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Economic growth, renewable and nonrenewable electricity consumption: A fresh evidence from a panel sample of African countries

Delphin Kamanda Espoir[1], Regret Sunge[2], and Frank Bannor[1]

Abstract

Energy transition has imposed a policy priority dilemma between economic growth and global warming mitigation. Existing studies in Africa have examined the impact of energy sources on growth but overlooked the differences across countries and regions. This study seeks to achieve two research objectives. First, it examines and compares the impact of renewable electricity consumption (REC) and nonrenewable electricity consumption (NREC) on growth in 48 African countries between 1980 and 2018. The study uses the recent panel estimators of cross-sectional dependence, slope heterogeneity, and cointegration. For the short and long-run marginal effects, the Pooled Mean Group estimator is used. Second, the analysis is extended to account for the heterogeneous effects of energy among African countries in four regional economic communities (EAC, COMESA, SADC, and ECOWAS). Here, we use the random-coefficients linear regression and kernel-based regularized least squares machine learning algorithm. The findings are as follows: (1) there is cointegration amongst the variables, (2) for the entire sample, both REC and NREC have positive and significant effects on growth, but NREC has an enormous impact, (3) the marginal effects of REC and NREC differ across African regions. Given the energy transition dilemma, there is a need for public-private partnership investments to bring a balanced mix between NREC and REC. Also, the heterogeneity suggests that a one-size-fit-all policy designed to increase growth through REC may not yield the same outcome in Africa. Therefore, while policies should speak to the common global agenda, there is a need to internalise and localise the strategies in each country and/or region.

Keywords: Renewable energy consumption, Economic growth, Climate change, Africa
JEL: O47, O55, Q42, Q54

1. Introduction

Accelerating the use of renewable energy (RE) is the flagship policy in the quest to reduce climate change and mitigate its effects at global level. Attainment of Sustainable Development Goals (SDGs) seven[3] and thirteen[4] rests on increased use of renewable energy sources. In Africa, the African Union Commission (AUC), 2015) sees renewable energy as indispensable for achieving Agenda 2063. Accordingly, governments have committed to increase the share of renewable energy in aggregate energy production to 50 percent by 2063. On one hand, the emphasis is in recognition of the opportunities renewable energy brings and the growing dangers of heavy dependence on nonrenewable energy consumption. The International Renewable Energy Agency (IREA) acknowledges that Africa's economy is set to benefit as new employment and other opportunities emerge from the new energy 'industry' (Müller & La Camera, 2019). Also, renewable energy is regarded as a vital policy tool for lowering greenhouse gas emissions (GHGs) and hence plays a key role in climate change mitigation strategies (Intergovernmental Panel on Climate Change (IPCC), 2018).

While the benefits of renewable energy consumption are undoubted, Africa faces a dilemma. Does the transition from nonrenewable energy to renewable energy works in Africa? Several reasons back

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[3] Ensure access to affordable, reliable, sustainable, and modern energy for all Goal

[4] Take urgent action to combat climate change and its impacts

this question. Firstly, on a positive note, already Africa has, by far, the highest share of renewable energy consumption in total energy consumption, recorded at 51.8% in 2018 (United Nations Department of Economic and Social Affairs Statistics (UNDESA), 2021). This is significantly higher than the world level (17.3%) while the closest region in the Americas (15.8%). Despite this, Africa is not benefiting much from this comparative advantage. It has been shown empirically (Adams et al., 2018; Azam et al., 2021; Kahia & Aissa, 2014) that the impact of nonrenewable energy consumption on economic growth in Africa is significantly higher than that of renewable energy. In another study, Maji et al. (2019) find that renewable energy retards economic growth in West Africa. Reducing nonrenewable energy consumption can threaten economic growth, while further increase in renewable energy consumption may work against the growth agenda.

Secondly, while the potential for Africa to yield gains from its vast renewable energy sources is there, the necessary infrastructure is limited. The South African Institute of International Affairs (SAIIA) identifies three constraints: finance, human and technical capacity, and domestic policies and politics (Adeniran & Onyekwena, 2020). It is estimated an annual average of $70 billion investment in renewable energy systems is required for the next 15 years if Africa is to realise significant gains from greener energies. This is an immense amount for most countries which are typically low-income economies. Also, green energy production demands highly specialised human and technical skills, which are relatively scarce in Africa. Furthermore, in a good number of African countries, fossil fuels are subsidised, making their continued use competitive than renewable energy. Apparently, for the period 1990 to 2016, fossil fuel energy consumption as a share of total energy consumption in Africa averaged approximately 40%.

Thirdly, Africa has the least energy consumption per capita despite having the highest share of renewable energy consumption. To put it in context, in 2018, Africa supplied only 5.6% of global energy (UNDESA, 2021a) even though its population is 16.7% of the global count (UNDESA, 2021b). Accordingly, the energy consumption per capita for 2018 was only 25.9 Gigajoules per capita against the world level, situated at 77.8 (UNDESA,2021). The next inferior region is Asia, with a consumption of 63.1 Gigajoules per capita. While the number of people without access to electricity fell from 1.2 billion in 2010 to 759 million in 2019, 580 million or 76.4% are from Africa (International Energy Agency (IEA), 2019).

Furthermore, the share of renewable energy in total energy consumption varies significantly across African regions. For example, the information on Renewable Electricity Consumption (REC) are often presented at Regional Economic Communities (RECMs): EAC, COMESA, SADC, and ECOWAS. Figure 1 shows the geographical territory of EAC, COMESA, SADC, and ECOWAS. Going by RECMs, the highest volumes of kWh of the REC, as is exhibited in Figure 2(b), are produced by COMESA (2.9), SADC (2.3), EAC (1.5), and ECOWAS (1.0). For Nonrenewable Electricity Consumption (NREC), as is shown in Figure 2(c), the order is SADC (13.3), COMESA (8.0), ECOWAS (2.0), and EAC (1.7). The regional variations are also reflected in the average GDP per capita (USD). According to information reported in Figure 2(a), the region with the highest average GDP per capita is SADC (2 106), followed by COMESA (1 895), ECOWAS (711), and EAC (679). Africa's regional heterogeneity of GDP per capita, REC, and NREC is too significant to ignore. This is important in crafting idiosyncratic energy mix policies for each region and country.

From the above background, in this paper, we examine and compare the impact of renewable and nonrenewable energy on economic growth in Africa. We appreciate the evidence from existing studies on Africa. A few studies (Khobai & Roux, 2018; Twerefou et al., 2018) have compared the impact of renewable and nonrenewable energy in Africa.

