RENEWABLE ENERGY CONSUMPTION AND OUTPUT GROWTH IN AFRICA: A NEW EVIDENCE

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(Received 27th Nov 2021; accepted 21st Mar 2022)

Abstract. Previous studies have shown that Africa's growing weight in energy production is felt mainly in the non-renewable energy sources such as coal, oil and natural gas. However, recently, studies have started to emerge showing that renewable energy sources in bioenergy, hydropower, wind and solar photovoltaic (PV) are fast developing and contribute to growth at some economic units within the region. This study adopted the system generalized method of moments (Sys-GMM), pooled ordinary least squares (POLS) and fixed effects (FE) models to examine the impact of renewable energy consumption on inclusive growth in a cross-sectional panel of 47 African countries, spanning 1990–2019. Our findings revealed that there is a weak convergence rate of inclusive growth between low-income countries and high-income countries of the African region. This implies that although renewable energy is fast developing, growth in the sector is not yet sufficient to promote inclusive growth in the entire region. A policy thrust towards strengthening the macroeconomic environment so as to reap from the investments into the renewable energy sector will lead to an improvement in Africa's growth architecture.

Keywords: *inclusive growth, renewable energy, carbon dioxide (CO_2) emissions, GMM, Africa*

Introduction

The demand for energy is borne out of the need to grow productivity in any economy. Energy demand therefore, is derived from the numerous activities (economic or non-economic) needed to accomplish growth. Most developed countries are working assiduously to completely migrate from carbon emission prone energy to alternative energy supplies like solar, wind, hydro, and biomass among others to meet their daily energy needs. Regrettably, in Africa, the energy need of the region centres mostly on fossil fuel whose cost of production is persistently high and environmentally inimical (Bhattacharya, et al., 2016; Adewuyi and Awodumi, 2017a; Agbanike et al., 2019). Africa houses a greater percentage of the poor in the world; therefore, the opportunity to overcome the development divide will depend on how fast the region takes advantage of the renewable energy mix for which the cost of production is rapidly declining, as is the

DOI: http://dx.doi.org/10.15666/aeer/2003_24392456

case with advanced economies which have leveraged the declining cost of production of renewable energy to drive their growth structures.

In the recent times, studies have started to emerge showing that renewable energy sources in bioenergy, hydropower, solar, and wind are contributing to the rapid growth of certain economies within the African region- a clear departure from the concentration of traditional use of biomass (Adewuyi and Awodumi, 2017a, b;Adu and Denkyirah, 2018). This is commendable but has to be stepped up. Thus, the link between energy consumption demand and national output growth abound in the literature (Apergis and Payne, 2014; Shahbaz et al., 2015; Bouznit, et al., 2016; Mitic et al., 2017; Paramati et al., 2018). Notwithstanding, there are still numerous studies and findings also on the relationship between energy consumption demand and economic growth which showed that either energy consumption does not lead to economic growth, or ambiguous or inconclusive (see Ozturk, Aslan and Kalyoncu, 2010; Yasar,2017; Ahmed and Shimada,2019).

This paper is driven by two main reasons; firstly, the absence of consensus in the literature on the relationship between renewable energy and economic growth in Africa. The second motivation resides on the necessity to reduce greenhouse gases emissions from the consumption of fossil fuel which characterizes energy consumption mix in Africa. There is the need to grow the share of renewable energy mix (wind, solar, hydropower, biomass and geo-thermal energy) in the total energy mix in Africa to achieve sustainable and inclusive development. According to Energy information administration report (EIA, 2016), renewable energy accounts for a paltry 22% of the world energy consumption and this is far less in the case of Africa, despite her huge potentials in renewable energy. Thus, increasing the share of renewable energy becomes a priority. Subsequently, for the desire to promote and achieve ‘green growth’ and less emission of carbon in Africa, cleaner energy sources through wind, solar, and biomass, become paramount (Waziri et al., 2018) and highly imperative. No doubt this paper contributes to the inconclusive debate in the literature regarding the exact link between renewable energy and economic growth.

To achieve this purpose, we employ more robust econometric techniques – system generalized method of moments (Sys-GMM), pooled ordinary least squares (POLS) and fixed effects (FE) models to evaluate our results and make policy prescriptions. Furthermore, this study disaggregates the entire African data into two components (Low-medium income and Low-income countries) following the World Bank (2020) classification. This is to take into account the diverse economic statuses of the countries in the different income classifications. The rest of this paper is structured as follows: The next section presents some stylized facts on Africa’s energy demand mix and energy-related carbon dioxide (CO_2) emissions structure, which is followed by review of relevant literature on the energy-growth relations. The subsequent section is Data and Methodology which describes the data, model specification and estimation technique, followed by presentation and discussion of the results from empirical analyses, while the last section concludes the study with policy prescription.

Stylized facts on Africa’s energy demand mix and energy-related carbon dioxide (CO_2) emissions structure

Africa is regarded as energy intensive growing economies. A focus on Africa’s energy structure shows that energy demand within the region has grown twice as fast as the global average in the past two decades. With a growing population and rapid demand for energy consumption especially for industrial production, transport, building and domestic uses, Africa is projected to emerge as a major force in global energy markets, higher than China and second to India by 2040 (IEA, 2019). Africa's growing weight in energy production is felt in non-renewable energy sources -coal, oil and natural gas. A cursory observation of Africa's primary energy demand mix shows that these sources of energy contribute to more than 80% of total energy demand (see *Table 1*).

