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Renewable energy consumption in Africa: Evidence from a bias corrected dynamic panel

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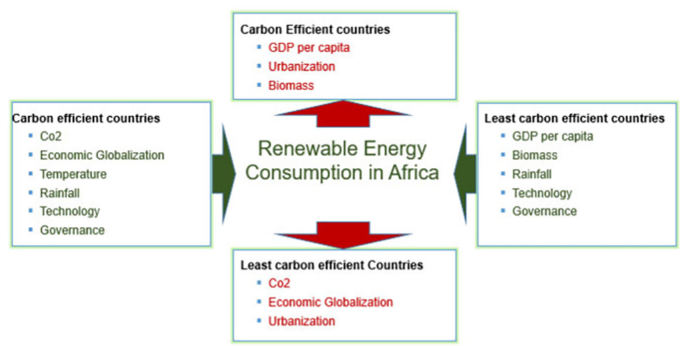
HIGHLIGHTS

- The study explores the drivers of renewable energy consumption in Sub-Saharan Africa.
- Corrected least squares dummy variable estimator for 32 African countries
- We abstract two groups of countries- Carbon Efficient and Least Carbon efficient countries.
- We find that economic, environmental and socio-economic factors promote renewable energy consumption in the region.

GRAPHICAL ABSTRACT



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ABSTRACT

Our study investigates the determinants of renewable energy consumption in Sub-Sahara Africa. We explore the driving factors of renewable energy consumption in the context of carbon intensity for 32 Sub-Saharan African countries from 1990 to 2015. Using carbon emission intensity to identify group-specific heterogeneity, we recognize carbon-efficient and least carbon-efficient countries in the region. By relying on the corrected least squares dummy variable estimator (LSDVC), we provide evidence on the driving factors of renewable energy consumption in Sub-Saharan Africa. Consequently, the findings point to varying degrees of impact on renewable energy consumption in the region. For instance, we observe advancement in technology, quality of governance, economic progress, biomass consumption, and climatic conditions influence renewable energy consumption. With a common occurrence across all groups, the implications indicate environmental, socio-economic, and climatic factors playing an important role in renewable energy consumption. The study further shows that urbanization and economic globalization depress efforts towards renewable energy consumption. Apart from these common factors, other controlling variables including; GDP per capita, environmental awareness, and biomass affect each group differently. We conclude that, policy implications can be drawn from common factors towards harmonization of clean energy markets and developing a policy mix that combines environmental, economic, and social factors in attaining the Sustainable Development Goals.

1. Introduction

Environmentalists and policymakers are clear on climate change and global warming, having severe implications on the earth's survivability.

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Also, they pointed to the trade-off between economic growth and sustainable development as one of the main factors (Marques and Fuinhas, 2011). As such, global multilateral environmental agreement, most especially, the United Nations Convention on Climate Change (1992), the Kyoto protocol (1998), and the Paris agreement (2015), require countries to enhance the reduction in carbon emitted per unit of a good produced, while also scaling up clean energy consumption by 2050. In response, there has been call to decouple economic growth from fossil fuel energy (International Energy Agency, 2016). Consequently, renewable forms of energy such as solar, wind, hydro, geothermal, tidal, and biomass have gained attention in policy reforms towards renewable energy consumption.

Despite the widespread support, the general momentum towards renewable energy consumption is still at the incipient stage in most countries. As of 2016, at the global level, the share of renewable energy consumed from the total primary energy remains well below 18%, while the share of advanced clean energy stays below 11% (International Energy Agency, 2016). Given the growth in renewable micro-grids in many African countries, declining prices of solar-photovoltaic, environmental awareness and policy towards increasing energy mix, this trend is expected to change (Ike et al., 2020; Niyonteze et al., 2020; Dobrotkova et al., 2018). According to Pillot et al. (2019), the share of renewable energy consumption is expected to double over the next 30 years. Nevertheless, this growth in consumption is expected to vary across regions and countries (Szabó et al., 2016). At the regional level, country-specific factors such as economic growth, environmental factors, population growth and urbanization, political factors, technological progress and trade policies will play a critical role in driving the change (Balcilar et al., 2018).

Currently, Sub-Sahara Africa lags in energy production and consumption despite the increasing global trend (Hafner et al., 2018). Thus, a situation many scholars have described as energy poverty. Energy poverty is reflected in consumption trends as the region consumes 3.3% of total world primary energy. In the view of Szabó et al. (2016), over 600 million people are without access to stable, reliable, and affordable energy supply. Moreover, in the energy economics literature, many factors cited explain energy poverty in Africa and by extension, the low levels of clean renewable energy consumption in the region despite the enormous and diverse energy resource in the region.

Our study builds on existing literature and ascribes some of the reasons to underinvestment in clean energy sources (Alola et al., 2019; Klagge and Nweke-Eze, 2020). Other factors include: political will and policy decisions towards adoption and consumption (Linnerud et al., 2014), lack of needed capital investment (Maji et al., 2019), off-grid solar powered infrastructure (Baurzhan and Jenkins, 2016), and high population growth and urbanization. Further, under-developed nature of the regional markets does not promote energy sharing among countries (Szabo et al., 2011). To gain an understanding into these intricate phenomena, we explore these driving factors at the regional level before drilling into group-specific differences and similarities.

Presently, these studies (Oppong et al., 2020; Nathaniel and Iheonu, 2019; Maji et al., 2019; Olanrewaju et al., 2019; Ergun et al., 2019; Da Silva et al., 2018; Attiaoui et al., 2017; Aïssa et al., 2014) examines the determinants of renewable energy consumption in Africa by either relying on a Panel ARDL approach or using a static panel estimator. We present our findings using a dynamic panel estimator that is robust to small sample bias and second order - serial correlation. The dynamic panel estimator allows the flexibility of estimating the evolving nature of environmental and economic relationships. Besides, our study explores the drivers through the lens of carbon emissions per unit of a good produced. Based on this selection, we abstract two groups of renewable energy consumers in the region. One group is carbon-efficient and the other group is the least carbon-efficient. We argue, by selecting countries based on carbon emission intensity, we are able to exploit the amount of carbon emitted per unit of goods produced and group countries based on similar carbon intensities. On this account, the study contributes to the literature in threefold: (1) add to literature and enhance our understanding on renewable energy consumption in SSA, (2) using a wider time frame and countries, (3) using a bias correcting dynamic estimation approach.