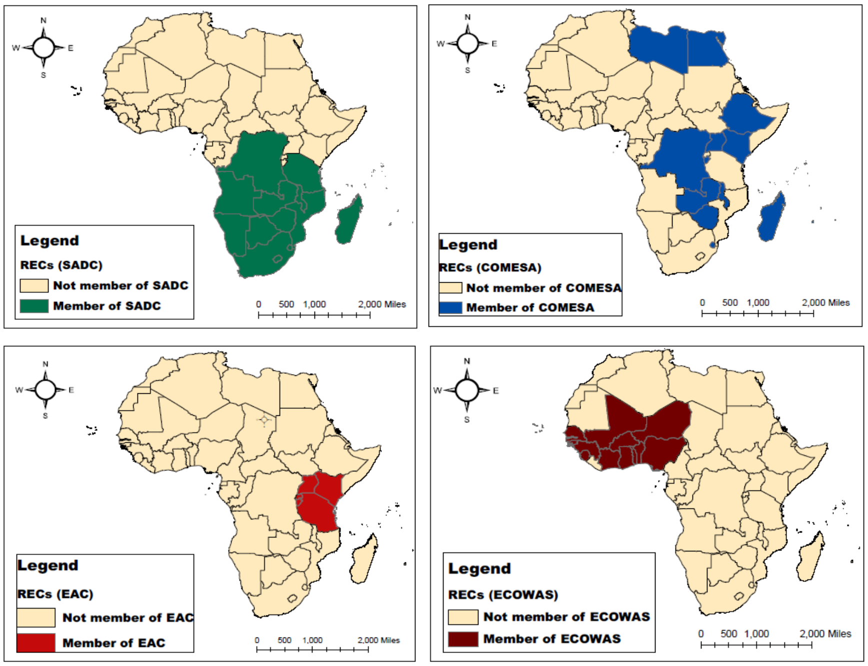

Figure 1: Geographical space of each of the African REC regions.
Source: Authors' self-painting based on a presentation provided by Espoir et al., (2021)

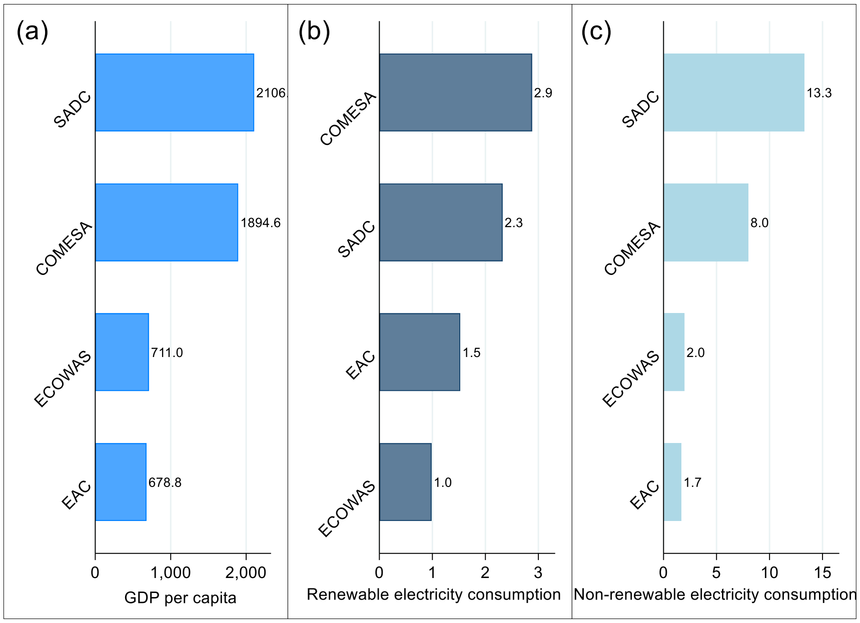

Figure 2: GDP per capita, renewable and nonrenewable electcity consumption across in Africa, 1980-2018.

Most studies (Eggoh et al., 2011; Kahia & Aissa, 2014) did not separate the two. Other studies looked at either the impact of renewable energy (Alege et al., 2018; Khobai & Roux, 2018; Maji et al., 2019) or nonrenewable energy (Awodumi & Adewuyi, 2020). In light of this, we first contribute to the existing literature in Africa by investigating the impact of both REC and NREC on economic growth by answering three important research questions: (1) what is the exact effect of REC and NREC on growth in Africa? (2) is the effect of REC and NREC on growth short or long-term? (3) does REC exercise a more positive impact on growth than NREC in Africa?

To respond to the three research questions as formulated above, we use the dynamic macro-panel estimators such as Polled Mean Group (PMG) and Dynamic Fixed Effects (DFE). Specifically, we use the PMG technique developed by Pesaran et al., (1999) on a sample group of 48 African countries for the period between 1980 and 2018. The PMG is an intermediate estimator that enables the short-term marginal effects to differ between countries while imposing homogeneity of the long-term marginal effects between countries. Hence, taking into account this specification may provide a robust assessment of the short and long-run coefficients that reflect the energy-growth nexus across African countries.

Additionally, we note that no attempt has been made to examine the impact according to different geographical regions of Africa or at least where African countries were included in the study sample. We submit that such studies assume that the use, type, and composition of energy in Africa are identical and hence have homogeneous impact on economic growth (see for example, Eggoh, 2011; Awodumi & Adewuyi, 2020; Ivanovski et al., 2021; Kouton, 2021). Contrary to these studies, we believe that the regional heterogeneity in Africa is too important to overlook. This is crucial in prescribing idiosyncratic energy mix policies for each African region. We posit that using a one size-fits all approach in Africa may not be appropriate and in some cases, it may lead to wrong policy design. Accordingly, unlike other studies, in addition to estimating and comparing the impact of REC and NREC on growth, we additionally contribute to existing literature by extending the analysis to four African RECMs (EAC, COMESA, SADC, and ECOWAS) and investigate the heterogeneous effects across these regions. Thus, the fourth research question is formulated as follows: (4) is the effect of REC and NREC homogeneous across the RECMs in Africa?

We answer the fourth research question through the use of the Swamy (1970) random-coefficients linear regression, a panel data technique that allows the marginal effects to vary across panels. Thus, this panel data technique enables us to obtain heterogeneous coefficients across the RECMs as asymptotic weighted averages. However, examining the distribution of the marginal effects can lead to interesting insights about non-constant marginal effects. In some cases, it is possible that a covariate (REC or NREC) has fairly uniform marginal effects, while in other cases the effects might be highly heterogeneous (e.g., the effects are negative in some and positive in other parts of the covariate space). Thus, we extend the RECMs analysis by empirically investigating the assumption of varying/uniform marginal effects of REC and NREC on growth across the RECMs. To do so, we implement the kernel-based regularized least squares (KRLS), a machine learning method described in Hainmueller and Hazlett (2014) that enables to tackle regression and/or classification problems without strong functional form assumptions or a specification search (Ferwerda et al., 2013). Thus, our approach contributes to enlarge the current energy-growth literature in Africa and in the world at large but also awaken up the policymakers.

The rest of this study is structured as follows. Section 2 provides a brief overview of renewable and nonrenewable energy sources in Africa, and Section 3 reviews the relevant literature. Section 4 presents the research methodology, and Section 5 presents and discusses the results. Section 6 concludes by summarising the policy implications of the results.