Table 1. *Energy demand – Africa*

Africa case										
	Energy demand (Mtoe)							**Shares (%)**		**CAAGR* (%)**
	2010	**2017**	**2018**	**2025**	**2030**	**2035**	**2040**	**2018**	**2040**	**2018-40**
Total primary demand	681	817	838	872	888	1 024	1 204	100	100	1.7
Coal	108	110	112	110	105	104	100	13	8	-0.5
Oil	161	193	194	257	304	335	362	23	30	2.9
Natural gas	90	126	133	171	198	229	290	16	24	3.6
Nuclear	3	4	4	4	7	9	19	0	2	7.6
Hydro	9	11	12	19	27	36	44	1	4	6.3
Bioenergy	308	368	378	280	180	197	212	45	18	-2.6
Other renewables	2	6	7	31	68	115	179	1	15	16.1

*Compound average annual growth rate
Source: IEA: Africa Energy Outlook, 2019

Although Africa is richly endowed with abundant renewable sources of energy such as bioenergy, hydropower, wind and solar photovoltaic (PV), current contributions from these sources to total energy demand is still very negligible. Available statistics show that the region is endowed with over 10 (TW) of PV, 350 (GW) of hydroelectric, 110 (GW) of wind and geothermal energy sources of 15 (GW), United Nations Environment Programme (UNEP, 2017). However, despite these huge endowments, Africa has not been able to meet successfully its energy needs. Some of the reasons adduced by energy experts for this challenging situation are weak economic growth, weak energy policies and lack of adequate investments into the different energy sources (UNEP, 2017). Within the last two decades, Africa's total investment in the energy sector is about 5.5% of the global total share; one of the lowest when compared with other regions. An International Energy Agency (IEA, 2019) report on Africa stated that in 2018, about $100 billion was invested in the Africa's energy sector. Of this amount, $70 billion was invested in fossil fuels; $13 billion was invested each in electricity networks and renewable energy respectively. However, these amounts of investment in renewables are meagre when compared to other regions.

United Nations Environment Program report (UNEP, 2017) posits that for Africa to solve the issue of low energy production and supply, and fast-track energy sufficiency, Africa's renewable energy sector investment requires between $43-55 billion per year through 2040. In the bid to fast-track energy sufficiency, the new comprehensive African Union's (AU) energy strategic framework was adopted in 2015. The strategic framework is divided into two critical structures – the Program for Infrastructure Development in Africa (PIDA) and the Africa Renewable Energy Initiative (AREI). While the PIDA aimed at closing Africa's vast infrastructure gap across transport, energy and water sectors, information and communication technologies, AREI is expected to accelerate the exploitation of the continent's huge renewable energy potential. *Inter alia*, the AREI policy framework is expected to achieve at least 10 gigawatts (GW) of new renewable energy generation capacity by 2020 and least 300 GW by 2030 (AfDB, 2015).

The increase in the renewable energy capacity is expected to impact positively on energy supply and improved access to electricity, especially in major cities and rural communities. A report by IRENA (2015) posits that "modern renewables can eliminate power shortages, bring electricity and development opportunities to rural villages, spur industrial growth, create entrepreneurs, and support the ongoing lifestyle changes across the continent" (p.7). However, with the current state of electricity infrastructure coupled with weak economic growth challenges, the region's electricity generation capacity (supply) has remained low and unable to help Africa meet its social and economic needs. Between 2017 and 2018, an average of 236 (GW) electricity was generated with the non-renewable sources contributing to a greater percentage of total electricity generation (see *Table 2*).

Received statistics show that over 600 million persons living in Africa have no access to electricity- with over 57% of this population coming from sub-Saharan (International Energy Agency IEA, 2018). A robust, uninterrupted electricity supply is a key prerequisite for improvement in economic activities, the functioning of the healthcare system and the maintenance of social welfare in an economy. In Africa, several thousand households, hospitals and healthcare facilities and private businesses have no access to electricity. Africa has the world's lowest per capita energy consumption which is far below the world average. With 17% of the world's population, the region consumes about 3.3% of global primary energy. Received statistics show that Africa consumes 42% of its oil production, 28% of gas, 22% of coal, 6% hydro, and 1% of renewable and nuclear energy respectively (UNEP, 2017).

Table 2. *Africa's electricity generation (GW)*

Africa case									
	Electrical capacity (GW)						**Shares (%)**		**CAAGR(%)**
	2017	**2018**	**2025**	**2030**	**2035**	**2040**	**2018**	**2040**	**2018-40**
Total capacity	228	244	398	550	709	924	100	100	6.2
Coal	48	48	53	50	45	37	20	4	-1.2
Oil	42	43	48	51	52	53	18	6	1
Natural gas	92	103	148	167	183	228	42	25	3.7
Nuclear	2	2	2	4	5	10	1	1	7.6
Renewables	44	48	144	273	414	579	20	63	12
Hydro	35	36	57	77	99	117	15	13	5.5
Bioenergy	1	1	4	7	9	11	0	1	13
Wind	5	5	25	51	72	94	2	10	13.8
Geothermal	1	1	2	5	9	14	0	2	14.9
Solar PV	3	4	52	124	209	316	2	34	21.5
CSP	1	1	4	9	17	26	0	3	16.2
Marine	-	-	0	0	0	0	-	0	n.a.

