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Research paper

Renewable energy consumption and economic growth nexus: A fresh evidence from West Africa



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ABSTRACT

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Keywords: Renewable energy West Africa Economic growth Panel DOLS This paper estimates the impact of renewable energy on economic growth in West African countries using panel dynamic ordinary least squares (DOLS) by employing a sample of 15 West African countries covering the 1995-2014 period. The results indicated that renewable energy consumption slows down economic growth in these countries. This is attributed to the nature and source of renewable energy used in West Africa, which is majorly wood biomass. The wood biomasses used in West Africa are usually unclean and highly polluting when burnt. On the other hand, the use of clean energy sources like solar, wind and hydropower which does not have a side effect on human health and the environment is less in West Africa. As such, renewable energy use can slow down economic growth by lowering productivity when unclean and inefficient sources are used. The study recommends that (1) cleaner technologies should be employed to optimize the benefits of wood biomass as a renewable source of energy while minimizing its adverse effects; (2) the share of other renewable energy mix of the sub-region of West Africa and (3) greater commitment to achieving sustainable renewable energy by West Africa an uthorities is needed.

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1. Introduction

Africa's energy sector is important to its economic growth and development process but yet it is among the most poorly understood energy system in the world (AEO, 2014). The increasing importance of climate change challenges and the need for devising ways to mitigate greenhouse gases while achieving sustained economic growth has occupied a centre stage in the energy-growth led literature. The use of conventional energy from fossil fuel sources like petroleum, natural gas and coal have been identified as the major contributor to greenhouse gases that leads to global warming.

Thus, this paper is motivated by a number of reasons notably: the need to reduce greenhouse gases from the consumption of fossil fuel energy sources; the need to increase the share of renewable energy mix (wind, solar, hydropower, biomass and geothermal energy) in total energy mix; the need to achieve sustainable economic growth and development which requires high level use of clean energy; absence of consensus on the exact relationship between renewable energy and economic growth and gap in the contemporary related literature of Africa on renewable energy and economic growth nexus. First, based on the World Bank report (2015), primary energy consumption has accounted for more than 60% of global CO_2 emissions leading to an increase in global warming. In order to address the problem of CO_2 emission's proliferation from fossil fuel energy sources, contemporary literature in Africa has emphasize the need to increase the use of renewable energy in place of fossil fuel energy (Maji, 2015; Rafindadi and Ozturk, 2016; Ozturk and Bilgili, 2015; Adewuyi and Awodumi, 2017a,b). This is because renewable energy especially wind, solar and hydropower does not emit CO_2 when used in the production process and unlike the fossil fuel energy, the quantity of these renewable energy sources on earth surface is not finite.

Second, the share of renewable energy has only accounted for about 22% of the world final energy consumption (EIA, 2016). This has further led to the growing concern by academics and energy policymakers to increase the share of renewable energy in total energy mix (Bhattacharya et al., 2016). Despite the huge potentials of renewable energy in Africa, wind, solar and biomass has only accounted for an insignificant portion of the world renewable energy mix. As at 2012, coal alone accounted for 56% of electricity generation in sub-Saharan Africa while hydro, gas, petroleum, and nuclear have accounted for 22%, 9%, 9% and 3% respectively. However, other renewable energy notably: wind, solar, biomass and geothermal have accounted for 1% only (AEO, 2014). Out of this 1%, biomass mainly unclean use of wood fuel and charcoal have constituted for the largest share. Hence, the

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need to increase the share of renewable energy in Africa, especially wind, solar, geothermal and clean biomass cannot be over emphasis.

Third, the pursuit of economic growth in West African is mostly at the expense of the environment and future generation (Waziri et al., 2018), largely due to the kind of energy sources that are combined with other resource input to produce goods and services. However, sustainable development can only be achieved when the need for future generation is not compromised to achieve that of the present generation. For sub-Saharan Africa and West Africa in particular to achieve sustainable economic growth and social development goal in the near future, cleaner energy sources like wind, solar, biofuel, and hydropower need be in place.

The fourth motivation for this paper is the absence of consensus in contemporary literature on the exact relationship between renewable energy and economic growth. Thus, empirical literature has shown mixed results (see Lin and Moubarak, 2014; Mandelli et al., 2014; Ackah and Kizys, 2015; Maji, 2015; Rafindadi and Ozturk, 2016; Bhattacharya et al., 2016; Amri, 2017; Hasanov et al., 2017). These, in addition to the fact that contemporary literature of West Africa on renewable energy and economic growth nexus have concentrated on using biomass to measure renewable energy (Amoo and Fagbenle, 2013; Adewuyi and Awodumi, 2017a,b; Adu and Denkyirah, 2018) and given less emphasis to solar, wind and hydropower as a measure of renewable energy have constituted a research gap.

Therefore, this paper examines the impact of renewable energy on economic growth in West Africa. The contribution of this paper to scientific knowledge is as follows. Unlike other African literature, the paper investigates the nexus between renewable and economic growth considering all forms of renewable energy by using renewable energy share of total final energy consumption that includes wind, solar, biomass, hydropower and geothermal to measure renewable energy. In addition, the paper contributes to the inconclusive debate on the literature regarding the exact link between renewable energy and economic growth nexus. To achieve this a robust econometric technique of panel dynamic ordinary least squares was employed which consider the recent issue of cross-section dependence, heterogeneity and homogeneity in a panel data analysis.