2. Overview of renewable and nonrenewable energy sources in Africa

Energy's important role in fostering economic growth has been an agenda for policymakers for the past two decades. The United Nations General Assembly announced the worldwide project "Sustainable Energy for All (SE4ALL) by 2030" in recognition of the need to enhance global access to cheap and ecologically friendly energy sources. The goal of “SE4ALL” is to provide universal access to modern energy services while also doubling renewable energy's proportion in the global energy mix. In line with the global energy agenda, the Africa Renewable Energy Initiative (AREI) was launched at the COP21 in Paris, endorsed by 54 African Heads of State in 2015. The aim of AREI is to assist African countries in making the transition to renewable energy systems that will help them achieve their low-carbon development goals while also improving their economic and energy security. Most African countries use nonrenewable energy sources for their economic production. An increase in renewables energy production is expected to boost production by increasing the low level of GDP per capita of many African countries. Figure (3) shows the spatial distribution of the average income (GDP per capita), Renewable Electricity Consumption (REC) and Nonrenewable Electricity Consumption (NREC) across African countries. Also, Figure 4 in the Appendix presents the country’s period average value of: (a) GDP per capita (current US $), (b) renewable electricity consumption (billions kwh), and (c) non-renewable electricity consumption (billion kwh), 1980-2018.

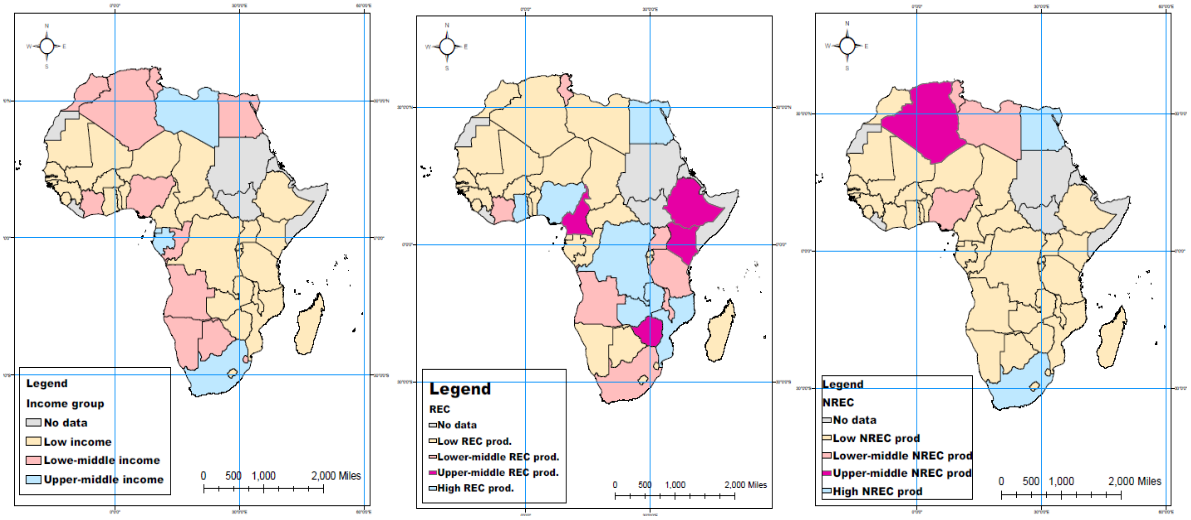

Figure 3: Spatial distribution of income, REC, and NREC across African countries, 1980-2018. Average GDP per capita (left), average REC (middle), and average NREC (right). For GDP per capita classification, we used the World Bank (2021) country income classifications available at https://blogs.worldbank.org/opendata/new-world-bank-country-classifications-income-level-2021-2022, REC and NREC are authors self-classification. Source: Authors’ self-painting.

By 2030, AREI plans to create at least 300 gigawatts (GW) of renewable energy (more than tripling the continent's present energy output). It lays out a clear path toward people-centered, equitably distributed renewable energy, with vastly expanded ownership structures that allow households, communities, cooperatives, farmers, small and medium-sized businesses, municipalities, and larger corporations to become both producers and consumers of electricity (AREI, 2018).

However, despite Africa's energy resources and potentially surpassing its present demands, the majority of its population and productive sectors face energy shortages. The electricity situation is particularly striking: almost two-thirds of the continent's population lacks access to power. The combined producing capacity of the 48 Sub-Saharan African countries, excluding the Republic of South Africa, is about 45 GW. Nearly a quarter of this capacity is unavailable due to various factors, including aged facilities and a lack of maintenance (AREI, 2018). As a result, Sub-Saharan Africa has the lowest power access rate globally, at only 32%. Large swaths of rural Africa remain unconnected to the power grid, and present generation capacity is frequently insufficient to satisfy demand in expanding urban and peri-urban regions (AREI, 2018).

Renewables are seen as relevant solutions to the power shortage in Africa. They account for just 5% of overall energy production, whereas coal accounts for 49%, with clean energy investments hitting a high of $329 billion (Liebreich, 2016). A large proportion of people have to depend on biomass for energy. Biomass energy provides for more than 30% of total energy consumption and more than 80% in several Sub-Saharan African countries (UNEP, 2017). For the vast majority of African homes, biomass is the primary source of energy for cooking, drying, and heating. Additionally, the African Development Bank projects that demand for primary energy (excluding biomass) by industry, electricity and transportation would rise by 8.9% each year (AfDB, 2014). Overall, per capita, energy consumption is expected to grow from 612 kWh in 2011 to 1,757 kWh by 2040 (AfDB, 2014). More so, total industrial energy consumption is expected to rise from 431 TWh in 2011 to 1,806 TWh by 2040, representing an annual growth of 5.1% (AfDB, 2014).

Africa has enormous potential in terms of renewable energy generation. It has been identified in solar, wind, hydropower, and geothermal renewable energy sources. Therefore, in line with the AREI, many African countries have set ambitious strategic goals and launched large-scale integrated energy programs. Investments in modern, efficient, and clean energy sources are thus critical to ensuring economic growth and development within the Africa region. In addition, it will help reconcile the twin challenges of expanding energy access and curbing climate change.

3. Literature review

3.1. Energy consumption and economic growth hypothesis

The empirical analysis of the relationship between energy consumption and economic growth is based on four hypotheses: growth, conservation, feedback, and neutrality. Firstly, the growth hypothesis postulates that energy consumption has a direct and indirect impact on economic growth. Directly, energy is an essential input in the economy's production function (Azam et al., 2021). An increase in energy consumption, therefore, increases economic growth. Indirectly, energy augments capital and labor inputs in the production process, thereby enhancing productivity and economic growth. This hypothesis implies a unidirectional causality from energy consumption to economic growth (Maji et al., 2019). When such is the case, energy preservation policies have adverse effects on economic growth.