*Compound average annual growth rate
Source: IEA: Africa Energy Outlook, 2019

In terms of carbon emission, Africa contributes only sparingly to global energy-related carbon dioxide (CO_2) emissions as a result of the underdeveloped nature of the energy and industrial sectors. *Table 3* presents carbon emission structure for the African region. Between 2017 and 2018, an average of 1198 million tonnes (Mt) of carbon emission was generated by the region and this is projected to increase to 1797 (Mt) by 2040. Received statistics show that as at today, the Asian continent is the highest global emitter of CO_2 (53%), North America (18%), Europe (17%), Africa and South America account for 3-4% of global emissions each (Ritchie and Roser, 2017). International Energy Agency (IEA, 2019) report on Africa's Energy Outlook stated that Africa's global share of CO_2 emissions in 2018 stands at 3.7% or 1.2 gigatonnes (Gt) CO_2.

Table 3. *Africa's CO_2 emissions (million tonnes)*

	Stated policies scenario									
	CO_2 emissions (Mt)							**Shares (%)**		**CAAGR (%)**
	2010	**2017**	**2018**	**2025**	**2030**	**2035**	**2040**	**2018**	**2040**	**2018-40**
Total CO_2	1 017	1 181	1 215	1 357	1 464	1 621	1 797	100	100	1.8
Coal	385	391	395	382	346	332	318	32	18	-1
Oil	450	541	551	668	750	846	948	45	53	2.5
Natural gas	182	248	269	307	368	443	532	22	30	3.1
Power sector	420	466	480	495	490	508	530	100	100	0.4
Coal	263	257	261	275	255	239	215	54	41	-0.9
Oil	54	59	62	63	59	62	60	13	11	-0.2
Natural gas	103	150	158	157	176	208	256	33	48	2.2
Final consumption	496	620	641	776	892	1 021	1 163	100	100	2.7
Coal	66	83	85	84	85	89	96	13	8	0.5
Oil	382	472	480	590	675	767	871	75	75	2.8
Transport	257	345	351	436	495	549	603	55	52	2.5
Natural gas	48	65	76	102	131	165	197	12	17	4.4

*Source: IEA: Africa Energy Outlook, 2019

North Africa and South Africa account for Africa's highest CO_2 emissions with 40% (about 490 million (Mt) CO_2) and 35% (about 420 Mt CO_2) respectively. The high CO_2 emissions from these two regions is as a result of the developed nature of their energy sectors relative to the other regions of the continent and the number of persons having access to electricity. In North and South Africa, about 98% and 85% respectively of the population have access to electricity (IRENA, 2017). However, despite the relatively small amount of carbon emission by Africa, the region is disproportionately exposed to the challenges of climate change.

Literature review

The link between energy (i.e. renewable energy) consumption and economic growth is often associated with four main hypotheses- the growth hypothesis, conservation hypothesis, the feedback hypothesis, and the neutrality hypothesis. These hypotheses give different directions of causality between energy consumption and economic growth (uni-directional, bi-directional and neutral). The growth hypothesis postulates that it is energy consumption that causes economic growth. This presupposes that a decline in energy consumption will lead to a decrease in economic growth (Adewuyi and Awodumi, 2017a). The second hypothesis is more like a reverse of the first; the conservation hypothesis posits that it is economic growth that causes the demand for renewable energy (Shahbaz and Feridum, 2012). 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. Feedback hypothesis asserts the existence of a bi-directional causal relationship between energy consumption and economic growth. That renewable energy drives economic growth just as economic growth can drive renewable energy consumption. Lastly, the Neutrality hypothesis postulates no causality between energy consumption and economic growth. In other words, that causality does not run from economic growth to renewable energy and vice versa (Stern and Cleveland, 2004).

In the recent times, a huge number of studies has attempted different methodologies to establish the empirical relationship between energy consumption and output growth. Some of the methodologies employed include the bootstrap panel analysis, the bivariate or multivariate error correction model, the Toda–Yamamoto analytical procedure that is within a production function framework, and the forecast error variance decomposition model. However, in spite of all these different methodologies, research findings showed that there are no clear-cut consensus on the impact or direction of causality between energy consumption and economic growth. Ighodaro (2010) adopted the Johansen cointegration and bivariate Granger causality methods to examine the relationship between energy consumption and economic growth in Nigeria. The study included monetary and fiscal policy variables and found a unidirectional causality running from energy consumption to economic growth. Akinlo (2008) examined the energy consumption and economic growth link for 11 Sub-Sahara African countries using the vector error correction model (VECM). The study found mixed results. While bi-directional relationship exists between energy consumption and economic growth for Gambia, Ghana and Senegal, a unidirectional causal relationship occurs for Sudan and Zimbabwe.

Ocal and Aslan (2013) investigated the relationship between renewable energy consumption and income growth in Turkey between 1990 and 2010 using the ARDL and Toda–Yamamoto causality tests approach. Findings showed that while the result of the ARDL presented a negative impact of renewable energy on economic growth, Toda–Yamamoto causality tests showed a unidirectional causality running from output growth to renewable energy consumption. Similarly, Pao and Fu (2013) examined renewable-non-renewable-growth nexus in Brazil from 1980-2010, using the multivariate error correction model. The results showed that while the cointegration test reveals that a long-run relationship exists from real GDP to renewable and non-renewable energy sources, the vector error correction model presents a bidirectional causality between economic growth and renewable energy, and a unidirectional causality from economic growth to non-renewable energy sources.