The study reveals that current levels of renewable energy consumption are contemporaneously correlated with past levels of renewable energy consumption. In brief, this is true for the two broad categories and the full sample. Moreover, we observe a positive relationship between CO_2 emissions per capita and renewable energy consumption. We show that human development improves renewable energy consumption in the full sample. Thus, confirming the importance of income and general wellbeing for renewable energy consumption. As expected, urbanization diminished renewable energy consumption. We also observe a positive relationship between biomass (forest area) and renewable energy consumption. Highlighting the importance of climatic indicators, we show that hydro-electric power and solar energy have induced renewable energy consumption in the region. Considering that most of the energy consumed in the zone is from hydro-powered plants, our indicators were absolute.

Moving on to the carbon-efficient group, the dynamic assessment of renewable energy consumption is still relevant to present energy consumption. Interestingly for this group, there is a negative relationship between income per capita, trade openness, and wood-derived biomass on the outcome variable. The implications point out that perhaps financial flows through trade into renewable energy is still lacking in these countries. Arguably, we agree on the same terms that the share of wood-derived biomass from renewable sources of power dominates the share. Hence, as income increases, we expect a lower portion of the energy consumed from renewable sources. This same connection highlights the negative relationship between biomass use and renewable energy use for these countries. In the case of the least carbon-efficient group, GDP per capita, and biomass (forest area) drive renewable energy consumption. In summary, these findings affirm historic precedents, present policy relevance, and future implications on renewable energy consumption in SSA.

2. Literature review

As a result of the constant threat of climate change due to Green House Gas emissions, there has been a general call towards the production of carbon-resilient sources of energy and the reduction in the consumption of fossil-based energies (Marques and Fuinhas, 2011). As such, scores of empirical studies have emerged to examine the development and consumption of renewable energy. For instance, Sadorsky (2009), points to the investigation of the relationship between renewable energy consumption, CO_2 emissions, and Oil prices for the G7 countries. The study provides evidence that CO_2 per capita and GDP per capita increased renewable energy consumption. Adding to the evidence, Apergis and Payne (2010) affirmed a long-run relationship between GDP and renewable energy consumption. On the determinants of renewable energy consumption with evidence from 64 countries between the years 1990 and 2011, Omri and Nguyen (2014) showed that oil price affects renewable energy consumption. According to the aforementioned, they documented that changes in GDP influence renewable energy use in high and Low-income countries. In the case of the full sample, trade openness positively drives renewable energy consumption. Other studies that modeled similar relationships include: (Bhattacharya et al., 2016; Fang, 2011; Omri et al., 2014; Salim and Rafiq, 2012; Sinha et al., 2018). What is striking in these findings is the link between renewable energy consumption and economic growth, trade openness, carbon emissions.

Apergis and Payne (2012) employed a panel time-series model to establish bidirectional causality among selected variables in their model. From this exercise, seven Central American countries showed a positive relationship between CO_2 emissions and renewable energy consumption. Energy prices also positively affected renewable energy consumption. Again, in an extensive study, Nguyen and Kakinaka (2019) showed a positive association between renewable energy consumption and CO_2 emissions for low-income countries. Similarly, Ohler and Fetters (2014) noted bidirectional causality amid economic growth and renewable energy consumption. Marques and Fuinhas (2011) applied a dynamic panel estimation technique for 24 European countries. Findings from the study showed a contemporaneous effect of lagged energy use on current energy use. They provide evidence in support of urbanization, CO_2 emissions, and economic growth in motivating renewable energy consumption in the selected countries. In contrast to these findings, Ocal and Aslan (2013) show that renewable energy consumption does not lead to economic growth but indicates a positive or negative relationship is time or country dependent.

The literature on renewable energy in Africa mainly focused on biomass and fire wood consumption. For instance (Adewuyi and Awodumi, 2017; Sulaiman et al., 2017) have documented that countries in Africa rely heavily on combustible biomass for heating and cooking. As yet, empirical studies that examine the share of renewable energy from total primary energy consumption spans Da Silva et al. (2018). In their work, they used a Panel ARDL approach to examine the determinants of renewable energy growth in Sub-Saharan Africa. Evidence selected in 17 SSA countries from 1990 to 2014 noted the relevance of economic growth to renewable energy growth in the region. On the relationship between CO_2 and renewable energy consumption, Nathaniel and Iheonu (2019) showed a negative relationship between these two variables in their study. Olanrewaju et al. (2019) finds a negative relationship between carbon intensity and renewable energy consumption in Africa. Added to this, Oppong et al. (2020) show a long run granger causality between GDP, CO_2 and renewable energy consumption for countries in Africa. This corroborates the findings of Attiaoui et al. (2017). In similar evidence, Nathaniel and Iheonu (2019) used an Augmented Mean Group estimation technique to document a unidirectional causality from renewable energy to CO_2 emissions for 19 countries in Africa. Contrary to these findings, Maji et al. (2019) used a panel dynamic ordinary least squares estimation technique to show that between 1995 and 2014, renewable energy consumption did not promote economic growth but rather slowed down economic progress for 15 West African countries. Ergun et al. (2019) used a static panel estimation technique for 21 African countries for the period 1990 and 2013 to argue that because most forms of renewable energy use is from biomass, economic progress or increases in GDP per capita may translate into lower levels of renewable energy consumption.

3. Material and method

3.1. Source of data and variable description

In investigating the key driving factors of renewable energy consumption in SSA, the study sourced data from the World Bank's World Development Indicators (WDI), the Quality of Governance database, and the KOF Swiss economic institute. The data spans from the period of 1990 to 2015 for selected 32 SSA countries. Fig. 1 shows a map of

Fig. 1. Selected countries used for the study.

Table 1
Summary statistics.