Secondly, the conservation hypothesis suggests unidirectional causality from economic growth to energy consumption (Hung-pin, 2014). This hypothesis implies that energy-saving policies may have little to no impact on economic growth. Thirdly, the feedback hypothesis argues for a bi-directional causality between energy consumption and economic growth (Odugbesan & Rjoub, 2020). It follows that the two are interdependent and complements each other. On the one hand, growth feeds from energy consumption. On the other, higher energy consumption is sponsored by increased economic growth. Lastly, the relationship can be explained by the neutrality hypothesis. In this rare situation, there is no causal relationship between energy consumption and economic growth (Alege et al., 2018). These four hypotheses have provided the foundation for empirical tests investigating the energy consumption-growth relationship. In this study, we explore the growth hypothesis by focusing on the direct effect of energy on growth. However, in the next section, we review the literature testing the four hypotheses.

3.2. Empirical Literature

The empirical debate on the relationship between energy consumption and economic growth is vast, still growing, and controversial. Our review acknowledged that evidence on the direction of causality, the presence or absence, and the nature of the long-run relationship among the variables vary according to countries and regions, study periods, econometric approaches, and sources and nature of energy consumed. In this study, we are interested in the source of energy, which can be renewable or nonrenewable. Some studies (Eggoh et al., 2011; Nondo & Kahsai, 2009; SOAVA et al., 2018; Sultan & Alkhateeb, 2019; Topolewski, 2021) did not separate between the two and therefore assessed the impact of total energy consumption while others (Aneja et al., 2017; Azam et al., 2021; Kahia & Aissa, 2014; Shahbaz et al., 2020) made the comparison. Also, few studies looked at either renewable energy consumption (Alege et al., 2018; Khobai & Roux, 2018; Maji et al., 2019) or non-renewable energy consumption (Awodumi & Adewuyi, 2020). While the majority of the studies reviewed confirms positive effects of energy consumption, evidence of negative impact is found in Maji et al. 2019), Chen et al. (2020), and (Abbasi et al., 2020). A summary of the studies we reviewed is given in Table 1.

Azam et al. (2021) compared the impact of renewable and nonrenewable electricity consumption on economic growth for ten newly industrialised countries from 1990 to 2015. Their analysis tested four hypotheses explaining the energy consumption-economic growth nexus: growth, conservation, feedback, and neutrality. The study employed panel unit root tests, panel cointegration, and panel Fully Modified Ordinary Least Square (FMOLS) estimator for analysis. The study established that both renewable and nonrenewable have a positive and significant long-run effect on economic growth. They found that a 1% increase in the former had a higher impact (0.095%) than the latter (0.017%). Granger causality tests suggested short-run and long-run bidirectional causality between renewable electricity consumption and economic growth. The study, therefore, confirmed the feedback hypothesis.

Awodumi & Adewuyi (2020) focuses on the impact of nonrenewable energy consumption on economic growth and CO_2 emissions for the top five oil producing countries in Africa[5] for the period 1980–2015. They classified nonrenewable energy into petroleum and natural gas. Following confirmation of nonlinearity and structural break in the data, the non-linear autoregressive distributed lag (NARDL) approach was used for analysis. Results suggested that per capita consumption of both energy types had an unequal impact on economic growth and carbon emission per capita in all countries but Algeria. For instance, for Nigeria, an increase in nonrenewable reduced economic growth but improved environmental quality. In Angola, nonrenewable energy consumption increases growth. However, the effect on environmental quality is mixed, varying with the type of energy consumption. The growth of these energy types did not significantly affect environmental pollution as it contributed to economic growth. In a similar study, Kahia & Aissa (2014) investigated the impact of renewable and nonrenewable energy consumption on economic growth in 13 net-oil exporting the Middle East and North African (MENA) countries from 1980–2012. The Pedroni (1999, 2004), Kao (1999), and Westerlund (2007) panel cointegration tests all confirmed long-run equilibrium amongst the variables. FOMLS estimation results suggested that both renewable and nonrenewable energy have positive and significant economic growth effects. As in Azam et al. (2021), nonrenewable energy was found to have a bigger impact (0.772%) than renewable energy (0.058%).

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[5] Algeria, Angola, Egypt, Gabon, and Nigeria

Table 1: Summary of the literature

Author(s)/Year	Countries/Region(s)	Period	Estimation Technique	Variables	Conclusion	Hypothesis
Azam et al. (2021)	10 Newly Industrialised Countries	1990-2015	Panel Unit Root Tests, Panel Cointegration, and panel Fully Modified Ordinary Least Squares (FMOLS) Estimator	RELC, NRELC, GDP, K, L, TRO	RELC↔ GDP NRELC↔RELC	Feedback
Awodumi & Adewuyi (2020)	5 top oil producing African Countries	1980-2015	Non-linear autoregressive distributed lag	PET, GAS, GDP, CO_2	Asymmetric relationship	-
Soava et al. (2018)	28 European Countries	1995-2015	Granger Causality, panel FMOLS	EC, GDP	Asymmetric EC↔ GDP=12 countries EC→GDP=11 countries GDP→EC= 4 countries EC≉GDP 1 country EC→GDP=long-run	All hypothesis
Khobai & Roux (2018)	South Africa	1994-2014	ARDL, VECM	REC, GDP	GDP→EC=short-run	Conservation
Twerefou et al. (2018)	West African Countries	1980-2015	FMOLS, DOLS	PET, ELC, GDP	GDP→EC=short-run	Conservation
Shahbaz et al. (2020)	Mixed	1980-2018	DOLS, FMOLS, and heterogeneous non-causality tests	REC, NREC, GDP	REC↔ GDP NREC→GDP	Growth feedback
Aneja et al. (2017)	BRICS	1990-2012	Pedroni Cointegration Tests, Panel vector error correction model	REC, NREC, GDP, GFC	GDP→REC GDP→NREC	Conservation
Topolewski (2021)	34 European countries	2008-2019	Generalised Methods of Moments (GMM)	GDP, TEC	GDP→TEC	Conservation
Nondo & Kahsai (2009)	COMESA Countries	1980-2005	Panel Unit Root Tests, panel Cointegration	GDP, TEC	TEC→GDP	Growth
Eggoh (2011)	21 African countries	1970-2006	DOLS and PMG	GDP, TEC	TEC↔GDP	Feedback
Sultan & Alkhateeb (2019)	India	1971-2014	VECM, Granger Causality	GDP, TEC	TEC→GDP=short-run TEC↔GDP=long-run	Growth feedback
Maji et. Al (2019)	15 West African Countries	1995-2014	DOLS, FMOLS, OLS	GDP, BIO, REC	-	RE, BIO have negative impact on GDP
Guo (2018)	China	1978-1991 1992-2016	-	GDP, TEC, L, K	GDP→TEC	Conservation
Kahia & Aissa (2014)	MENA	1980-2012	Pedroni, Kao, Westerlund, Panel error correction	REC, NREC, GDP	GDP→REC=short-run REC↔ GDP long-run NREC↔ GDP	Conservation Growth Feedback