Ahmed and Shimada (2019) selected a panel of 30 emerging and developing countries using data from the World Development Indicators (WDI) of the World Bank, Renewable Energy Country Attractiveness Index (RECAI) by Ernst and Young, and employed the Cobb-Douglas production function. The findings show a significant long-run relationship between renewable energy consumption and economic growth for selected South Asian, Asian and most of the African countries (Ghana, Tunisia, South Africa, Zimbabwe and Cameroon). But for the Latin American and the Caribbean countries, economic growth depends on non-renewable energy consumption. Renewable energy consumption in the selected countries of these two regions is still at the initial stage.

Other studies with differentiated methodology found a bidirectional relationship between renewable energy consumption and economic growth. Ozcana and Ozturk (2019) examined the renewable energy consumption-economic growth relations in 17 emerging countries, covering the period of 1990–2016. The study adopted the bootstrap panel causality test and found no causal relationship between renewable energy demand and economic growth.

Zafar et al. (2019) investigated the impact of non-renewable and renewable energy on economic growth among Asia-Pacific Economic Cooperation countries (APEC) during the period of 1990–2015. The study adopted the second-generation panel unit root test and Westerlund cointegration test and found that a bidirectional causal relationship runs between economic growth, renewable and non-renewable energy consumption. Rahman and Velayutham (2020) adopted the panel Fully Modified Ordinary Least Squares (FMOLS) and panel Dynamic Ordinary Least Squares (DOLS) estimation techniques to examine the renewable and non-renewable energy consumption- economic growth connection among five South Asian countries from 1990–2014. The study found a positive relationship between renewable and non-renewable energy consumption on economic growth.

Aydin (2019) examined the relationship between renewable and non-renewable electricity consumption and economic growth in 26 OECD countries from 1980–2015, adopting the Time and Frequency domain Granger causality tests. The study found that while Time and domain Granger causality test showed that a bidirectional relationship runs from non-renewable electricity energy consumption and economic growth, the Frequency domain Granger causality test presents a bidirectional temporary and permanent causality relationship between output growth and renewable-non-renewable electricity consumption. Sarkodie and Adams (2020) applied the Bayesian and nonlinear autoregressive distributed lag (NARDL) estimation approach to investigate the relationship between electricity access and income inequality in South Africa from 1990-2017. They included corruption index as a determinant of the level of development of government and political institutions and found that although the level of corruption is high, there is a long-run unequal effects between income level and access to electricity.

Kouton (2021) examined the impact ofrenewable energy consumption on growth in some African countries using Generalized Method of Moments (GMM) estimation technique for a period of 1991–2015. The study found a significant positive relationship between renewable energy consumption and aggregate growth in the region.

Following the ambiguousness of results of different studies on renewable energy-growth mix, it is necessary to further extend the investigation for 47 African countries, within the period of 1990–2019 using the system generalized method of moments (Sys-GMM), pooled ordinary least squares (POLS) and fixed effects (FE) model. The essence of adopting these estimation techniques is to obtain a more robust result that provides policymakers appropriate information in the crafting of policy interventions that would strengthen Africa’s growth and development architectures.

Data and methodology

Model specification

This study adopts the endogenous growth model (Solow, 1956) which has capital and labour as main factors of production to analyse the impact of energy consumption demand on aggregate national income. The justification for adopting the endogenous growth model is consistent with the energy–growth literature where multivariate growth models have widely been used (see, Akinlo (2008) Bhattacharya et al., 2016; Koçak and Şarkgüneşi, 2017; Maji et al., 2019). According to the growth theory, national wellbeing is mostly achieved and sustained when technological progress interacts with the stock of human capital. As investment in capital stock interacts with human capital, a critical mass of inclusive growth is achieved. However, in the absence of appropriate investment in the capital stock and a weak human capital formation, inclusive aggregate growth is affected negatively.

According to Khan and Chaudhry (2019), human capital formation is essential for aggregate economic growth. Hur (2014) posits that sustainable investment in critical mass of human capital promotes inclusive growth through the creation of additional employment. However, a poor human capital formation creates limited employment opportunities in the environment with high unemployment. A reduced employment opportunity is therefore inimical to growth of national output. The energy sector is one of the sectors that have the highest capacity to create several forms of additional employment (both skilled and unskilled) and cause economic growth when adequate investments are made. Building on the endogenous growth framework, the neoclassic production function is therefore stated as follows:

$$Y = f\,(K, L) \qquad \text{(Eq.1)}$$

where, the output produced (Y) is a function of the combined input of capital (K) (henceforth, KAP) and Labour (L) (henceforth, LABF). Since endogenous growth model comprises technology, this study incorporates the renewable energy (REN) variable as an input factor. This study further augments the function by including variables of health and monetary policy (broad money) as control variables. While the health variable (government expenditure) provides insight of the state of the health sector within the countries, broad money (BRM) provides information on the level of macroeconomic instability in the different economies (see Omotor, 2008; Kouton (2021). A highly volatile business environment occasioned by high price volatility impacts negatively on aggregate growth over time (see Kumah and Sandy, 2013). Thus:

$$Y = f\,(KAP, LABF, REN, HEX, BRM) \qquad \text{(Eq.2)}$$

From *Equation 2* a new production function with time period is stated as:

$$\mathrm{Y_{it} = f\,(KAP_{it}, LABF_{it}, REN_{it}, HEX, BRM_{it})} \qquad \text{(Eq.3)}$$

where*Y* stands for output growth, proxied by the GDP per person employed (at Constant 2011 Purchasing Power Parity $USD) (Raheem etal., 2018; Oyinlola andAdedeji, 2019; Kouton, 2021). Unlike GDP growth rate which previous studies adopted (for example; Maji et al., 2019), this study adopted the GDP per person employed, which is a broader concept of inclusive growth than the regular GDP growth rate (Kouton, 2021). *KAP* stands for physical capital measured by gross capital formation (GRCF); *LABF* represents the labour force in country *i*, time *t*. *REN*, represents total renewable energy demand by country *i*, time *t*. *HEX* represents government expenditure on the health sector; while *BRM*, denotes broad money rates in country *i*, time *t* (Ighodaro, 2010).

From *Equation 3* above, we re-specified the function as follows (all the variables are specified in log-linear form):

$$\hat{y}_{it} = \alpha + \widehat{\delta_i y}_{it-1} + \beta_i kap_{it} + \beta_i labf_{it} + \beta_i ren_{it} + \beta_i hex_{it} + \beta_i brm_{it} + \gamma_i + \varepsilon_{it}$$
(Eq.4)

where$i = 1,\ldots,$ N is the number of countries (N = 47); time period (t = 29); δ_i, is the intercept β_i, and represents the coefficient of the parameters; γ_i captures the country-specific effect. $\varepsilon_{it}$is the error term in period *i*at time *t*.

Data

Secondary data were sourced for 47 countries from 1990-2019[1]. This period captures the period where virtually all the countries witnessed a positive economic growth and development in their energy sectors. Specifically, Energy data classified into renewable and non-renewable and expressed in tera-joule (TJ), were sourced from Word Development Indicators (WDI) (World Bank, 2020). Data for capital (proxied by gross capital formation and expressed as a percentage of GDP), broad money, GDP (per person employed) and the labour force data were also sourced from the World Bank database (WDI, 2020).

Estimation technique

Equation 4 above is estimated using the System Generalized Method of Moments (Sys-GMM) estimation technique. However, the pooled ordinary least squares (POLS) and fixed effects (FE) estimation methods are adopted to ascertain the robustness of the GMM results. Unlike in other instrument variables such as ordinary least square (OLS) and Two-stage least square (TSLS), GMM provides a more superior and efficient estimates. According to Hansen (1982) and (Bond etal., 2001), GMM estimates are known to be superiorly efficient asymptotically, compared to the estimates of other estimators. The application of GMM in a panel data framework, enables us include the initial level of our dependent variable (GDP) at lag level in order to correct for misspecification bias and account for conditional convergence across countries (see Eggoh, 2009). Although, the lag of the initial level of the dependent variable (GDP) leads to the issue of endogeneity and causes measurement errors, GMM estimator removes the presence of the endogeneity between the lagged dependent variable and the other regressors.

Secondly, the adoption of GMM as an estimator takes care of the challenges of country-specific effects or time-invariant country-specific variables, by taking into account the first differences of the equation. However, studies have shown that at first difference, the level of variables show some level of limitation and weakness. Solving

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[1] See *Appendix 1* for list of selected countries and *Appendices 2* and *3* for country classifications into Low-medium and Low-income respectively.

this limitation, requires that the estimate of level and first-difference regression to be treated as a “system” in the presence of persistency (see Blundell and Bond, 1998). To solve the limitations of the first-difference estimator, two-step System GMM is applied. According to Windmeijer (2005), Roodman (2009a) and Hauk and Wacziarg (2009), the two-step System GMM provides better results than the first-difference GMM because it presents unbiased lower standard errors.

In this study, we adopt the two-step System GMM approach to investigate the energy consumption–economic growth nexus. In order to avoid the problem related to misspecification or over-identification of parameters which is likely to *overfit* the endogenous variables[2] and weaken the informative power of the Hansen-J test (Roodman, 2009b), we follow the rule of thumb which stipulates that the number of instruments should be close to the number of countries (Roodman, 2009a) and the number of lags of endogenous variables limit to t-1 and t-2. To check for the joint validity of the GMM estimator and of the instruments variable, the J-Statistics test is employed. The study also tests for the absence of serial correlation in the model, using the Arellano-Bond Serial Correlation Test. Following the rule of thumb, we reject the null hypothesis in the absence of a negative first-order correlation of the residuals and accept the null hypothesis in the absence of a second-order correlation of residuals at a probability value greater than 5% level of significance.

Results and discussion

Table 4 provides the descriptive statistics and correlation analysis of the variables used in the regression analysis. From the table, it is shown that the average GDP per person employed (Y) during the period is US$3.920, with a median value of US$ 3.864. The consumption of renewable energy (REN) has an average value of 1.710 TJ and a median value of 1.885TJ. Broad money (BRM) presents the highest mean, average and maximum values.