	Obs	St. dev	Min	Max	Kurtosis	Skewness
REN	831	22.042	10.634	98.343	3.662	−1.274
CO_2 emissions per capita	800	1.637	0.017	9.979	19.195	3.97
Oil price	832	32.957	12.983	107.272	1.972	0.715
GDP per capita	832	2263.661	164.337	11,937.6	8.32	2.344
HDI	779	0.387	1.03	2.719	2.381	0.51
Urban population growth	832	1.731	−1.477	17.499	13.384	1.315
Trade openness	832	0.401	0	2.078	2.817	0.479
Economic globalization	832	10.117	15.746	85.185	4.361	0.477
Biomass	829	294,000	382	1,600,000	15.782	3.393
Rainfall	832	41.673	9.168	236.563	3.153	0.412
Temperature	832	2.692	17.381	29.541	2.413	−0.085
Governance	650	0.127	0.083	0.898	3.968	0.298
Technology	829	4.829	0	31.067	19.61	3.882

the chosen countries- specific carbon intensities. The selection of countries is limited to the availability of data for the variables selected in the study. Therefore, Table 1 provides a summary of the reported descriptive statistics of the variables, including the mean, standard deviation, minimum, maximum, kurtosis and Skewness of the distribution. From the table, the kurtosis of all the variables remains greater than +1; indicating a very peaked distribution with most of the variables having heavier tails than a normal distribution.

3.1.1. Environmental variables

As part of the covariates, we source spot oil price measured in $ per bbl from the yearly statistical reviews of British petroleum. As a measure of environmental awareness, we use CO_2 emissions per capita. We expect higher levels of CO_2 emissions to give rise to calls for environmental protection, which in turn drives renewable energy consumption (Marques and Fuinhas, 2011). We define climatic effects as average annual temperature and mean annual rainfall. We anticipate either a positive or a negative impact on the outcome variable. From a hydroelectric generating point of view, there is the likelihood of high average rainfall needed to fill up water bodies for hydro-electricity generation. On the temperature side, a high yearly average temperature could signal potential investment into solar infrastructure, but this can potentially constrict hydro-electricity generation.

3.1.2. Economic variables

For the economic variables, we use GDP per capita to reflect economic progress, with the data taken from the World Development Indicators (WDI). Chang et al. (2009) demonstrate that higher-income countries are likely to consume from renewable sources than those with low income per capita. To complement the economic indicators, we use HDI to measure general economic well-being. Additionally, we also define economic globalization and trade openness as a conduit, through which investment and technological innovation diffuse to countries with lower technological capacity. The study expects either a positive or negative effect on the outcome variable. In the view of Omri and Nguyen (2014), trade openness facilitates the cross-border movement and exchange of goods, which is inherently energy reliant. Added to this, the advent of technology could either push or drag renewable energy consumption in the region.

3.1.3. Socio-economic variables

We anticipate a direct effect of urbanization on energy use and by extension, renewable energy consumption. For instance, Chen (2018) shows that in urban areas where energy demand is high, urbanization could increase the demand for alternative sources of energy. Next, as a proxy for wood-derived biomass, the study anticipates a positive relationship between forest areas and energy consumption in the region. The argument remains that, SSA countries use wood derived biomass for cooking and heating. In another context, Gan and Smith (2011) posit that countries endowed with renewable resources effectively produce and consume such resources. The reverse also holds but on the condition of developing a high-level technology to harness the opportunities. We also include the quality of governance indicator to reflect institutional policies towards renewable energy consumption in the region. Here, we expect countries with higher quality of governance to influence renewable energy consumption positively.

3.2. Empirical models

Following Omri and Nguyen (2014), the study develops an empirical model that augments standard empirical models by including temperature, rainfall, urbanization, technology, governance, and biomass as part of the controls. Expressly, in an econometric form, the determinants of renewable energy consumption for the full sample and group-specific cases is stated as follows:

$$\begin{aligned} REC_{it} = {} & \beta_0 + \beta_1 CO_2 \text{per cap}_{it} + \beta_2 HDI_{it} + \beta_3 \text{Eco} - \text{glob}_{it} \\ & + \beta_4 \text{temp}_{it} + \beta_5 \text{Rain}_{it} + \beta_6 \text{urban}_{it} + \beta_7 \text{Biomass}_{it} \\ & + \beta_8 \text{Technology}_{it} + \beta_9 \text{Governance}_{it} + u_{it} \end{aligned} \tag{1a}$$

$$\begin{aligned} REC_{it} = {} & \beta_0 + \beta_1 CO_2 \text{per cap}_{it} + \beta_2 \text{GDP per capita}_{it} + \beta_3 \text{Eco} - \text{glob}_{it} \\ & + \beta_4 \text{temp}_{it} + \beta_5 \text{Rain}_{it} + \beta_6 \text{urban}_{it} + \beta_7 \text{Biomass}_{it} \\ & + \beta_8 \text{Technology}_{it} + \beta_9 \text{Governance}_{it} + u_{it} \end{aligned} \tag{1b}$$

where, REC represents renewable energy consumption, which is a function of; CO_2 emissions, HDI, GDP per capita, trade openness, rainfall, temperature, urbanization, and biomass, technology and governance. Therefore, applying a panel data dimension to the function in Eqs. (1a) and (1b) yields the following equation:

$$REC_{it} = \beta_0 + \beta_{i,t} \Sigma CV_{i,t} + u_{it}. \tag{2}$$

where CV captures all the covariates mentioned in Eqs. (1a) and (1b). $u_{i\,t}$ is a function of the fixed effects and the unobserved white noise.

3.3. Estimation method

Estimating panel models require certain assumptions: First, the covariates should not correlate with each other. Next, the model should be free from serial correlation. The variables should be exogenous; whiles the distribution remains normal. In our model, variables like GDP per capita, CO_2 emissions per capita, and urban population growth change over time. This means, to be able to correctly predict the outcome of a model, time varying factors should be taken into consideration. Hence using OLS or the fixed effects model may produce biased coefficients and imprecise standard errors.

One such approach to correcting these measurement errors and unobserved heterogeneities in static panels is to include dummy variables or taking first differences. However, a problem with these approaches is the persistence of a correlation between the lagged term (REC_{it-1}) and the error term (u_{it}). Blundell and Bond (1998) solved this by proposing the System GMM estimator. However, recent literature suggests that the system GMM estimator performs poorly (small sample bias problem) when the sample is characteristically small.