Moreover, to the best of our knowledge, the use of dynamic panel least squares in an endogenous growth model for West African countries has not been included in the literature. Finally, the findings of this study will serve as a guide for policymaking on renewable energy sources and its relevance to economic growth. It will equally provide empirical backing for some existing policies and programmes targeting renewable energy enhancement in the energy mix to reduce too much reliance on fossil fuel in West Africa.

The paper is organized as follows. Section 1 presents the introduction. Section 2 focused on the literature review. Section 3 described the methodology. This includes the theoretical framework, econometric technique and sources of data. Section 4 reported the results and discussed the main findings while Section 5 handles the conclusion and policy implication.

2. An overview of literature

2.1. Empirical literature review

The need to incorporate greener economic growth process to achieving developmental goals of countries in the next few decades has made investigating the link between renewable energy and economic growth to become an attractive area in the literature in recent times. Despite the interest in this area, empirical evidence has produced mixed results (Sebri, 2015). Furthermore, most studies have concentrated on a single country (Ocal and Aslan, 2013; Lin and Moubarak, 2014; Dogan, 2015; Maji, 2015; Rafindadi and Ozturk, 2016) that employs the time series methods of analysis.

One of the limitations of a single country study is that they are often hindered by the small sample that reduces the power of their unit root and cointegration (Streimikiene, 2016). For instance, Ocal and Aslan (2013), Lin and Moubarak (2014), Maji (2015) and Rafindadi and Ozturk (2016) investigate the relationship between renewable energy and economic growth for different countries with a sample period of fewer than 45 observations. To overcome this limitation in time series analysis, recent literature has used a panel unit root and panel cointegration test advanced by (Pedroni, 1999) by combining both time series and cross-sectional data.

Thus, the power of panel analysis has encouraged its application to examine the nexus between renewable energy and economic growth for sustainable development (Chang et al., 2015; Alper and Oguz, 2016; Kahia et al., 2016; Bhattacharya et al., 2016; Amri, 2017; Hasanov et al., 2017; Koçaka and Şarkgüneşi, 2017). Despite differences in methods, sample period and panel of countries studied, Chang et al. (2015), Kahia et al. (2016) and Amri (2017) all discovered a bidirectional relationship between renewable energy consumption and economic growth. For instance, Chang et al. (2015), employed a Granger causality for a panel of G7 countries with a sample period between 1990–2011: Kahia et al. (2016) used a panel error correction method for a sample period of 1980–2012 for MENA oil exporting countries while Amri (2017) utilized a dynamic simultaneous equation with sample period of 1990-2012 for group of 72 countries based on their level of development.

Furthermore, another group of panel studies also found a positive and significant impact of renewable energy consumption on economic growth (Alper and Oguz, 2016; Bhattacharya et al., 2016; Inglesi-Lotz, 2016; Koçaka and Şarkgüneşi, 2017; Hasanov et al., 2017). Alper and Oguz (2016) examined the role of renewable energy consumption in economic growth for a panel of new European member countries. A similar investigation was carried out by Bhattacharya et al. (2016) for 38 top renewable energy consuming countries. Inglesi-Lotz (2016) provided a similar result for a group of OECD countries. Hasanov et al. (2017) also reveal supporting evidence for 10 Eurasian oil exporting countries.

There exist four main hypotheses that summarize the link between energy consumption (in this context renewable energy) and economic growth namely: the growth hypothesis, conservation hypothesis, the bidirectional (feedback) hypothesis and the neutral hypothesis. The growth hypothesis emphasis that it is energy consumption that causes economic growth, thus, energy has both a direct and indirect effect on economic growth (see Adewuyi and Awodumi, 2017a). For instance, renewable energy development like solar, wind, hydropower and biomass is required for green and sustainable growth. The development of renewable energy facilitates employment opportunity in both the public and private sectors. Employment provides income to people while expending the income increases economic growth. The conservation hypothesis posits that it is economic growth that causes the demand for renewable energy. When an economy is growing, income per head also increases and also the energy required for the growth, thus it is economic growth that drives renewable energy consumption. Increase in total expenditure by households, investors, government and export are what necessitates the development of renewable energy. Moreover, the bidirectional hypothesis suggests complementarity between renewable energy consumption and economic growth. In other words, renewable energy drives economic growth just as economic growth can drive renewable energy consumption. Lastly, the neutral hypothesis maintains that causality does not run from economic growth to renewable energy and vice versa.

In Africa, the need to develop other cleaner energy sources (solar, wind, hydropower and geothermal) beside biomass; the need to achieve sustainable economic growth and development target by 2030; the increasing demand to reduce Greenhouse Gas (GHG) emissions from fossil fuel energy sources have become an issue of concern.

Literature on renewable energy in Africa and West Africa, in particular, have concentrated on biomass and wood fuel consumption (see Amoo and Fagbenle, 2013; Ozturk and Bilgili, 2015; Adewuyi and Awodumi, 2017a; Sulaiman et al., 2017). They opined that majority of African countries rely on combustible biomass as their main source of energy for cooking and heating but have failed to include other cleaner energy sources like solar, wind and geothermal in their analysis. Although recent survey studies (see, Abam et al., 2014; Adewuyi and Awodumi, 2017b) have maintained that huge potentials for cleaner energy source like solar, wind and geothermal exist in Africa, empirical study to this effect is still at the infant stage.