Overall, all the variables in the study present positive mean values, suggesting an overall upward trend in all the countries in the sample. It is also observed that variability is highest for gross capital formation (KAP), while health expenditure (HEX) appears to be the least volatile variable among the series. The correlation matrix shows that there is no high correlation between the explanatory variables, suggesting that there is no multi-collinearity challenge. The highest and lowest values of the correlation coefficients is 0.604 and 0.015 respectively, and are observed between gross capital formation (KAP) and labour force (LABF); and labour force and health expenditure (HEX) respectively.

Table 5 presents the results of the analysis from *Equation4*. From the table, it is shown that the coefficient of the dependent variable (GDP per person employed) is positive and significant. A positive coefficient of the dependent variable implies weak convergence rate of inclusive growth between low-income countries and high-income countries of the region. Whereas this result is consistent with the findings of Maji et al. (2019), it is inconsistent with Kouton (2021) that found negative and significant relationship. A negative and significant coefficient of inclusive growth as posits by growth theorists, suggest that countries of low levels of economic inclusion experience high rates of

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[2] Over-fitting of endogenous variables occurs when the model is too complex. This gives rise to wrong coefficients of the p-values (Roodman, 2009).

inclusive growth faster than countries with high levels of economic inclusion (see Kouton, 2021).

Table 4. *Descriptive statistics and correlation matrix*

	Y	**KAP**	**LABF**	**REN**	**HEX**	**BRM**
Mean	3.920	9.346	6.528	1.710	0.695	11.068
Median	3.864	9.336	6.613	1.885	0.690	11.294
Maximum	5.074	10.950	7.777	1.993	1.310	13.541
Minimum	2.988	6.575	5.050	-1.229	0.102	0.460
Std. dev.	0.440	0.698	0.592	0.445	0.170	1.348
Skewness	0.366	0.118	-0.332	-3.518	-0.001	-1.280
Kurtosis	2.242	3.013	2.426	18.466	3.097	7.844
Jarque-Bera	64.825	2.619	45.249	16960.745	0.555	1748.950
Probability	0.000	0.270	0.000	0.000	0.758	0.000
Sum	5488.271	10532.716	9203.937	2411.340	979.554	15473.145
Sum sq. dev.	270.813	547.924	493.306	278.399	40.805	2537.347
Observations	1400	1127	1410	1410	1410	1398
Correlation matrix						
Y	1.000					
KAP	0.525*	1.000				
LABF	-0.280*	0.604*	1.000			
REN	-0.619*	-0.488*	-0.041	1.000		
HEX	-0.267*	-0.235*	0.015	0.136*	1.000	
BRM	0.043	0.431*	0.389*	-0.135*	-0.055***	1.000
Observations	1127	1127	1127	1127	1127	1127

Y, stands for gross domestic product (GDP) per person employed; KAP, represents gross capital formation; LABF, represents total labour force; REN, is the total renewable energy consumption from all renewable energy resources; HEX, stands for government expenditure in the health sector; BRM, stands for broad money which explains the structure of government monetary policy framework. All variables are in log-form. *, ** significant at 1% and 10% respectively

Table 5. *Energy demand and output growth. Dependent variable: GDP per person employed*

Variable	**GMM result (first differences)**	**GMM orthogonal deviation test**
	Coefficient	Coefficient
Y(-1)	0.698* (0.051)	0.956* (0.014)
KAP	0.042** (0.023)	0.011 (0.008)
LABF	-0.040 (0.044)	-0.027 (0.019)
REN	-0.070** (0.036)	-0.019** (0.011)
HEX	-0.013 (0.018)	0.000 (0.014)
BRM	-0.007** (0.004)	0.005* (0.001)
Mean dependent var	0.004	-0.044
S.E. of regression	0.025	0.021
J-statistic	12.672	13.191
Prob (J-statistic)	0.000	0.000
S.D. dependent var	0.020	0.064
Sum squared resid	0.674	0.459
No of Observation	1049	1049
Cross section included	43	43

Standard errors in parentheses, * $p < 0.01$, ** $p < 0.1$. All explanatory variables were lagged by one period (t-1). E-views 10.All variables are in log-form

This outcome is a true reflection of the African situation. For many decades, economic activities and growth performance of low-income economies are still far away from those of the dominant economies like Nigeria, South Africa, Egypt and Morocco.

The renewable energy (REN) result showed a negative and significant coefficient at 5%. This result implies that Africa’s renewable energy sector is still underdeveloped and unable to cause inclusive growth unlike in the case of the non-renewable energy sector (Omotor, 2008; Ighodaro, 2010). An undeveloped renewable energy sector indicates that: few persons are employed into the sector; and the cost of production of energy in the sector will remain high. High cost of production translates to high price of energy which, leads to low energy consumption. While this result is consistent with Maji et al. (2019) who also found that renewable energy sector demand in 15 African countries reduces output growth, it does not collaborate with the findings of Kouton, (2021) that found positive relationship. Although recent development reports have shown that Africa’s renewable energy sector is fast developing, the level of growth is still very low compared to the contributions of the non-renewable energy sector (see EIA, 2016).

One of the fundamental reasons for the weak growth in the renewable energy sector is the issue of level of investment within the sector. An IEA report on Africa’s energy outlook (IEA, 2019) stated that in 2018, about $100 billion worth of investment went into the Africa’s entire energy sector. Of this amount, USD$70 billion was invested in fossil fuels with USD$13 billion invested each in electricity networks and renewable energy development. This level of investment in the renewable energy sector is low and inadequate to develop the sector to the level where it can cause inclusive growth that reduces the high rates of poverty and inequality facing the region. The coefficient of capital (KAP) conforms to apriori expectation with a positive and significant value at 10%. Although the coefficient is rightly signed and significant, the magnitude is low (0.042%). This low magnitude of capital reinforces our earlier view that the level of capital (investment) in the renewable sector is weak and requires an average investment of US$ 70 billion per year of investment between 2015 and 2030 (IRENA, 2015).