Our cross-sectional element of the data consists of 16 countries in each group for a period of 25 years. Given the small size of our panel, estimating this with a system GMM regression could lead to a small sample bias problem. As such, Bruno (2005) proposes a model that corrects this problem by extending the work of Kiviet et al. (1999) to accommodate unbalanced panels. Unlike the conventional system GMM estimator, Bruno (2005) posits that the LSDVC estimator is efficient in bias correction under unbalanced panels characterized by missing observations (Flannery and Hankins, 2013). Under a strictly exogenous assumption of parameter selection, Bruno (2005) shows that the LSDVC is a preferred estimator as compared to the system GMM estimator when the panel is short. Similar to the case of our full sample, Buddelmeyer et al. (2008) showed that even when $T = 5$ and $N = 20$, the LSDVC yields consistent and reliable estimates. On this ground, the study implements the LSDVC estimator with fixed effects that is robust in the presence of unbalanced panels; second-order serial correlation; and unobserved heterogeneity in a dynamic panel setting. Our study estimates LSDVC estimator initialized by a dynamic panel estimate, which relies on a recursive bias correction up to $N^{-1}T^{-2}$ with time fixed effects following 100 bootstrapped replications to check the statistical significance of the coefficients (Bruno, 2005). The empirical strategy for the LSDVC estimator is reported in the Eq. (3).

$$REC_{i,t} = \alpha_i REC_{i,t-1} + \beta_i CV_{it} + f_i + u_{i,t} \quad (3)$$

where $REC_{i,t}$ is the outcome variable over space and time (REC); $REC_{i,t-1}$ is the lagged dependent variable with a first-order autoregressive process. Also, the inclusion of fixed effects f_i is to control for observations that are not randomly selected. CV_{it} encapsulates the exogenous factors driving renewable energy consumption in the region. In addition, the U_{it} is the error term independent of the f_i term.

4. Empirical results

4.1. Correlation analysis

Table 2 shows the correlation coefficient of the variables in the model. Starting with the urbanization coefficient, we observe that the elasticity of urbanization is positively related to renewable energy consumption in all groups. Also, we observe a significant negative correlation between technology, trade openness and renewable energy consumption across all groups. The outcome indicates low levels of investment in renewable energy in the region. However, economic globalization and wood derived biomass are positive and significant for the full sample and the carbon-efficient group. Governance is significantly negative for the full sample and the least carbon efficient group. In the case of the full sample and the least carbon-efficient group, we show a positive correlation between temperature, rainfall and renewable energy consumption. Also, in the carbon-efficient group, we observe a negative correlation.

4.2. Fisher unit root test

Because panel data combines both elements of time series and cross-sectional data, we need to check the stationarity of the variables to ascertain that they don't fluctuate the mean. Additionally, the results from the model may be spurious with nonstationary models and this could lead to unintended conclusions. Hence, to implement a stationarity check, we employ the Fisher Unit root test with an Augmented Dickey-Fuller option under the null hypothesis; all panels have a unit root, as against the alternative of no unit root. Also, Table 3 presents the results of the Fisher unit root on the variables used in this study. For instance, the test result at levels confirms, some variables are stationary (Urban population growth, biomass, economic globalization, governance, rainfall, and temperature). Using the first difference, we transformed non-stationary variables at levels (CO_2 emissions per cap, oil price GDP per cap, and technology) to stationary variables. Meaning the order of integrations is one.

4.3. Pre-testing of the model

Before estimating the dynamic panel, we first present the drivers of renewable energy consumption in a static lens thus, estimating a pooled OLS and fixed effects regression. Our results presented in Table 8 reports consistent but inefficient outcomes. To show this, we performed several diagnostic checks. First, to ascertain the suitability of variables in the model, we performed a test of collinearity of the covariates in the model. Table 4 reports the output of the VIF test for multicollinearity. As a rule of thumb, none of the reported values were greater than 10. Hence, one can be confident of no perfect collinearity in the model. We further test for cross-sectional dependence in the model using the Pesaran test for cross-sectional dependence for the full sample ($T < N$) and the Breusch Pagan test ($T > N$) for the groups. To demonstrate, our results in Table 8, the full sample document no cross sectional dependence among the variables. The group specific cases however report the presence of cross-sectional dependence. As a final step, we performed the Wooldridge test for serial correlation in the model. At this point, our result reports the presence of serial correlation in the model that may cause the standard errors to be bias and the estimates to be less efficient. As such, using the pooled OLS and the fixed effect result

Table 2
Correlation table.

	REN_full sample	REN_carbon efficient	REN_least carbon efficient
CO_2 emissions per cap	−0.61***	−0.81***	−0.64***
Oil price	−0.12***	−0.16***	−0.12**
GDP per cap	−0.59***	−0.73***	−0.54***
HDI	−0.49***	−0.18***	−0.45***
urban population growth	0.38***	0.24***	0.44***
Trade openness	−0.37***	−0.22***	−0.37***
Economic globalization	0.07**	0.21***	0.05
Biomass	0.28***	0.31***	0.30***
Rainfall	0.11***	−0.28***	0.35***
Temperature	0.16***	−0.32***	0.43***
Governance	−0.23***	0.22***	−0.46***
Technology	−0.75***	−0.77***	−0.74***
N	832	416	416

***, **, * indicates 1, 5, and 10 percent level of significance.

Table 3
Fisher unit root test.

	Levels		First difference	
	Statistic	P-value	Statistic	P-value
REC	55.7816	0.7582	323.9597	0.0000
CO_2 emissions per capita	60.206	0.6114	680.3012	0.0000
Oil price	27.3654	1.0000	884.4531	0.0000
GDP per cap	74.4327	0.175	400.7311	0.0000
Urban pop	219.3379	0.0000	403.5189	0.0000
Trade openness	46.1573	0.9548	547.4045	0.0000
Biomass	323.1709	0.0000		
Temp	245.5009	0.0000	1267.837	0.0000
Rainfall	680.2298	0.0000	1733.8793	0.0000
Economic glob	114.0764	0.0000	794.9713	0.0000
Governance	84.7850	0.0015	320.1269	0.0000
Technology	53.0149	0.8347	574.9351	0.0000

Table 4
Test for multicollinearity using VIF.