In the transition to sustainable development goals (SDGs), a lot of argument is consistent with fact that extreme poverty has been minimized in most part of the world with the exception of Africa (see Asongu et al., 2017a). This suggests that economic growth experienced in the pre-transition period in Africa did not spread significantly to enhance the standard of living of Africans. However, increased clean energy development (like solar, wind and hydropower) can provide an opportunity for inclusive economic growth and development through job creation in the region.

Despite the global concern to mitigate Greenhouse Gas (GHG) emissions from conventional energy sources by increasing the share of clean energy mix in total energy; recent consulted literature in Africa have only contributed in the following areas: the use of biomass in Africa (Ajoku, 2012); current energy situation in Africa (Mandelli et al., 2014); green growth on renewable energy (Ackah and Kizys, 2015); inclusive municipal solid waste management (Mbah and Nzeadibe, 2016); determinant of renewable energy (Silva et al., 2018); environment, ICT and inclusive development (Asongu et al., 2017b; Asongu, 2018); economic growth in the ECOWAS sub-region (Frimpong et al., 2018) and comparative sustainable development in sub-Saharan Africa (see Asongu, 2018) among others.

Thus, this enquiry uses renewable energy (include all renewables) as a % of total energy consumption in a growth theory to investigate the impact of renewable energy on economic growth in West African countries. Beside the motivations of the study highlighted above, to the best of our knowledge, the use of dynamic panel least squares in an endogenous growth theory for West African countries has not been included in the literature consulted. This has constituted a literature gap.

2.2. Brief overview of biomass energy in Africa

In recent times, Africa has been witnessing economic growth and human development. To sustain these developments, access to modern energy is a significant factor. Equally, Africa is one of the continents of the world that is rich in renewable energy resources and has the potential of providing sustainable energy for sustained economic growth.

However, the main renewable energy consumed in Africa is biomass, especially in the sub-Saharan part of the continent. Also, the biomass used in the region is predominantly traditional biomass and waste (Wicke et al., 2011). Traditional biomass and waste cover more than 50% of the total primary energy demand in Africa. Equally, the total primary energy consumption in Africa is dominated by biomass and it will continue to be an important energy source in the future (IEA, 2010). IEA (2010) projects that by 2035 the share of biomass in the total primary energy consumption will be between 51% and 57%. Nevertheless, there are variations in the consumption of biomass across sub-regions and countries of Africa. For instance, Dasappa (2011) reports that the consumption of traditional biomass is over 90% in countries such as Central African Republic, Rwanda, and Burundi due to high poverty rate.

In sub-Saharan Africa, which houses West, South, East, and Central Africa, most people rely heavily on traditional biomass as their main energy source as compared to North Africa. In this region, the composition of energy as shown by Fig. 1 includes 81% solid biomass, 0.3% other renewables, 1.0% coal and peat, 1.9% hydro, and 2.7% natural gas (Stecher et al., 2013).

As opposed to clean or modern biomass, traditional biomass is unclean and can be harmful to human health. As defined by Eleri and Eleri (2009), "Traditional biomass refers to unsuitable use of fuelwood, charcoal, tree leaves, animal dung and agricultural residues for cooking, lighting and space heating".

Unlike modern biomass, which produces efficient energy, traditional biomass use can lead to serious health problems such as lung cancer, respiratory tract diseases, and other chronic pulmonary diseases (Chum et al., 2011). This is mainly resulted from heavy reliance on the traditional biomass for cooking by more than 80% of Africa's population (IEA, 2010). However, biomass has the potential of providing clean and efficient energy in the future in Africa as it is in developed countries.

3. Methodology

3.1. Empirical framework and models

The theoretical framework of this paper is the endogenous growth theory. The theory argues that economic growth can be achieved within a system as a result of internal processes and that human capital can be improved through technological advancement. Investment in human capital and innovation positively contribute to economic growth. The rationale of choosing this theory is that: First, the relevance of capital stock and human capital (labour) in economic growth has since been emphasized in the endogenous growth model (see Barro, 2003). Second, the theory has technological advancement and/or innovation component that enhances economic growth within a system. This second reason provides a safe ground to include renewable energy (environmental friendly energy source) in a growth model as an additional input requirement. Additionally, it has recently been stressed that capital requires the use of energy, as such, energy is also an important requirement in the production process (Adewuyi and Awodumi, 2017a). Furthermore, growth model has been augmented by including energy consumption in the literature (see, Rafindadi and Ozturk, 2016; Streimikiene, 2016; Inglesi-Lotz, 2016). However, this study used renewable energy rather than conventional energy, as such, further extend the debate. Hence, the augmented endogenous growth model for a panel of West Africa is presented as follows.

$$Y_{it} = f(A_{it}, L_{it}, K_{it}) \tag{1}$$

If $A_{it} = A(RE_{itj} \text{ and } PLS_{it})$, then we can safely re-write the augmented endogenous growth model as follows:

$$Y_{it} = f(RE_{itj}, PLS_{it}, L_{it}, K_{it})$$
⁽²⁾

Where Y represents economic growth, *RE* denotes renewable energy, j is a subscript that captures renewable energy as a share of total energy and total biomass (*BIOM*), *PLS* represents



Fig. 1. The composition of energy in Sub-Saharan African Africa (excluding South Africa). *Source:* Stecher et al. (2013).

political stability, *L* represents Labour and *K* indicated capital. Furthermore, i = 1, ..., N represent the cross-section of the countries; t = 1, ..., T indicates the time period.