Table 1: Summary of literature (*continued*)

Author(s)/Year	Countries/Region(s)	Period	Estimation Technique	Variables	Conclusion	Hypothesis
Belke et al. (2020)	25 OECD Countries	1981-2007	Johansen Cointegration, DOLS, panel-based error-correction Granger causality	TEC, GDP	TEC↔ GDP	Feedback
Kouton (2021)	44 sub-Saharan Countries	1991-2015	REC, inclusive GDP	REC, inclusive GDP	REC↔ inclusive GDP	Growth
Abbasi et al. (2020)	Pakistan	1970-2018	NLARDL	REC, NREC, GDP	-	-
Alege et al, (2018)	40 sub-Saharan countries	2001-2014	Pedroni, Kao, Panel error correction, Granger causality	REC, GDP	REC↔ GDP	Feedback

Also, panel error correction model results disclosed that the nature and direction of causality varies for the two energy sources. For renewable energy, there is unidirectional causality from economic growth in the short-run. In the long run, there is bidirectional causality. For non-renewable energy, bidirectional causality is confirmed in both the short-run and long-run.

Soava et al. (2018) examined the causal relationship between renewable energy and economic growth for 28 European Union countries from 1995-2015. The study found that increased renewable energy causes a positive impact on economic growth. However, in six countries, including Sweden and the United Kingdom, the impact was found to be insignificant. Granger causalities show bidirectional causality in 12 countries, unidirectional causality from energy consumption to economic growth in 11 countries, unidirectional causality from economic growth to energy consumption in four countries. There was no causality between the two in Malta. Also, Belke et al. (2020) analysed the relationship between economic growth and energy consumption for 25 OECD countries from 1981 to 2007. The study confirmed the cointegration and bidirectional causality relationship between the two.

In South Africa, Khobai & Roux (2018) assessed the impact of renewable energy consumption on economic growth. The study used quarterly data for the years 1990-2014 and applied the ARDL and VECM methods to establish the short-run and long association and test for causality, respectively. The study confirmed the long-run association between the variables. It was established that a 1% increase in renewable energy consumption led to approximately 1.37% economic growth. Causality results vary between short-run and long-run. In the former, unidirectional causality is confirmed from economic growth to renewable energy consumption. The reverse causality was found in the latter. Khobai & Roux (2018) argued that South Africa depends much on energy consumption. They advocate that energy policies must promote energy efficiency and increased the use of green energy. In another country study, Sultan & Alkhateeb (2019) investigated the energy-economic growth nexus for India for the period 1971-2014. The results confirmed a stable and long-run relationship between the two variables. Causality tests revealed a short-run unidirectional causality from energy use to economic growth. In the long run, the causality became bidirectional. However, Nyoni & Phiri (2018) provided contrasting results for South Africa using data for the period 1991-2016. Using linear and nonlinear autoregressive distributive lag (ARDL) models, the study found no evidence of cointegration between renewable energy and economic growth. They ascribed the relationship to inefficient use of renewable energy in complementing sustainable growth in South Africa.

Other studies (Maji et al., 2019; Nondo & Kahsai, 2009; Twerefou et al., 2018) provided subregional evidence. Twerefou et al. (2018) investigated the impact of total energy consumption, petroleum consumption, and electricity consumption on economic growth for West African countries for the period 1980 to 2015. Analysis was executed using the FMOLS approach. The study found no causality relationship running from total energy consumption and the respective two forms of energy consumption. However, the conversation hypothesis was confirmed by means of a uni-directional causality from economic growth to electricity consumption. Long-run results indicate that total energy consumption had a significantly negative impact on economic growth. A 1 % increase in total energy consumption caused a 0.14% fall in economic growth. The authors attributed the negative relationship to overdependence on biomass in West Africa. However, the disaggregated energy sources had positive and significant impact. In contrast to Azam et al. (2021), renewable energy (electricity) was found to have a bigger impact (0.107%) on economic growth than non-renewable energy (petroleum) (0.058%). In another study for West Africa over the period 1995-2014, Maji et al. (2019) used the DOLS, FMOLS, and OLS to show that renewable energy and biomass retards economic growth. As in Twerefou et al. (2018), the result was attributed to the source and nature of renewable energy used in West Africa, which is predominantly wood biomass. In addition, they bemoaned less use of cleaner energy sources such as wind, solar, and hydropower in the region. Another sub-regional evidence is provided by Nondo & Kahsai (2009) for 19 COMESA countries for the years 1980-2005. Panel unit root tests and panel Granger causality tests established a long-run relationship between the two variables. In addition, the findings reveal unidirectional causality from energy consumption to economic growth, in line with the growth hypothesis. Drawing from these findings and noting the abundance of renewable energy sources in COMESA, the authors recommended promoting and developing an expanded supply of clean energy in the region.

Eggoh et al. (2011) attempted to differentiate the impact of energy consumption on economic growth according to two country groupings: net energy-exporting and net energy-importing countries. After allowing for cross-sectional dependence and structural breaks in the data, the DOLS and PMG approaches were used for the investigation. Their thesis was that the impact might vary according to the respective classifications. However, there was no difference between the two groups. The study revealed a long-run equilibrium relationship between energy consumption and real GDP for the entire sample as well as for each country grouping. While energy consumption was found to have a positive and significant impact on the whole sample and the two groupings, it is essential to note that the effect varies. For the entire sample, a 1% increase in energy use increases GDP by 0.36%. However, the impact is higher for net-exporters (0.57%) than for net-importers (0.27%). Considering the reverse relationship, the results are tilted in favor of net-importers, whose economic growth is more elastic to economic growth.

Comparison of growth effects of renewable and nonrenewable energy consumption is also given by Shahbaz et al. (2020). The investigation covered 38 renewable-energy-consuming countries from 1990 to 2018. Three approaches, the DOLS, FMOLS, and heterogeneous non-causality, were applied. The empirical results validated a long-run and significant relationship between renewable and nonrenewable energy consumption and economic growth for the whole country sample. However, we note interesting findings from individual country estimates. The results are heterogeneous in many respects of the relationship. First, nonrenewable energy consumption had a higher impact than nonrenewable energy consumption in most countries (27). Also, no-renewable energy was found to positively affect 81.6% of the countries against 68.4% for renewable energy consumption. However, renewable energy impact is significant in 30 countries against 21 for nonrenewable energy consumption. In four countries, namely United Kingdom, Turkey, India, and France, the impact of both renewable and non-renewable energy consumption was found to be negative. We also observe that for six countries, South Africa, the USA, Morocco, Israel, and Belgium, the impact is insignificant for both types of energy consumption.