The result of the labour force meets our apriori expectation in terms of magnitude and direction. Although the result is not significant, the negative outcome of the coefficient is similar to those obtained by Raheem et al. (2018) and, Oyinlola and Adedeji (2019). The underlying reason for this result is possibly that Africa’s labour force is not only weak to stimulate growth, but it is characterised with low productivity and profit (Gupta, 1993). Pertaining to the coefficient of health variable (HEX), although the parameter presents a negative relationship with the dependent variable, it is not significant at any level. This result conforms to that of Ighodaro (2010) and it underlines the fact that the health sector in Africa is underdeveloped to meet the health needs of the continent. Similarly, the result of broad money is negative and significant, implying that Africa’s macroeconomic environment is weak and not favourable to inclusive growth (Ighodaro, 2010; Oyinlolaand Adedeji, 2019).

Table 6 presents the result of the disaggregated data into Low-medium and Low-income countries. From the result it shows that there is not much significant difference in the outcomes of the variables both in terms of magnitude and direction. However, the result of the orthogonal deviation showed that broad money (BRM) is positive and significant for Low-medium countries. This result therefore implies that macroeconomic environment among the Low-medium countries is robust enough to drive economic growth within the region.

Table 6.*Energy demand and output growth (disaggregated data). Dependent variable: GDP per person employed*

	Low-medium income		**Low-income**	
Variable	**GMM Result (first differences)**	**GMM orthogonal deviation test**	**GMM result (first differences)**	**GMM orthogonal deviation test**
	Coefficient		**Coefficient**	
Y(-1)	0.771*(0.076)	0.969*(0.022)	0.513*(0.044)	0.834*(0.029)
KAP	0.028(0.033)	0.022(0.066)	0.099**(0.042)	0.055**(0.022)
LABF	-0.173(0.389)	-0,099(0.075)	-0.751***(0.438)	-0.446***(0.240)
REN	-0.024(0.017)	0.000(0.010)	-0.057(0.084)	-0.021(0.054)
HEX	0.028(0.024)	0.004(0.013)	-0.061***(0.032)	0.022(0.015)
BRM	-0.002(0.005)	0.005*(0.002)	0.013(0.017)	-0.010(0.013)
Mean depend var	0.013	-0.073	0.017	-0.072
S.E. of regression	0.046	0.035	0.052	0.047
J-statistic	11.699	12.718	7.165	7.594
Prob (J-statistic)	0.001	0.000	0.007	0.006
S.D. dependent var	0.038	0.093	0.044	0.109
Sum squared resid	0.780	0.444	0.629	0.514
No of Observation	371	371	242	242
Cross section	26	26	19	19

Standard errors in parentheses, * $p < 0.01$,** $p < 0.05$. *** $p < 0.1$. All explanatory variables were lagged by one period (t-1). All variables are in log-form. E-views 10

Robustness tests

To validate the consistency of our results, GMM orthogonal deviation and Arellano-Bond Serial Correlation tests were employed. From the results of GMM orthogonal deviation test, our findings show that apart from the capital variable (KAP), the results of other variables are not significantly different from those obtained from first difference. Arellano-Bond Serial Correlation test results in*Table 7* show that at first lag period (AR(1)), there exists a serial correlation since the probability value is less than the 5% threshold. However, the second-order result (AR (2)) produced no serial correlation, implying that our model is of good fit.

Table 7. *Arellano-Bond serial correlation test (observations: 1049)*

Test order	**m-Statistic**	**rho**	**SE(rho)**	**Prob.**
AR(1)	-3.783	-0.289	0.076	0.000
AR(2)	-1.388*	-0.039	0.028	0.165

E-views 10. Probability value > 5%. H_0 = There is no serial correlation

We also further subjected the GMM results by estimating two additional models using pooled ordinary least squares (POLS) and fixed effects (FE) following Bond (2002) and Kouton (2021). According to Bond, if in dynamic panel estimation, the results of the lagged dependent variable lies between those of the POLS and FE, then the dynamic panel result is robust and appropriate. This is because while the estimation from FE model in the dynamic form leads to a downward bias of the lagged dependent variable coefficient, the POLS lead to an upward bias (Kouton, 2021). *Table 8* presents the two supplementary results from POLS and FE models. Our results show that the coefficient of the lagged dependent variable (0.698) lies between those of the POLS (0.976) and FE (0.885) as suggested in Bond (2002).