Next, the unit root test was carried out to ascertain the stationarity of the variables. As such, we conduct a panel unit root test advanced by Levin et al. (2002) Im et al. (2003) and Fisher-ADF and Fisher PP of Maddala and Wu (1999). Besides, the recent issue of cross-section dependence, heterogeneity and homogeneity in a panel unit root and cointegration analysis is of relevance to this study. Controlling for heterogeneity has become an important issue of concern in panel empirical studies (Baltagi and Pesaran, 2007). The first generation panel unit root tests assume cross-section independence in the dynamics of the autoregressive parameters (Kahia et al., 2016). However, the two types of test under this category that is used in this study include; the homogeneity test that assumes common persistence parameters across cross-section and; the heterogeneity tests that assumes uncommon persistence parameters across the cross-section. The difference between them lies in how the alternative hypothesis is presented. However, we have restricted our analysis to three main panel unit root tests namely: Levin et al. (2002) test statistic for the homogeneity, the Im et al. (2003) and Fisher-ADF and Fisher PP of Maddala and Wu (1999) for the heterogeneity test. Thus, the specification proposed by Im et al. (2003) is as follows:

$$y_{it} = \rho_i y_{i(t-1)} + \sigma_i x_{it} + \epsilon_{it} \tag{3}$$

where x_{it} represent the combination of all the explanatory variables in the model; ρ_i denotes the autoregressive elasticities, ϵ_{it} is the residual term while and t remain as defined earlier. Im et al. (2003) gives room for a different order of serial correlation (Apergis and Payne, 2010) and follows the normal averaging of augmented Dickey Fuller (Inglesi-Lotz, 2016) given as:

$$\epsilon_{it} = \sum_{j=1}^{n-1} \theta_{ij} \epsilon_{it-1} + \varepsilon_{it} \tag{4}$$

Substituting Eq. (4) into Eq. (3) yield the following:

$$y_{it} = \rho_i y_{i(t-1)} + \sum_{j=1}^{n-1} \theta_{ij} \epsilon_{it-1} + \sigma_i x_{it} + \varepsilon_{it}$$
(5)

Where ρ_i represents the number of lags in the ADF regression. The null hypothesis is each variable in the panel has a unit root while the alternative suggests that at least one of the series in the panel is stationary. Despite that the unit root specification focused on the most recent Im et al. (2003), for the purpose of robustness, we have also conducted the unit root test for Levin et al. (2002), Breitung t-stat, Fisher-ADF and Fisher PP proposed by Maddala and Wu (1999).

Once the estimated panel unit root tests reveal evidence that the variables are stationary, then we can proceed with Pedroni's (1999, 2004) panel cointegration test to established the long-run relationship among the variable. To test the null hypothesis of no cointegration, Pedroni (1999, 2004) suggest two types of cointegration methods. The first panel test based on within dimension that includes four statistics (panel *v*-statistic, panel rho-statistic, panel PP-statistic and panel ADF-statistic). The second type of the panel cointegration test is based on between dimension approaches. This includes rho-statistic, group PP-statistic and group ADF-statistic. As hinted by Streimikiene (2016) the seven statistics are asymptotically distributed as standard normal which details are contained in the work of Pedroni (1999).

Since the Pedroni's (1999, 2004) approach allows for cointegration test in a model containing more than one exogenous variable, the long-run model can be parameterized as follows:

$$lnY_{it} = \gamma_{it} + \delta_{i}t + \pi_{1i}lnRE_{itj} + \pi_{2i}lnPLS_{it} + \pi_{3i}lnL_{it} + \pi_{4i}lnK_{it} + \mu_{it}$$
(6)

$$\mu_{it} = \rho_{it}\mu_{it-1} + \varepsilon_{it} \tag{7}$$

Where i = 1, ..., N represents the cross-sectional observation, t = 1, ..., T refers to the time period. Y represents GDP per capita, *RE* denotes renewable energy consumption, *j* is a subscript that captures renewable energy as a share of total energy and total biomass (*BIOM*), *PLS* represents political stability, *L* refers to labour, *K* is the level of capital while π represent the elasticities to be estimated. The parameters γ_{it} and δ_i respectively allow for country specific effects and deterministic trend effects. The symbol μ_{it} is error term expected to be normally and identically distributed with zero mean and constant variance. We expect that the elasticities π_{1i} , π_{2i} , π_{3i} and $\pi_{4i} > 0$, however, in event of inefficient utilization of production input and absence of political stability, then, π_{1i} , π_{2i} , π_{3i} and $\pi_{4i} < 0$.

The long-run equilibrium model in Eq. (6) can be estimated using the Dynamic Ordinary Least Squares (DOLS). The DOLS has the capacity to correct endogeneity, simultaneity and serial correlation problem through the differenced leads and lags. Thus, in order to generate unbiased estimator of long-run estimates, DOLS augments the static regression with leads, lags and the contemporaneous values of regressors in first difference (Mc-Coskey and Kao, 1998; Kao and Chiang, 2000). Besides, the use of DOLS estimator for this study was informed due to its asymptotic efficiency and robustness in a small sample. Moreover, the Fully Modified Ordinary Least Squares (FMOLS) and the Ordinary Least Squares (OLS) are further used to serve as a robustness check.

