short-run and long-run causal relationships were investigated with ECM model. Evidence from the study reveals a cointegration relationship between the variables. The estimation results show that electricity consumption has a detrimental effect on carbon emissions, while renewable electricity output mitigates it. Besides, electricity generation from natural gas, oil and coal have detrimental effects on carbon emissions while electricity generation from hydro alleviates it. Similarly, electricity generation from natural gas, oil and coal are the main contributors to carbon emissions (from electricity and heat production). The study also shows the estimation results of individual-specific country.

The implication of this paper is that electricity consumption and generation are significant determinants of carbon emissions in African countries. Hence, the continent's efforts to lessen carbon emissions should incorporate both electricity consumption and generation. Specifically, electricity consumption has taken place at the expense of carbon emissions in African countries. Hence, it is necessary to adopt electricity consumption policies that do not aggravate carbon emissions. Since renewable electricity output does not intensify carbon emissions, it may be necessary for the countries to increase the proportion of renewable electricity output in their entire electricity generation. This study also emphasizes that the sources of electricity matter in the

Table A.1

Summary of descriptive statistics and correlations.

Variables	CO2	GDP	ELEC	RENEW	HYDRO	OIL	GAS	COAL
Minimum	0.017	161.833	21.627	0.001	0.008	0.001	0.016	0.002
Mean	1.603	2678.616	705.519	46.677	44.748	21.482	19.529	12.726
Maximum	10.043	12120.56	4777.05	100.00	100.00	100.00	97.794	100.00
Standard Dev.	2.344	2814.07	973.924	38.472	38.806	28.615	30.662	28.583
No. of observations	925	925	925	925	925	925	925	925
GDP	0.812							
ELEC	0.902	0.688						
RENEW	−0.544	−0.449	−0.500					
HYDRO	−0.533	−0.456	−0.498	0.990				
OIL	0.109	0.097	−0.040	0.990	−0.456			
GAS	0.155	0.165	0.059	−0.439	−0.410	−0.207		
COAL	0.421	0.314	0.608	−0.407	−0.402	−0.195	−0.266	

Notes: CO2 = carbon emissions (measured in metric ton per capita), GDP = real GDP per capita (measured in 2010 constant USD), ELEC = electricity consumption (measured in kWh per capita), RENEW = renewable electricity output (measured as a percentage of total electricity output), HYDRO = electricity generation from hydro (measured as a percentage of total), OIL = electricity generation from oil (measured as a percentage of total), GAS = electricity generation from natural gas (measured as a percentage of total), COAL = electricity generation from coal (measured as a percentage of total). The minimum values of some of the variables (i.e. electricity generation sources) in the Table are small because the proportions of electricity generation from such sources were small in certain years for some countries.

Table A.2

Robustness checks using DOLS estimations.

Variables	(1)	(2)	(3)	(4)	(5)	(6)
GDP	3.729*** (0.799)	2.917* (1.610)	3.017*** (0.923)	3.644*** (0.727)	6.506*** (1.583)	4.559*** (1.308)
GDP ²	−0.191*** (0.054)	−0.117* (0.114)	−0.136** (0.063)	−0.181*** (0.050)	−0.353*** (0.106)	−0.243*** (0.090)
ELEC	0.214*** (0.078)					
RENEW		−0.030 (0.080)				
HYDRO			−0.126** (0.056)			
OIL				0.003 (0.015)		
GAS					0.129*** (0.0040)	
COAL						−0.019 (0.032)
R-Squared	0.991	0.993	0.988	0.991	0.992	0.996

Notes: ***, ** and * indicate statistically significant at 1%, 5% and 10%, respectively, Standard errors in parenthesis.

continent's quest to control carbon emissions. Countries should strive to increase the proportion of electricity generation from hydro (which does not aggravate carbon emissions) rather than oil, natural gas and coal (which intensify carbon emissions).

Moreover, the countries should formulate policies and programs that can lessen carbon emissions, and make them fundamental agenda in their energy and environmental policies in order to attain sustainable development. This study has succeeded in unveiling the direct effects of electricity consumption and generation on carbon emissions in African countries using a disaggregated approach. The limitation of our study is the inability to include all the African countries in our sample due to unavailability of data on electricity consumption and generation in some African countries. As data become available, we suggest that future research should include all the African countries in the sample. We also recommend that future study should examine these issues in developed economies for the purpose of inferences. Finally, it is recommended that future study should employ the interaction model to determine how the interaction between renewable and non-renewable electricity generation influence carbon emissions.

CRediT authorship contribution statement

Kizito Uyi Ehigiamusoe: Conceptualization, Methodology, Writing - original draft.

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.

Appendix

See [Tables A.1](#) and [A.2](#).

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