Table 8. *GMM, GMM orthogonal, fixed effects and pooled OLS results*

Variable	**GMM result**[a] **(first differences) (1)**	**GMM orthogonal**[b] **deviation test (2)**	**Fixed effects result (3)**	**Pooled OLS result (4)**
	Coefficient	**Coefficient**	**Coefficient**	**Coefficient**
Y(-1)	0.698* (0.051)	0.956* (0.014)	0.885* (0.025)	0.976* (0.010)
KAP	0.042*** (0.023)	0.011 (0.008)	0.034** (0.014)	0.021* (0.007)
LABF	-0.040 (0.044)	-0.027 (0.019)	-0.156* (0.055)	-0.017**(0.008)
REN	-0.070*** (0.036)	-0.019*** (0.011)	0.004 (0.010)	0.000 (0.002)
HEX	-0.013 (0.018)	0.000 (0.014)	-0.011 (0.013)	0.012**(0.005)
BRM	-0.007*** (0.004)	0.005* (0.001)	0.002 (0.002)	0.000 (0.001)
Constant			1.144* (0.355)	0.000 (0.027)
R^2			0.998	0.998
Adjusted R^2			0.998	0.998
Mean dependent var	0.004	-0.044		
S.E. of regression	0.025	0.021		
J-statistic	12.672	13.191		
Prob (J-statistic)	0.000	0.000		
No of observation	1049	1049	1093	1093
Cross section included	43	43	44	44

All variables are in log-form. E-views 10

[a,b] Results as earlier stated in *Table 5*

*, **, *** significant at 1%, 5%, 10% respectively.Standard errors in parentheses

Conclusion and policy prescription

In this study, the relationship between renewable energy demand and inclusive growth was examined. The study adopted the system generalized method of moments (Sys-GMM), pooled ordinary least squares (POLS) and fixed effects (FE) models to examine this relationship in a cross-sectional panel of 47 African countries, spanning 1990–2019. The variables included in the models are GDP per person employed which measured inclusive growth, capital, measured by gross capital formation, labour force ratio, health expenditure which captures government activities in the health sector and broad money which captures the macroeconomic effectiveness. Our findings revealed that there is a weak convergence rate of inclusive growth between low-income countries and high-income countries of the African region. This implies that although the renewable energy is fast developing, the growth in the sector is not yet sufficient enough to promote inclusive growth in the region.

The levels of labour productivity and capital investment (domestic and foreign) in the African economy, most especially in the renewable energy sector, are weak. From the forgoing, to foster inclusive growth and promote social development, African governments need to create the enabling structure that increases capital investments into the renewable energy sources that has the capacity to create employments (especially in manufacturing renewable energy-based products) and provide income that would improve the living conditions of the most vulnerable households. Currently, the sector is challenged with difficulties in attracting adequate and affordable finance from both domestic and foreign agencies. Increase in renewable energy demand will allow Africa to unlock and fully realize its growth potential. To achieve this objective, this study suggests that various governments, through public-private partnership, should embark on aggressive renewable energy projects across the continent.

Since the availability of renewable energy sources varies from one country to another, these projects should be country specific. Projects related to power generation from geothermal sources should be implemented in parts of Africa with huge abundance of renewable energy sources. However, the success of implementation of these projects will mostly depend on policy frameworks that integrate local communities to own the projects. The policy frameworks should be such that target major stakeholders (that is, local workers, businesses and communities) who are willing to invest in the renewable sector and provide cheap energy to the communities. Secondly, the successful implementation of the project will also depend on the framework that integrates the renewable energy sector with other sectors with high absorptive capacity. Sectors with higher absorptive capacities have been documented in development studies literature as sector that creates more resources and foresters inclusive growth. Lastly, there is the urgent need for African governments to revitalize their different health sectors to meet modern day challenges. The COVID-19 pandemic has exposed the sorry state of the healthcare system in Africa and creates huge uncertainty around the sector. However, this study is limited to panel data analysis, and policies are prescribed for the entire panel and sub-panels; hence, future studies can utilize time-series analyses for country-specific findings and policies.

Acknowledgements. The authors would like to thank the Editor-in-Chief and anonymous reviewers for their time and suggestions which were most helpful in improving this article.

Conflicting interests. The authors declare that they have no potential conflicting interests with respect to the research, authorship, and/or publication of this article.

Funding information. The authors received no financial support for the research, authorship,and/or publication of this article.

Disclaimer. The views expressed in this article are those of the authors and not an official position of their institutions.

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APPENDIX

Appendix 1.*List of countries*

Algeria, Angola, Benin, Botswana, Burundi, Cabo Verde, Cameroon, Central Africa Republic, Chad, Congo Republic, Congo DR, Cote d’Ivoire, Djibouti, Egypt, Equatorial Guinea, Eswatini, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea Bissau, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Morocco, Mozambique, Niger, Nigeria, Papua New Guinea, Rwanda, Senegal, Sierra Leone, South Africa, Seychelles, Sudan, Tanzania, Togo, Tunisia, Uganda, Zambia, Zimbabwe

Appendix 2.*Low-medium countries according to World Bank (2020) classification*

Algeria, Angola, Benin, Botswana, Cabo Verde, Cameroon, Congo Republic, Congo DR, Cote d’Ivoire, Egypt, Eswatini, Ethiopia, Gabon, Ghana, Kenya, Lesotho, Mauritania, Mauritius, Morocco, Nigeria, Papua New Guinea, Senegal, Sierra Leone, South Africa, Seychelles, Tanzania, Tunisia, Zambia, Zimbabwe

Appendix 3.*Low-income countries according to World Bank (2020) classification*

Burundi, Central Africa Republic, Chad, Congo Republic, Djibouti, Equatorial Guinea, Ethiopia, Gambia, Guinea, Guinea Bissau, Liberia, Madagascar, Malawi, Mali, Mozambique, Niger, Rwanda, Sudan, Togo