3.2. Data

All the data including renewable energy were sourced from the World Bank's World Development Indicators (WDI), World Governance indicator (WGI) and Material Flows website (www. materialflows.net). The data were collected for 15 West African countries for the period of 1995 to 2014 with 375 observations as the sample size. Moreover, the data were analysed in three groups namely: all sample countries in West Africa; sample of 5 largest countries in West Africa with the highest per capita GDP and 10 remaining countries with low per capita GDP. The five largest countries with the highest per capita GDP are Nigeria, Ghana, Mauritania, Senegal and Benin. The reason for selecting 5 largest countries based on per capita income and 10 countries with lower per capita income is to serve as robustness to 15 panels of countries. The justification of choosing the countries based on per capita GDP or income is due largely to the main objective of the study which is to examine the impact of renewable energy on economic growth. In this case, economic growth is measured by per capita GDP.

The variable for renewable energy consumption is measured as renewable energy consumption (% of total final energy consumption), the variable for biomass is measured as total biomass used in million tonnes of oil equivalents (Mtoe), the variable for political stability is measured as political stability and absence of violence, the variable for economic growth is measured as GDP per capita (constant 2010 US\$), the variable for labour was measured as Labour force participation rate total (% of total population ages 15–64) while that of capital was measured as Gross fixed capital formation (constant 2010 US\$). The use of GDP per capita and labour in this work is consistent with recent literature (see Dogan, 2016), while the use of labour force participation rate supports the work of Kahia et al. (2016). Labour force participation rate is the proportion of the population that is economically active in production (WDI, 2015). All the variables were converted to their logarithms form.

The West African countries included in the panel analysis are Benin, Burkina Faso, Cape Verde, Guinea, Ghana, The Gambia, Guinea-Bissau, Liberia, Mali, Mauritania, Nigeria, Niger, Sierra Leone, Senegal and Togo. However, there are missing data in the case of Saint Helena, Ivory Coast and Sou Tome and Principe, as such, they were excluded from the study, leaving us with 15 West African countries.

4. Results and discussion

Before estimation of the panel DOLS model, some preliminary tests such as unit root, summary statistics and correlation tests were conducted. Equally, Pedroni and Kao cointegration tests were then performed to ascertain the existence of a long-run relationship between the variables.

Table A.1 reports the results of the unit root tests (in Appendix). The results from Levin et al. (2002), Breitung (2001), Im et al. (2003), ADF-Fisher and PP-Fisher suggest that all the variables become stationary at first difference. For instance, the result shows that the variable of economic growth measured by per capita GDP is not stationary at level except for ADF-Fisher. However, economic growth is stationary at first difference for Levin et al. (2002), Breitung (2001), Im et al. (2003), ADF-Fisher and PP-Fisher. Similarly, the variable of renewable energy measured by renewable energy consumption % of total final energy consumption formally becomes stationary at first difference. Furthermore, with the exception of Levin et al. (2002), none of the considered panel unit root reveals stationarity of labour force at level but all methods show that labour force is stationary at first difference. Again, the variable of capital was formally stationary

Table 1	
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Pedroni	and	Kan	residual	cointegration	test

	WA15 $Y = f$	(RE, L, K)	WA5 $Y = f(R$	2E, L, K)			
	Statistics	p-value	Statistics	p-value			
V-stat	1.2278	0.1098	1.3806*	0.0837			
rho-stat	0.0239	0.5095	-0.1215	0.4516			
PP-stat	-2.7423***	0.0031	-2.0402**	0.0207			
ADF-stat	-1.4622^{*}	0.0718	-0.7615	0.2232			
Group rho-stat	1.3974	0.9189	1.0041	0.8423			
Group PP-stat	-3.1475^{***}	0.0008	-6.3487***	0.0000			
Group ADF-stat	-1.4343^{*}	0.0757	-1.5095^{*}	0.0656			
Kao	-3.7057***	0.0001	-2.8116***	0.0025			

Note: ***, ** and * indicate significance at 1%, 5% and 10% levels, respectively. WA15 refers to 15 West African countries. WA5 refers to five largest West African economies based on per capita income (i.e., Nigeria, Ghana, Mauritania, Senegal and Benin).

at first difference I(1). The fact that all the variable included in the estimation were formally stationary at I(1) also informed the use of panel DOLS as the estimator technique. Table A.2 (in Appendix) presents the summary of the descriptive statistics which include mean, median, standard deviation, minimum, maximum, skewness, Kurtosis and the total observation. The values of the Kurtosis indicates that the series are normally distributed. Table A.3 (in Appendix) displays the correlation matrix of all the variables. Importantly, the correlation matrix shows no high correlation between the explanatory variables. As such, we can safely conclude that our model is free from multicollinearity problem because the rule of thumb is that the persistence of the correlation coefficient among engaged variable should be less than 0.800 (Asongu et al., 2017b). The highest value of correlation coefficients in Table A.2 is 0.624.

Next, we checked the existence of cointegration relationship among our modelled variables using both Pedroni (1999, 2004) and Kao and Chiang (2000) cointegration tests (see Table 1) for two groups of West African countries, i.e., WA15 and WA5. Both the two tests' results for cointegration confirmed the existence of a long-run relationship among our variables, as we could reject the null hypothesis of the two tests. The null hypothesis of the two tests suggests no cointegration among the variables. Under Pedroni test, about four out of seven statistics from both within and between dimension are significant and hence suggest the existence of a long-run relationship between the variables. Equally, Kao cointegration test statistic is significant, which suggests the existence of a long-run relationship between the same variables. Therefore, rejecting the null hypothesis of no cointegration confirms the existence of a long-run relationship among the variables, as suggested by our results.