	Full sample		Carbon efficient		Least carbon efficient	
Variable	VIF	1/VIF	VIF	1/VIF	VIF	1/VIF
CO_2 emissions per cap	2.18	0.459441	3.89	0.260531	3.76	0.265764
HDI	1.90	0.525603	3.04	0.329209	2.01	0.496525
Log rainfall	1.61	0.622814	4.10	0.243650	2.99	0.334741
Log Temperature	2.05	0.488912	3.34	0.299718	3.73	0.268315
Governance	1.99	0.503704	2.41	0.414785	3.36	0.297423
Economic globalization	1.57	0.637732	3.60	0.277569	2.00	0.500003
Urban Population growth	1.50	0.665495	1.86	0.536377	1.37	0.731201
Log Biomass	1.25	0.801565	2.01	0.498631	1.26	0.794723
Log Technology	3.13	0.319686	2.82	0.335438	5.17	0.193595
Mean VIF	**2.05**		**2.43**		**2.36**	

may not be ideal for a causal interpretation due to biased standard errors, small sample bias problem and the dynamic nature of relationships. Hence, we use the LSDVC estimator which is robust to second-order serial correlation, unobserved heterogeneity, corrects the problem of small sample bias and robust to gaps in unbalanced panels for our analysis.

4.4. Estimation for the full sample

Firstly, we seek to present the dynamic effect of the determinants of renewable energy consumption for the whole sample. Secondly, there is a discussion on the carbon-efficient group and the least carbon-efficient group. To sum up, by employing the corrected LSDV estimator, we show the key factors driving renewable energy consumption in SSA.

The estimator controls for the dynamic effect by including the first lag of the dependent variable as an independent variable in the model and the variables assumes a strictly exogenous assumption. Moreover, concerning the robustness of the result, we bootstrapped the standard errors to 100 replications to ensure an accurate prediction of the outcomes (Bruno, 2005). Approximately, the accuracy of the bias is up to O $(1/NT^{2})$ and initialized with the Blundell and Bond (BB) estimator. Further, using this adjustment ensures the consistency and efficiency of the results. We report our discussion for the full sample in Table 5. From the results, the first lag of the dependent variable is positive and significant which implies that current levels of renewable energy consumption is dependent on past patterns of renewable energy consumption. This affirms the appropriateness of using the dynamic panel estimator. It also validates the idea that changes in consumption patterns take time. All things considered, the study underscores that including the lag of the dependent variable in the model improves the explanatory power of control variables.

Column 9 of Table 5 reports the preferred regression output. Also, Columns (1–8) report the parsimonious regression with various degrees of controls. Moreover, an elaborative way to capture the true effect on the dependent variable in a dynamic panel setting is to capture country-specific factors that do not change over time. We achieve this by controlling for time effects in all the specifications. The first column which is our baseline regression examines the role of CO_2 emissions per capita on renewable energy consumption and using HDI as control. Here, our result documents a positive and significant relationship between CO_2 emissions per capita and renewable energy consumption. However, with the inclusion of several classes of control variables in the model, the size of the effect diminishes and loses statistical significance in column (9). Therefore, we interpret the outcome in column (7) as $(e^{0.042}-1)^{*}100 = 4.29\%$ increase in renewable energy consumption when CO_2 emissions per capita increase by a unit. Our result corroborates the findings of (Apergis and Payne, 2014; Sadorsky, 2009, Salim and Rafiq, 2012). An important note of caution is, as we control for technological progress and governance, the coefficient - CO_2 per capita losses its significance in explaining renewable energy consumption in the region.

The role of human development is positive in column 9. Our coefficient of regression shows that a marginal improvement in human development drives renewable energy consumption in the region. In terms of elasticity, we show that the partial elasticity of HDI on renewable energy consumption is 15.5%. Our coefficient shows that human development is prominent for renewable energy consumption and that continuous improvement in economic development is necessary for renewable energy consumption. This outcome is consistent with (Chen, 2018).

Table 5
Regression results full sample.

	LSDVc_1	LSDVc_2	LSDVc_3	LSDVc_4	LSDVc_5	LSDVc_6	LSDVc_7	LSDVc_8	LSDVc_9
L.log REN	2.236***	2.519***	2.486***	2.552***	2.483***	2.521***	2.648***	2.347***	2.227***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
CO_2 emissions per cap	0.109***	0.099***	0.097***	0.088***	0.080***	0.084***	0.042*	0.020	−0.020
	(0.021)	(0.021)	(0.021)	(0.021)	(0.021)	(0.021)	(0.022)	(0.023)	(0.028)
HDI	−0.221***	−0.139*	−0.124*	−0.119*	−0.087	−0.099	−0.019	0.067	0.155*
	(0.070)	(0.072)	(0.074)	(0.072)	(0.071)	(0.072)	(0.074)	(0.070)	(0.085)
Urban pop growth		−0.113***	−0.113***	−0.118***	−0.119***	−0.120***	−0.131***	−0.118***	−0.111***
		(0.011)	(0.011)	(0.011)	(0.011)	(0.010)	(0.011)	(0.013)	(0.017)
Trade openness			−0.014						
			(0.017)						
Economic globe				−0.003***	−0.003***	−0.002***	−0.004***	−0.004***	−0.004***
				(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Log Biomass					0.081**	0.092**	−0.002	−0.078*	0.161**
					(0.039)	(0.039)	(0.040)	(0.044)	(0.065)
Log Rainfall						−0.010	0.036	0.045*	0.067**
						(0.023)	(0.026)	(0.027)	(0.033)
Log Temp							2.190***	1.770***	1.306**
							(0.450)	(0.471)	(0.604)
Log Technology								0.006	0.020*
								(0.007)	(0.011)
Governance									0.277*
									(0.153)
N	326	326	326	326	326	326	326	323	243

Bias correction initialized by Blundell and Bond estimator. Bias approximation is accurate up 100 replications. Bootstrapped standard errors reported in paranthesis. ***, **, * indicate $p < 0.01$, $p < 0.05$ and $p < 0.1$ respctively.

In contrast to these findings (Salim and Shafiei, 2014; Ding and Li, 2017), our empirical results show a negative relationship between urbanization and renewable energy consumption in the region. Our coefficient of regression shows a 0.11% reduction in renewable energy consumption in the region. A cautious explanation of this outcome may be required. A possible reason could be that the growth rate of urbanization in Nigeria and South Africa may have influenced the overall outcome. Another reason could be due to rapid urbanization coupled with rising demand for energy. As such, governments in the region focus more on fossil-based sources of energy than renewable forms of energy.