In a related study, Aneja et al. (2017) also compared the impact of renewable and non-renewable energy consumption for the BRICS[6] countries for the years 1990–2012. The study documented a unidirectional causality from economic growth to renewable and nonrenewable energy consumption. Hence the conservation hypothesis is supported. Also, the study indicates a long-run relationship among GDP per capita, renewable energy consumption, nonrenewable energy consumption, and gross fixed capital formation. In another study, Chen et al. (2020) demonstrated that the impact of renewable energy on economic growth could either be positive or negative. They posit that the direction of association depends on the quantities of renewable energy used. Employing a threshold model from a sample of 103 countries in the 1995 to 2015 period, they show that the effect is negative

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[6] Brazil, Russia, India, China, and South Africa.

before a certain consumption threshold, becoming positive thereafter. This finding holds for developing and/or non-OECD countries. Furthermore, they demonstrate that the relationship is insignificant developed countries but positive for OECD countries.

Adamas et al. (2018) controlled for regime type in investigating the effects of renewable energy and nonrenewable energy on economic growth in 30 sub-Saharan African countries from 1980-2012. The study endorsed significant long-run relationship amongst the variables from heterogeneous panel cointegration and panel-based error correction tests. However, they find that the short-run was not robust. The findings follow Kahia & Aissa (2014) and Azam et al. (2021) in that nonrenewable energy was found to have a more significant impact than renewable energy. Specifically, a 10% increase in renewable and nonrenewable energy is associated with a 0.27% and 2.11% increase in economic growth, respectively. Controlling for democracy revealed that the impact of both energy source consumption enhances economic growth. The effect of governance is also captured by Abbasi et al. (2020) for Pakistan over the years 1970 – 2018. Results from nonlinear autoregressive distributed lag modeling (NARDL) indicated different impact of the energy sources. While renewable energy had positive effects, nonrenewable energy was found to have a negative impact on economic growth. As in Adamas et al. (2018), better governance, as measured by reduction in terrorism, increased economic growth. Kouton (2021) provided a unique analysis on 44 sub-Saharan African countries over the period 1981-2015. Instead of examining the relationship on economic growth, the study considered the effect on "inclusive" growth. The focus on inclusive growth was in recognition that while Africa has been experiencing notable economic growth in recent years, the continent still records high poverty and inequality levels. Results from GMM estimation disclosed that renewable energy provides positive and significant inclusive growth effects.

4. Methodology and data

In this section, we introduce the data and different econometric methods, such as cross-sectional dependence, panel unit root, and cointegration tests for the variables of interest. Additionally, we explain our estimation procedure where panel data estimators and machine learning regression technique are introduced (see Figure. 5 for the methodological flowchart).

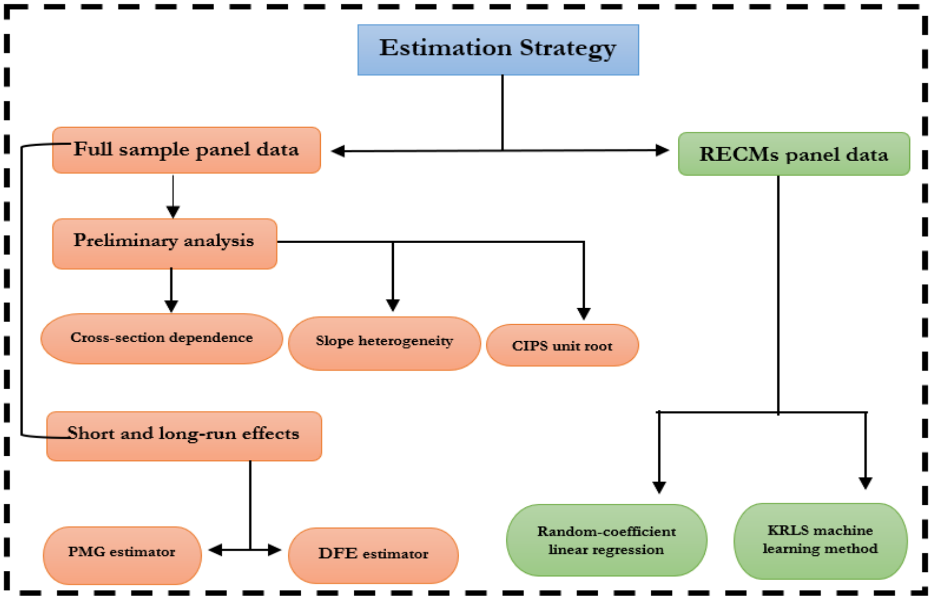

Figure 5: Model estimation procedure

4.1. Data and variables

We employ panel data from the World Bank and the U.S. Energy Information Administration databases (EIA)[7] from 1980 to 2018. We use GDP per capita measured in billions of 2010 U.S. dollars as a proxy for economic growth. The NREC and REC are the explanatory variables in this study. NREC is the sum of gasoline, oil, and coal production (measured in billion kilowatt-hours). In contrast, REC is measured as the sum of the hydroelectricity and non-hydroelectricity renewables (solar, tide, wave, wind, biomass and waste, and fuel cell). The REC is also measured in billion kilowatt-hours. We use variables transformed into logarithms to achieve a robust analysis, avoid possible heteroscedasticity, and minimise biases related to variable outliers. A cursory inspection of the data's energy time-series and cross-sectional dimensions shows a positive association between NREC, REC, and GDP per capita (see Figure 6) over 1980-2018. The positive relationship is consistent with the argument that electricity is consumed in all sectors with extensive demand. The energy demand is driven by important aspects such as industrialisation, urbanization, huge population growth, good quality of life and modernisation in the economic sectors. However, a two-way scatter plot in Figure 6 is not enough to draw a robust conclusion on the energy-growth nexus in Africa. Thus, a powerful analysis of the data using appropriate econometric techniques is required.

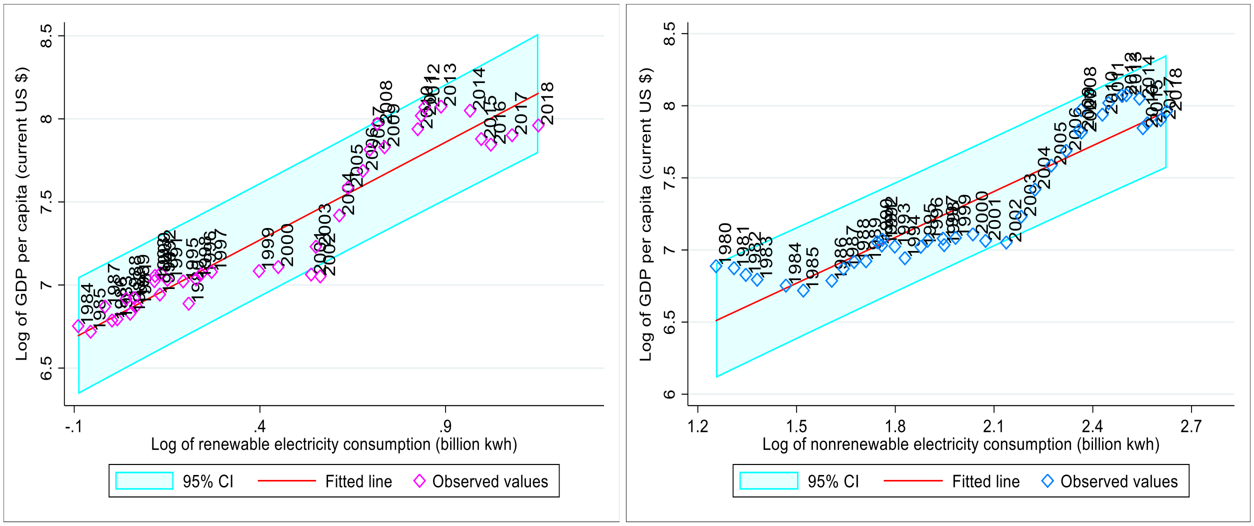

Figure 6: REC and NREC vs. GDP per capita: Time-series and cross-sectional plots, 1980-2018.