Having confirmed the existence of a long-run relationship between the variables, the long-run model is estimated using panel DOLS. Table 2 reports the estimated long-run results. First, the West African countries are estimated in a single model as a group (WA15). Second, the countries were segregated into two groups of five largest economies (WA5) and ten lower income economies (WA10), and estimated in two different models, respectively. The results for all the groups of West African countries (i.e., WA15, WA5, and WA10) indicate that renewable energy has a significant negative effect on economic growth. The results of robustness checks from panel FMOLS and pooled OLS equally yield the same negative and significant coefficients. It suggests that an increase in renewable energy consumption in West African countries marginally reduces economic growth. This finding does not come as a surprise, as most of the renewable energy used in West African sub-region come from wood sources, i.e., wood biomass (Sulaiman et al., 2017).

Wood biomass constitutes a large part of renewable energy used in sub-Saharan Africa, where West African sub-region is

Table 2

Impact of renewable energy on economic growth.

Variables WA15 $Y = f(RE, L, K)$			WA5 $Y = f(R)$	WA5 $Y = f(RE, L, K)$		WA10 $Y = f(RE, L, K)$			
	DOLS coefficient	FMOLS coefficient	OLS coefficient	DOLS coefficient	FMOLS coefficient	OLS coefficient	DOLS coefficient	FMOLS coefficient	OLS coefficient
lnRE _{it}	-0.3428^{*} (-1.9452)	-1.2070^{***} (-4.2071)	-1.0742^{***} (-17.3909)	-0.4807^{***} (-3.4627)	-0.2050* (-1.7291)	-0.2229*** (-3.0731)	-0.7001^{**} (-2.0607)	-0.3828** (-2.1122)	-1.4290^{***} (-18.8674)
lnL _{it}	0.0090 (0.01847)	0.0910 (0.1014)	-0.5654^{***} (-3.7146)	0.4979 (0.6261)	-0.4837 (-0.7317)	-0.9567^{***} (-11.656)	0.3949 (0.6179)	0.1029 (0.2321)	-0.3377^{*} (-1.6583)
lnK _{it}	0.1939*** (5.7788)	0.1454*** (2.8946)	0.1771*** (13.4927)	0.0916* (1.9595)	0.1038*** (3.2291)	0.1989*** (11.9767)	0.1706*** (3.7993)	0.1711*** (6.5965)	0.0741*** (3.7160)

Note: ***, ** and * indicate significance at 1%, 5% and 10% levels, respectively. While figures in parentheses are t-statistic. *lnRE* is the natural logarithm of renewable energy consumption, *lnL* is the natural logarithm of labour and *lnK*, is the natural logarithm of capital. WA15 refers to 15 West African countries. WA5 refers to five largest West African economies based on per capita income (i.e., Nigeria, Ghana, Mauritania, Senegal and Benin). WA10 refers to the remaining ten countries with lower per capita income in the region.

Table 3

Impact of biomass on economic growth (robustness).

Variables WA15 $Y = f(BIO, L, K)$		WA5 $Y = f(BIO, L, K)$			WA10 $Y = f(BIO, L, K)$				
	DOLS	FMOLS	OLS	DOLS	FMOLS	OLS	DOLS	FMOLS	OLS
	coefficient	coefficient	coefficient	coefficient	coefficient	coefficient	coefficient	coefficient	coefficient
InBIOM _{it}	-0.2056***	-0.3927^{***}	-0.3798***	-0.0957^{*}	-0.0064	-0.0512	-0.1864^{***}	-0.4062^{***}	-0.3951^{***}
	(-5.2771)	(-11.8918)	(-18.8631)	(-1.8779)	(-0.0471)	(-1.2160)	(-4.4864)	(-14.7095)	(-20.3378)
lnL _{it}	0.1074	-0.0326	-0.9567^{***}	0.1458*	-2.8281***	-1.0563^{***}	0.6230***	0.5839***	-0.1231
	(1.1781)	(-0.3559)	(-6.4673)	(1.8412)	(-4.7336)	(-10.1198)	(4.0188)	(4.9509)	(-0.6448)
lnK _{it}	0.3886***	0.5155***	0.4445***	0.3356***	0.2645***	0.2053***	0.2633***	0.3838***	0.3350***
	(11.92710)	(18.0390)	(24.1370)	(10.1495)	(7.3906)	(6.5348)	(5.6721)	(12.4413)	(14.6728)

Note: ***, ** and * indicate significance at 1%, 5% and 10% levels, respectively. While figures in parentheses are t-statistic. *InBIOM* is the natural logarithm of biomass energy consumption, *InL* is the natural logarithm of labour and *InK*, is the natural logarithm of capital. WA15 refers to 15 West African countries. WA5 refers to five largest West African economies based on per capita income (i.e., Nigeria, Ghana, Mauritania, Senegal and Benin). WA10 refers to the remaining ten countries with lower per capita income in the region.

Table 4

Biomass, renewable energy, political stability and economic growth (robustness).