Given that combustible biomass is consumed excessively in the region, our results are unsurprising as the consumption of biomass (forest area) increases renewable energy consumption in the region. We do not expect a long term relationship between these two variables due to the exhaustible nature of forest resources. Based on this result, we interpret this outcome through the lens of wood-derived biomass consumption. Further, our coefficient of regression shows a percentage increase in wood-derived biomass drives renewable energy consumption by 0.16%. Moving on to climatic stress, we present evidence in support of the growth in solar energy consumption in this region. Our results show that when daily temperature increases by one (1) degree Celcius, renewable energy consumption will increase by 1.31%, which is also true for hydro-forms of energy in region. As hydro-electricity is the dominant form of energy production in the region, it is not surprising that the effect on renewable energy consumption improved by 0.067%. From an economic point of view, our result signals the enormous potential in solar energy generation in the region. Another possible reason for the positive impact is the significant drop in solar-PV prices in the world market, which has driven off-grid solar investment in the region. Considered alongside the variables in the model, economic globalization is significant and has a negative effect on renewable energy consumption. What this means is that the share of investment into renewable energy, is dominated by the share of investment into fossil-based fuels.

Moving on, other factors such as technological progress and the quality of governance could have a direct effect on renewable energy consumption in the region. As shown in column 9 of Table 5, our result confirms, the conjecture that technological progress is paramount to renewable energy consumption in the region. The coefficient of the regression output point to a 0.02 improvement in renewable energy consumption when technology improves by 1%. In recent times, due to advancement in technological innovations over the past decade, prices of solar-pv has dropped significantly in the world market leading massive investment in solar energy in the region in recent times. The effect of governance on renewable energy consumption is undeniable. We expected a positive association with renewable energy consumption when the quality of governance improves. This is exactly what we observe. The coefficient of the regression show an improvement in renewable energy by 28% when quality of governance improves by 1%. An implication from this finding is; when environmental concerns are embedded in long term development plans of countries, a 100% green economy is achievable in the region.

4.5. Estimation for the carbon efficient group

In this section, we discuss the factors that promote renewable energy consumption among the carbon-efficient group of countries. Table 6 reports the estimated effect on the outcome variable with a focus on the result reported in column 10. The first point of interest is evidence of the previous level of renewable energy consumption on current levels of renewable energy consumption. Our findings unveil strong statistical significance, which reveals persistence. Moreover, persistence implies that renewable energy consumption is sustainable over the years. Next, we show that the partial elasticity of CO_2 emissions per capita improves renewable energy consumption by about 25%. Our coefficient suggests that environmental awareness promotes renewable energy consumption. This finding is consistent with empirical literature (Sadorsky, 2009), documenting that environmental concerns are important in driving renewable energy consumption.

Moving on to GDP per capita, the expectation is that as countries progress, standards of living improves that could translate into better decisions on environmental quality and protection. Hence, one would

Table 6
Regression results carbon efficient countries.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	LSDVc_2	LSDVc_2	LSDVc_3	LSDVc_4	LSDVc_5	LSDVc_6	LSDVc_7	LSDVc_8	LSDVc_9	LSDVc_10
L.log REN	5.084***	5.427***	6.055***	6.176***	4.400***	5.292***	4.877***	3.711***	3.823***	5.233***
	(0.000)*	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Log Oil price	−0.103***									
	(0.020)									
Co2 emissions per cap		0.838***	0.726***	0.685***	0.671***	0.748***	0.649***	0.539***	0.564***	0.245***
		(0.058)	(0.062)	(0.065)	(0.066)	(0.067)	(0.068)	(0.067)	(0.063)	(0.088)
Log GDP per capita		−0.693***	−0.479***	−0.498***	−0.349***	−0.560***	−0.488***	−0.396***	−0.379***	−0.524***
		(0.039)	(0.051)	(0.050)	(0.044)	(0.046)	(0.047)	(0.047)	(0.050)	(0.130)
Urban population			−0.157***	−0.163***	−0.106***	−0.094***	−0.086***	−0.070***	−0.080***	−0.162***
			(0.016)	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)	(0.022)
Trade openness				−0.069**						
				(0.029)						
Economic globalization					0.004***	0.006***	0.005***	0.002**	0.002***	0.010***
					(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Log Biomass						−0.546***	−0.477***	−0.327***	−0.240***	−0.116
						(0.038)	(0.039)	(0.040)	(0.051)	(0.108)
Log rainfall							−0.039	0.042	0.068**	0.147**
							(0.032)	(0.033)	(0.027)	(0.063)
Log temp								3.492***	4.035***	5.346***
								(0.424)	(0.502)	(0.672)
Log Technology									0.021***	0.029**
									(0.008)	(0.012)
Governance										1.375***
										(0.288)
Obs.	189	173	173	173	173	173	173	173	170	114
Year Dummy	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Bias correction initialized by Blundell and Bond estimator. Bias approximation is accurate up 100 replications. Bootstrapped standard errors reported in paranthesis. ***, **, * indicate $p < 0.01$, $p < 0.05$ and $p < 0.1$ respctively.

expect a higher share of renewable energy consumption as countries progress economically. Our result however, portrays a negative relationship between GDP per capita and renewable energy consumption. We join Ergun et al. (2019) in arguing that most of the countries in this category consume a larger fraction of their share of renewable energy from the "traditional source". As such, as these countries develop we expect a negative relationship. Another explanation of this outcome is because countries are expected to grow in order to improve on the quality of life of its citizens, fossil fuels which come as a cheaper alternative to cleaner forms of renewable energy consumption will be intensively used to drive development (Ergun et al., 2019). The estimated impact reveals that renewable energy consumption declines by 0.52% when GDP per capita increases by a percentage.

Moving on to economic globalization, our findings reveal that a 1% improvement in trade improves renewable energy consumption by 1%. This result supports earlier empirical works (Chen, 2018). Indeed, our finding shows that investment into the renewable sector in these countries is gaining momentum. From another angle, the impact of trade on renewable energy consumption could imply that the technological possibilities for the development of the renewable sector assessable for both off-grid and grid installation. We see this impact as the regression result for technological innovation improves renewable energy consumption by 0.03%.