4.2. Model specification

The aim of this study is to investigate the energy-growth nexus in Africa. Specifically, we seek to analyse the short and long-run impact of renewable and nonrenewable electricity consumption on economic growth, and the causal relationship between the energy variables and growth. Also, we investigate whether the existing impact of energy sources is homogeneous across countries grouped into four different RECMs. Our model specification follows the framework of Azam et al., (2021). The estimated model is specified as follows:

$$\mathrm{GDP}_{i,t}=\beta_{o,i}+\beta_{1,i}\mathrm{NREC}_{i,t}+\beta_{2,i}\mathrm{REC}_{i,t}+\varepsilon_{i,t} \tag{1}$$

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[7] US Energy Information Administration database, 2020 [https://doi.org/Annually update of energy available at: http://www.eia.gov].

where GDP is the gross domestic product per capita, a variable we use as a proxy for economic growth, NREC is non-renewable electricity consumption, REC is renewable electricity consumption, and ε is the stochastic error term. Also, note that $\beta_{o,i}$ is s the unobserved country fixed effect, $\beta_{1,i}$ and $\beta_{2,i}$ are the long-run equilibrium coefficients. All the variables are used in natural logarithm form.

4.3. Estimation strategy

Given that the World economies, including those of Africa, have become financially and economically integrated in the past three decades, it is now compulsory to start panel data analysis with cross-sectional dependence (CD) test (Bersvendsen & Ditzen, 2021; Espoir & Ngepah, 2021). This test is essential because failing to account for cross-sectional dependence could lead to spurious estimated effects between energy source variables and growth (Herzer & Vollmer 2012). A second preliminary analysis of panel data concerns slope heterogeneity. Traditional panel data methodologies estimate variations between cross-sectional units by fixed constants (using fixed and random effects techniques). However, some panel datasets exhibit individual variability in the slopes across cross-sectional units. Overlooking this variability may bias the relationship results and cause incorrect inference (Chang et al., 2015; Espoir et al., 2021b). Concerning the long-run analysis, there is a third issue that is unit root test. If there is CD in the data, traditional panel unit root tests developed under the independence assumption of the errors are invalid. A panel unit root test that accommodates CD should be appropriate. Therefore, to investigate the energy-growth nexus across African countries, we start our procedure by examining the issue of cross-sectional dependence, slope heterogeneity, and panel unit root.

4.3.1. Cross-sectional dependency and slope heterogeneity test

There is a high possibility of rejecting the basic hypothesis of panel unit root when there is CD in the panel data (O'Connell, 1998). In addition, CD induces to parameter distortion problem. Without considering the CD in the panel, the results are significantly affected (Yıldırım et al., 2020). Thus, we use the Pesaran (2004) CD test to check for the presence of cross-sectional dependence in the variables of interest. Pesaran CD test statistics are calculated as follows:

$$Pesaran_{CD} = \sqrt{\frac{2T}{N(N-1)}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{\rho}_{i,j}\right)} \qquad \mathrm{N}(0,1) \tag{2}$$

where $\hat{\rho}_{i,j}$ is the sample estimate of the pairwise correlation of the residuals.

The specification of the CD test as expressed in Eq. (2) tests the following hypotheses:

H_0: no cross-sectional dependence
H_1: has the cross-sectional dependence

Next, we investigate whether or not the slopes are homogeneous across panel units. To achieve this, we use the standard delta ($\tilde{\Delta}$) test proposed by Pesaran and Yamagata (2008). This test is developed upon the standardised version of Swamy's (1970) test. The Swamy's (1970) test necessitates panel data where N is small relative to T. In contrast, the Pesaran and Yamagata (2008) test analyses slope homogeneity in large panels where N and T → ∞. For the $\tilde{\Delta}$ test, Pesaran and Yamagata (2008) presented two steps to be applied to obtain the test statistic. First, the authors suggested to compute the modified version of Swamy's test as:

$$\tilde{S}=\sum_{i=1}^{N}\left((\hat{\beta}_i-\tilde{\beta}_{WFE})\frac{'X_i'M_\tau X_i}{\tilde{\sigma}_i^2}(\hat{\beta}_i-\tilde{\beta}_{WFE})\right) \tag{3}$$

where $\hat{\beta}_i$ and $\tilde{\beta}_{WFE}$ are vectors of coefficients from pooled OLS and weighted fixed effect pooled estimator, respectively. $\tilde{\sigma}_i^2$ is the estimator of σ_i^2 and M_τ is an identity matrix. Using Swamy's statistic from Eq. (5), the standard delta statistic is developed as:

$$\tilde{\Delta}=\sqrt{N}\left(\frac{N^{-1}\tilde{S}-K}{\sqrt{2k}}\right) \tag{4}$$

Considering the null hypothesis of slope homogeneity with the condition of (N, T)→ ∞ so long as $\sqrt{N}$/T, the $\tilde{\Delta}$ test has asymptotic standard normal distribution ($\varepsilon \sim N(0, \sigma^2)$. Furthermore, for the small sample properties, the $\tilde{\Delta}$ test can be improved under the same condition of normally distributed errors through a bias adjusted version as:

$$\tilde{\Delta}_{adj}=\sqrt{N}\left(\frac{N^{-1}\tilde{S}-E(\tilde{Z}_{i,t})}{\sqrt{Var(\tilde{Z}_{i,t})}}\right) \tag{5}$$

where the mean $E(\tilde{Z}_{i,t})=k$ and the variance $Var\left(\tilde{Z}_{i,t}\right)=\frac{2K(T-k-1)}{T+1}$