Variables	WA15 $Y = f(BI0)$	WA15 $Y = f(BIOM, PLS, L, K)$			WA15 $Y = f(RE, PLS, L, K)$		
	DOLS coefficient	FMOLS coefficient	OLS coefficient	DOLS coefficient	FMOLS coefficient	OLS coefficient	
<i>InBIOM</i> _{it}	-0.3590^{***} (-3.4860)	-0.4443^{***} (-9.6620)	-0.3984^{***} (-16.7546)	-	-	-	
InRE _{it}	-	-	-	-0.6212** (-2.6344)	-0.1683^{**} (-2.4093)	-1.0703^{***} (-13.3824)	
InPLS _{it}	0.0504 (0.5140)	0.0155 (0.2770)	0.0402 (1.5336)	-0.1029 (-0.8401)	-0.0063 (-0.4286)	0.0081 (0.2589)	
lnL _{it}	-0.3731 (-1.2961)	-0.1620 (-1.2254)	-1.0324^{***} (-6.1447)	0.8202** (2.3029)	-0.1489 (-0.5197)	-0.6221^{***} (-3.3143)	
lnK _{it}	0.5515*** (6.3229)	0.5621*** (15.3794)	0.4725*** (22.3253)	0.2879*** (7.2254)	0.1740*** (10.9512)	0.1825*** (11.7211)	

Note: *** and ** indicate significance at 1% and 5% levels, respectively. While figures in parentheses are t-statistic. *InBIOM* is the natural logarithm of biomass renewable energy consumption. *InRE* is the natural logarithm of renewable energy consumption. *InPLS* is the natural logarithm of political stability, *InL* is the natural logarithm of labour and *InK*, is the natural logarithm of capital. WA15 refers to 15 West African countries.

located (IREA, 2013). These wood biomasses used are mostly traditional, unclean and highly polluting, which can cause some health complications through indoor air pollution and by extension, can negatively affect economic growth through productive time lost due to illness. The use of traditional wood biomass has been associated with many respiratory and pulmonary infections, which are capable of leading to mortality and morbidity. Equally, these infections incur costs on individuals by increasing their medical expenses, which lower their income. Importantly, the use of traditional biomass can lower individuals' productivity since when they are sick from indoor air pollution related infections, their productivity will reduce and thus reducing output growth. To further support this finding, WHO (2014) reports that indoor air-related infections from wood biomass use caused more than 500,000 thousand deaths in sub-Saharan Africa, which is about 10% of the total mortality in that year. These deaths contributed significantly to labour force reduction. Also, the process of gathering wood biomass for use as fuel keeps away non-disabled men and women from productive activities as they travel a long distance and it takes many hours to collect woods for fuel use. Therefore, the adverse effect of renewable energy on economic growth in West Africa is justifiable by the given explanations.

On the other hand, the finding of this study contradicts Narayan and Doytch (2017), where renewable energy was found to be a driver of economic growth in a sample of 89 countries comprising low, lower middle, upper middle, and high-income economies. However, the contradiction is not surprising as none of the West African countries was included in Narayan and Doytch (2017)'s sample. Thus, their finding has no implication on West African sub-region.

The control variables, denoted by labour and capital reveal insignificant and significant positive coefficients, respectively, as suggested by panel DOLS estimates for all the groups of West African countries. It suggests that capital is more effective in facilitating economic growth than labour in West African sub-region. The robustness checks by panel FMOLS shows the same pattern of results regarding the coefficients of labour and capital for all the groups of West African countries. Equally, the robustness checks by pooled OLS reveal a similar pattern of results regarding the coefficients of labour and capital for all the groups.

Since renewable energy in West Africa is dominated by biomass, renewable energy is replaced with biomass in the model and estimated it as a robustness check. Table 3 presents the result of the estimated impact of biomass on economic growth in West Africa. The DOLS result indicates that biomass has a significant negative impact on economic growth for all the three categories of West African countries (i.e., WA15, WA5, and WA10). This finding substantiates the earlier result of the impact of renewable energy on economic growth. Equally, FMOLS and OLS show similar results. The finding further justifies the negative impact of biomass on economic growth.

Next, renewable energy and biomass models were estimated by including political stability as a control variable to check whether it could influence their results. However, the results of the two models equally show similar results (see, Table 4) for a group of West African countries. That is, both renewable energy and biomass still retain their significant negative effect on economic growth in the presence of political stability. Furthermore, the results from FMOLS and OLS are consistent with the result displayed by DOLS.

5. Conclusion and policy implications

This study estimated the relationship between economic growth and renewable energy in West African countries using panel DOLS by employing a sample of 15 countries covering the 1995-2014 period. The countries were categorized into three groups. The first group comprises fifteen West African countries, which were captured in the main model. The second group consists of five largest West African economies, which were captured in the second model to serve as robustness. Last, the third group covers ten lower income West African countries, which also serve as robustness. The results indicate that renewable energy use is negatively related to the economic growth of West African countries. The results for WA15, WA5, and WA10 show a similar pattern, which reveal that the estimates were robust. The finding shows that the kind of renewable energy used in West Africa rather slows down economic growth than facilitating it. This could be attributed to the fact that the popular and major renewable energy in the sub-region comes from wood biomass, which is mostly traditional and unclean. The usage of this kind of renewable energy is widespread in the sub-region, and its cost (adverse effects) through indoor air pollution outweighs its benefits. Therefore, marginally, the use of renewables in West Africa reduces growth as shown by this study.

To validate the outcome of this study from panel DOLS, the same model was estimated using panel FMOLS and pooled OLS. The results of both panel FMOLS and pooled OLS corroborate the finding of panel DOLS. Thus, the finding can be considered robust and reliable for statistical inference.