In what follows, we discuss the role of socio-economic factors on renewable energy consumption. Focusing on urbanization, we show that urban growth depresses renewable energy consumption by 0.16%. This finding highlights the damaging impact of urbanization on renewable energy consumption in these countries. Also, we argue that perhaps due to existing energy poverty, national governments are forced to rely on non-renewable sources, which are relatively cheaper to produce and distribute. However, a prudent policy action from national government could promote renewable energy consumption. The finding in our estimate shows exactly that. That is, quality of governance improves renewable energy consumption. Our regression model further focused on wood-derived biomass. Here we point out that renewable energy consumption declines by about 0.16%. We show that the natural resource base pushes for less consumption of cleaner forms of renewable energy. Probably, the dependence on biomass which is cheaper and readily available does not encourage cleaner forms of renewable energy consumption. All in all, our climatic controls (temperature and rainfall) show a positive effect on renewable energy consumption. The strongest of the effect is seen in solar energy (temperature), which highlights the potential for greater renewable energy consumption in these countries.

4.6. Estimation for the least carbon efficient group

We note that in the preferred regression reported in column 10 of Table 7, we controlled for time effects in all cases. First of all, as expected, the lag effect of renewable energy consumption on the outcome variable is persistent and significant. Our estimates confirm that CO_2 emissions depress renewable energy consumption for these countries. This outcome is not surprising as environmental concerns are perhaps not paramount in the development plans of these countries. The coefficient of CO_2 emissions per capita shows that renewable energy consumption declines by 7% when CO_2 emissions per capita increase by a metric ton.

With our primary focus on the results reported in column 10 of Table 7, we show that GDP per capita contributes to renewable energy consumption among these countries. An obvious implication is financial development and economic growth is a pre-condition for renewable energy consumption for this group of countries. Also, the marginal effect reveals a 0.32% increase in renewable energy consumption when GDP per capita increases by 1%. Next, we show that urban population growth deters renewable energy consumption. The partial elasticity coefficient of urban population growth on renewable energy consumption is approximately 28%. Considering the magnitude of the decline, it remains imminent that there is already a depressing energy situation in the region which has been exacerbated by population growth and urbanization. Trade openness and economic globalization does not contribute to renewable energy consumption for the select group of countries. Going further, our results reveal a negative relationship between economic

Table 7
Regression results for least carbon efficient countries.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	LSDVc_2	LSDVc_2	LSDVc_3	LSDVc_4	LSDVc_5	LSDVc_6	LSDVc_7	LSDVc_8	LSDVc_9	LSDVc_10
L.log REN	2.566***	2.780***	3.136***	3.088***	3.149***	3.281***	3.407***	3.392***	3.249***	5.411***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Log oil price	0.457***									
	(0.081)									
CO_2 emissions per cap		0.077***	0.051*	0.043	0.042	0.034	0.037	0.020	−0.017	−0.077***
		(0.026)	(0.027)	(0.027)	(0.027)	(0.027)	(0.026)	(0.026)	(0.038)	(0.028)
Log GDP per cap		0.550***	0.418***	0.473***	0.412***	0.437***	0.458***	0.465***	0.371***	0.320***
		(0.083)	(0.085)	(0.092)	(0.086)	(0.086)	(0.086)	(0.087)	(0.083)	(0.089)
Urban population growth			−0.232***	−0.226***	−0.225***	−0.259***	−0.268***	−0.262***	−0.289***	−0.284***
			(0.020)	(0.020)	(0.020)	(0.020)	(0.020)	(0.020)	(0.019)	(0.021)
Trade openness				−0.053**						
				(0.023)						
Economic globalization					−0.005***	−0.004**	−0.004***	−0.004**	−0.003**	−0.009***
					(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Log biomass						0.535***	0.560***	0.552***	0.400***	0.932***
						(0.073)	(0.073)	(0.075)	(0.077)	(0.064)
Log rainfall							−0.096***	−0.072**	−0.059	0.088**
							(0.034)	(0.037)	(0.047)	(0.044)
Log temp								1.359**	0.564	0.079
								(0.633)	(0.606)	(0.884)
Log Technology									0.061***	0.077***
									(0.018)	(0.017)
Governance										0.600***
										(0.189)
Obs.	193	177	177	177	177	177	177	177	174	151
Year Dummy	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Bias correction initialized by Blundell and Bond estimator. Bias approximation is accurate up 100 replications. Bootstrapped standard errors reported in paranthesis. ***, **, * indicate $p < 0.01$, $p < 0.05$ and $p < 0.1$ respctively.

Table 8
Pre-testing of the panel.

DEP VAR	Full model		Carbon efficient		Least carbon efficient	
	OLS	FE	OLS	FE	OLS	FE
CO_2 emissions per cap	−0.114***	−0.123***	−0.431***	0.127**	−0.0895***	−0.0956***
	(0.00662)	(0.0127)	(0.102)	(0.0506)	(0.0054)	(0.0138)
HDI	0.0437	0.201***	0.0132	0.743***	0.316***	0.0655
	(0.0325)	(0.0456)	(0.0202)	(0.0828)	(0.0292)	(0.0595)
Urban population growth	0.0154*	0.00305	0.0106*	0.00398	0.0440***	0.0247***
	(0.00836)	(0.00416)	(0.00543)	(0.00453)	(0.0104)	(0.00565)
Economic globalization	0.00209**	−0.00011	−0.00464***	−0.00232***	0.00733***	0.00240***
	(0.00085)	(0.00059)	(0.00073)	(0.00065)	(0.00122)	(0.00085)
Log Biomass	0.0201***	−0.150***	0.0396***	0.525***	0.0642***	−0.0993**
	(0.00577)	(0.0336)	(0.0045)	(0.0844)	(0.00678)	(0.0388)
Log rainfall	0.191***	−0.0228	−0.107***	0.0127	0.227***	−0.0423
	(0.0225)	(0.0243)	(0.0161)	(0.0335)	(0.0265)	(0.0298)
Log temp	0.252**	−0.246	−0.442***	−0.0568	0.612***	−0.353
	(0.125)	(0.352)	(0.0979)	(0.448)	(0.121)	(0.449)
Log Technology	−0.0816***	−0.0349***	−0.0191**	0.0131	−0.133***	−0.0885***
	(0.0146)	(0.00732)	(0.00738)	(0.00807)	(0.0177)	(0.0121)
Governance	−0.00084	−0.117***	0.134**	0.0449	−0.586***	−0.199***
	(0.0973)	(0.0435)	(0.0627)	(0.0517)	(0.131)	(0.0677)
Constant	2.271***	6.553***	5.957***	−2.92	−0.0809	6.353***
	(0.54)	(1.245)	(0.369)	(2.073)	(0.45)	(1.543)
Panel serial correlation		246.184***		62.875***		235.623***
Observations	569	569	245	245	324	324
R-squared	0.763	0.447	0.759	0.541	0.906	0.603
Mean VIF	2.05		2.43		2.36	
Cross Sectional Dependence		0.7065		0.000		0.000
Year Fixed Effects	YES	YES	YES	YES	YES	YES