The policy recommendations from this study are as follows. First, since the major and most popular source of renewable energy in West Africa is wood biomass, cleaner technologies for the optimal utilization of wood biomass are needed such that its benefits will be harnessed without posing any adverse effects to the health of the population. To achieve this, a prototype of the European Union (EU) member countries' renewable wood energy policy can be incorporated in the Economic Community

Table	A. I		
Panel	unit	root	tests.

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Variable	Form	Method	t-stat & (p-value)	Conclusion
lnY _{it}	Level 1st difference	LLC Breit IPS ADF-Fisher PP-Fisher LLC Breit IPS ADF-Fisher PP-Fisher	$\begin{array}{c} -0.6698 \ (\ 0.2515) \\ 0.7456 \ (0.7720) \\ -0.4738 \ (0.3178) \\ 41.495 \ (0.0790) \\ 16.775 \ (0.9722) \\ -10.1670 \ (0.0000) \\ -3.3551 \ (0.0004) \\ -12.059 \ (0.0000) \\ 164.519 \ (0.0000) \\ 201.499 \ (0.0000) \end{array}$	Non-stationary Non-stationary Stationary Stationary Stationary Stationary Stationary Stationary Stationary
InRE _{it}	Level 1st difference	LLC Breit IPS ADF-Fisher PP-Fisher LLC Breit IPS ADF-Fisher PP-Fisher	$\begin{array}{l} -2.7415\ (0.0031)\\ -0.8547\ (\ 0.1963)\\ -1.5892\ (0.0560)\\ 43.530\ (0.0526)\\ 38.238\ (\ 0.1437)\\ -13.512\ (0.0000)\\ -9.7089\ (0.0000)\\ -10.786\ (0.0000)\\ 145.489\ (\ 0.0000)\\ 199.238\ (0.0000)\end{array}$	Stationary Non-stationary Stationary Stationary Stationary Stationary Stationary Stationary Stationary
InL _{it}	Level 1st difference	LLC Breit IPS ADF-Fisher PP-Fisher LLC Breit IPS ADF-Fisher PP-Fisher	$\begin{array}{c} -2.9854 \ (0.0014) \\ 2.4638 \ (\ 0.9931) \\ 0.6106 \ (0.7293) \\ 24.236 \ (0.7612) \\ 14.1915 \ (\ 0.9936) \\ -6.0072 \ (\ 0.0000) \\ -4.9434 \ (\ 0.0000) \\ -5.8161 \ (0.0000) \\ 88.1768 \ (0.0000) \\ 103.683 \ (0.0000) \end{array}$	Stationary Non-stationary Non-stationary Non-stationary Stationary Stationary Stationary Stationary Stationary
lnK _{it}	Level 1st difference	LLC Breit IPS ADF-Fisher PP-Fisher LLC Breit IPS ADF-Fisher PP-Fisher	-2.0304 (0.0212) 1.58870 (0.9439) -2.0703 (0.0192) 49.998 (0.0124) 45.317 (0.0361) -15.084 (0.0000) -3.9270 (0.0000) 184.975 (0.0000) 249.642 (0.0000)	Stationary Non-stationary Stationary Stationary Stationary Stationary Stationary Stationary Stationary

Note: lnY_{it} is the natural logarithm of income, lnRE is the natural logarithm of renewable energy consumption, lnL is the natural logarithm of labour and lnK, is the natural logarithm of capital.

Table A.2	
Descriptive	statistics

Descriptive statistic				
	lnY _{it}	lnRE _{it}	lnL _{it}	lnK _{it}
Mean	6.4802	4.2397	4.2245	20.2420
Median	6.3043	4.4109	4.2563	20.2534
Maximum	8.1589	4.5835	4.4473	24.9766
Minimum	4.7487	3.0541	3.8795	15.1395
Std. Dev.	0.5911	0.3347	0.1431	1.6295
Skewness	0.6468	-1.1020	-0.5442	0.3190
Kurtosis	3.5864	3.1896	2.3992	3.5554
Observations	374	374	374	374

Note: lnY_{it} is the natural logarithm of income, lnRE is the natural logarithm of renewable energy consumption, lnL is the natural logarithm of labour and lnK, is the natural logarithm of capital.

of West African States' renewable energy strategies. Similar or advanced clean technologies employed by EU countries may be adopted by West African countries. Second, the share of other renewable energy components such as solar, wind and geothermal need to be increased in the renewable energy mix of the subregion. Last, greater commitment toward achieving sustainable renewable energy is needed by West African countries.

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Table A.3

Variables	lnY _{it}	<i>lnRE_{it}</i>	lnL _{it}	lnK _{it}
lnY _{it}	1			
lnRE _{it}	-0.6244	1		
lnL _{it}	-0.1954	0.0258	1	
lnK _{it}	0.5477	-0.0632	-0.1258	1

Note: lnY_{it} is the natural logarithm of income, lnRE is the natural logarithm of renewable energy consumption, lnL is the natural logarithm of labour and lnK, is the natural logarithm of capital.

Table A.4

List of West African countries included in the study.

S/N	Countries	S/N	Countries	S/N	Countries
1	Benin	6	The Gambia	11	Nigeria
2	Burkina Faso	7	Guinea-Bissau	12	Niger
3	Cape Verde	8	Liberia	13	Sierra Leone
4	Guinea	9	Mali	14	Senegal
5	Ghana	10	Mauritania	15	Togo

Appendix

See Tables A.1-A.4.

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