Robust standard errors in parenthesis. ***, **, * indicates 1, 5, and 10 percent level of significance.

globalization and renewable energy consumption. The regression coefficient show a decline in renewable energy consumption by 9% owing to intensifying economic globalization. However, technological progress induces renewable energy consumption for these countries. We show that as technology advances, renewable energy consumption improves by about 0.08%. Our finding for this group of countries is affirmed as huge inflows of financial investment has been received in the coal, petroleum and gas sector of these countries over the past decade. Our work affirms the finding of Amri (2017).

We now turn our attention to the socio-economic implication of renewable energy consumption for these countries. The coefficient of regression for urbanization is negative and statistically significant, which means that ecological civilization was likely not included in the national development plans of these countries. In column 10, renewable energy consumption reduces by about 28% when the urban population grows by 1%. Here, we show that people are not aware of the effect of urban population growth on sustainable energy consumption in the region. This has further implication on land use change in the era of major structural change. On climatic shocks, we observe an improvement in renewable energy consumption by 0.09% when hydro-power is improved in the region. As expected, wood-derived biomass induces renewable energy consumption in a positive direction. Our result shows a 0.9% increase in renewable energy consumption in the region. We argue again that this outcome is expected given that biomass remains one of the most consumed form of renewable sources of energy. On quality of governance, the outcome in this category is no different from the full sample and the carbon efficient group. This signifies an important reason to include good institutional reforms towards achieving the sustainable development goals.

5. Conclusion and policy implication

The study aimed at identifying the key factors that drive the consumption of energy from renewable sources. Using a dynamic estimator which is robust to second-order serial correlation, heteroscedasticity, and Nickel bias, the study estimated the determinants of renewable energy consumption for 32 Sub Saharan African countries. Further, the study defined two broad classes of renewable energy consumers in SSA because of cross country differences in carbon emissions per unit of a good produced. Emerging questions from the categorization sought to understand what factors contribute to the similarities and differences in the determinants of renewable energy consumption in SSA. For instance, dwelling on the commonalities, the study observes common factors such as; quality of governance, technological innovation, and climatic factors drive renewable energy consumption in both carbon efficient and least carbon efficient countries. Our study also show urbanization depresses renewable energy consumption for both groups and further points to the relevance of green growth in urban cities in Africa.

Aside from the common factors, our study identified factors such as environmental awareness (Co_2 emissions per cap), GDP per capita, and economic globalization to having different impacts on renewable energy consumption in the region. Of first order importance, the study found that whereas carbon efficient show strong environmental concerns leading to increases in renewable energy consumption, the least carbon efficient countries show a negative association for environmental concerns with renewable energy consumption. The stark difference between these two groups implies that environmental awareness is country and region dependent. Next, our results show that globalization and GDP per capita have different effects on renewable energy consumption. A focus on the carbon efficient group shows that economic globalization is paramount to renewable energy consumption. Perhaps, under them being carbon efficient signals to development partners into investing in renewable forms of energy in these countries. Shifting focus to the least carbon efficient group, we observe that economic globalization does not promote renewable energy consumption in these countries. Another important difference is the role of income per capital on renewable energy consumption. Evidently, in the case of the carbon efficient group, economic progress does not promote renewable energy consumption; rather discourages renewable energy consumption. Moreover, the results indicate income is necessary to decouple carbon emissions from economic growth from the lenses of the carbon efficient group. In other words, the positive relationship affirms the hypothesis that economic growth is needed for renewable energy consumption.

From general observations, a critical look at the results showed climatic conditions playing an impactful role on renewable energy consumption. This outcome is consistent across all groups with varying degrees of impact. More particularly, our results show that the effect on renewable energy consumption is stronger for the carbon efficient group than the least carbon-efficient. It is innocuous to argue that climatic conditions positively impact renewable energy consumption through investment in solar energy and hydro-electricity. The study also documents the nexus between wood-derived biomass (forest area) and renewable energy. As an important carbon sink, forested areas has provided societies with wood for energy consumption. Our study shares this insight into the least carbon intensive countries. We show that countries belonging to this category are heavily reliant on traditional bioenergy for cooking and heating. Our result support the notion that perhaps, this countries overwhelmingly rely on biomass for their daily livelihood. For the carbon-intensive group, our result did not find any relationship between traditional biomass and renewable energy consumption.

In conclusion, we can glean several policy implications from the findings. First, given that some similarities exist on the drivers of renewable energy consumption, national governments should build a common environmental policy to regulate and foster renewable energy consumption in the region. For instance, the building of energy markets where grid sharing is encouraged could improve renewable energy consumption in other African countries, as well as, ending the energy poverty in the region. Also, on account that GDP per capita improves renewable energy consumption for the whole sample implies economic progress, is a precondition for renewable energy consumption. Knowing that material use will increase as countries grow, policy implementers in the region, should look into long term impacts of economic growth on environmental degradation. Again, as with urban city development, policy implementers need to encourage environmental protection through sustainable land-use practices; minimizing biomass consumption at the local level. Likewise, there should be off-grid solar infrastructure in rural and urban areas and encourage localization of energy markets in the region. Further, since economic globalization promotes renewable energy consumption in the region, governments should foster investments into green technologies, and the management of green technologies to encourage sustainability in the least carbon efficient regions.

CRediT authorship contribution statement

Conceptualization: Alessandro Olper; Samuel Weniga Anuga. Acquisition of data: Richmond Baye. Analysis and/or interpretation of data: Richmond Baye. Drafting the manuscript: Richmond Baye. Revising the manuscript critically for important intellectual content: Samuel Darkwah; Issa Justice Musah-Surugu; Albert Ahenkan.

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.

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