4.3.2. Panel unit root and cointegration test

According to Espoir and Ngepah (2021), when the data exhibit positive evidence of CD, the first generation of panel data tests such as Levin et al. (2002), Im et al. (2003) and the Fisher type of tests suggested by Maddala and Wu (1999) cannot be applied as they provide inaccurate results. The incorrectness of the results from the first generation of panel unit root tests is because they are all developed under the strict assumption of independence. Pesaran (2007) proposed a CIPS panel unit root test that enables the cross-sectional dependence by considering the averages of lagged levels and differences for each unit. The Pesaran (2007) panel unit root approach is denoted as cross-sectionally augmented Dickey-Fuller, and can be computed as follows:

$$\Delta y_{i,t}=\varphi_i+\pi_i y_{i,t-1}+\lambda_i \bar{y}_{i,t-1}+\sum_{j=0}^{p}\delta_{i,j}\Delta\bar{y}_{i,t-j}+\sum_{j=1}^{p}\phi_{i,j}\Delta y_{i,t-1}+v_{i,t} \tag{6}$$

where $\bar{y}_{i,t-1}$ and $\bar{y}_{i,t-j}$ are the cross-sectional averages of lagged levels and first difference, λ and δ are coefficients to be estimated, φ and π and are the intercept and trend, respectively, and ϕ is the lead coefficient. The Pesaran (2007) tests the null hypothesis indicating that each variable contains a unit root ($H_0 : \pi = 0$) for all country in the sample group. In contrast, the alternative hypothesis states that at least one of the variables in the panel is stationary (H_1: π < 0), for at least one of the countries (for more details see Espoir and Ngepah, 2021). To reject or not the null hypothesis, the CIPS statistic is used and calculated as the average of the individual CADF statistics as follows:

$$CIPS=N^{-1}\sum_{i=1}^{N}tr_i \tag{7}$$

where tr represents the t-ratio obtained by OLS technique on the coefficient of π_i in the regression Eq. (6). The calculated t-ratio is compared with critical values tabulated by Pesaran (2007).

Testing for unit root in panel data is essential for panel cointegration test. Once the variables are integrated of the same order, it is possible to ascertain whether there is or not a long-run relationship among the variables. Investigating the long-run co-movements between the variables is achieved through cointegration. Given the positive evidence of CD among the variables of interest (as we shall see it later), in this study, we utilise the error-correction-based panel cointegration proposed by Westerlund (2007). This statistical procedure is relevant in the presence of CD. It investigates whether there exists an error correction for individual panel units or for the entire panel. This statistical procedure tests two different null hypotheses (no cointegration in some cross-sectional panels and no cointegration in all cross-sectional panels). It is computed as follows:

$$\Delta z_{i,t}=a_i' d_i+\xi_i\left(z_{i(t-1)}+\zeta_i' y_{i(t-1)}\right)+\sum_{j=1}^{m}\phi_{i.j}\Delta z_{i(t-1)}+\sum_{j=0}^{m}\varphi_{i.j}\Delta y_{i(t-1)}+\omega_{i,t} \tag{8}$$

where ξ_i is the adjustment term, d_i is a vector of deterministic components, including constant and linear time trends, $z_{i,t}=(x_{i,t}, y_{i,t})$ is the k+1 panel unit dimensioned vector of integrated variables, while other parameters introduce the nuisance in the variable of interest.

The Westerlund (2007) test assesses the null hypothesis of cointegration. The rejection of this hypothesis suggests the existence of cointegration for at least one cross-sectional unit in the panel. However, the test is constituted of two categories of statistics with each category having two statistics. The two statistics of the first category are known as panel mean statistics (P_τ, P_a), while the two statistics of the second category are also known as the group mean statistics (G_τ, G_a). The panel mean statistics, which tests the cross-sectional in all panel units can be calculated as follows:

$$P_\tau=\frac{\hat{\xi}_i}{SE(\xi_i)} \tag{9}$$

$$P_a=\mathrm{T}\xi_i \tag{10}$$

For the panel mean statistics, the rejection of the null hypothesis signifies no cointegration for the entire pane. On the other hand, the statistics of Westerlund group mean statistics can be calculated as follows:

$$G_\tau=N^{-1}\sum_{i=1}^{N}\frac{\hat{\xi}_i}{SE(\xi_i)} \tag{11}$$

$$G_a=N^{-1}\sum_{i=1}^{N}\frac{\mathrm{T}\xi_i}{\xi_i'(1)} \tag{12}$$

where G_τ and G_τ are group mean statistics, and test the null hypothesis of no cointegration in the cross-sectional panel. The rejection of this hypothesis means the existence of cointegration for at least one cross-sectional unit in the panel.

4.3.3. Pooled Mean Group Model and Dynamic Fixed Effect

To estimate the short and long-run slope coefficients, we use the Pooled Mean Group (PMG) methodology developed by Pesaran (1999). This estimation method is within the scope of the panel cointegration analysis. It estimates the long-run slope coefficient as the weighted average for the entire panel but allows heterogeneity and the exchange of error correction terms between groups in the short-term period. For convenience, consider X as a vector of explanatory variables, that is X = (NREC, REC). An Autoregressive distributive lag (ARDL) (p, q1, …, qk) dynamic panel specification functional form can be presented as:

$$GDP_{i,t}=\sum_{j=1}^{p}\vartheta_{i,t}\, GDP_{i,t-j}+\sum_{j=0}^{q}\delta_{i,j}X_{i,t-j}+\tau_i+\varepsilon_{i,t} \tag{13}$$

where $GDP_{i,t}$ is the dependent variable and X is a k x 2 vector of explanatory variables. $\vartheta_{i,t}$ are scalars; and τ_i is the country unobserved specific effect. p and q are lags of the dependent and independent variables varying from country to country respectively. There is a long-run relationship when the variables under consideration are cointegrated of order I(1) and the error terms is I(0). Nevertheless, deviations from the long-run trajectory may happen. Under this scenario, a vector error correction model (VECM) can be established, deviations from long-term equilibrium can be estimated. Thus, the error correction model can be specified as follows:

$$GDP_{i,t}=\Phi_i(GDP_{i,t-j}-\theta_i X_{i,t})+\sum_{j=1}^{p-1}\vartheta_{i,j}^{*}\Delta GDP_{i,t-j}+\sum_{j=0}^{q-1}\delta_{i,j}^{*}\,\Delta X_{i,t-j}+\tau_i+\varepsilon_{i,t} \tag{14}$$

where $\Phi_i=-\left(\sum_{j=1}^{p}\vartheta_{i,j}\right)$; $\theta_i=\sum_{j=0}^{q}\delta_{i,j}\,/\left(1-\sum_k \vartheta_{i,k}\right)$; $\vartheta_{i,j}^{*}=-\sum_{m=j+1}^{p}\vartheta_{i,m}$ for j=1,2, …, p-1; and $\delta_{i,j}^{*}=-\sum_{m=j+1}^{q}\delta_{i,m}$ for j=1,2, …, q-1.

Note that Φ_i stands for the speed of adjustment of the error correction coefficient. When the error correction coefficient is 0, it suggests that there is no significant short-run relationship. Also, note that the country-specific estimated error correction coefficient is expected to be negative and less than 1. Furthermore, we notice that the estimation of the PMG requires a large time dimension. Often, a short-time period produces biased estimates. In the current study, the time dimension is not enough and the panel units cannot be increased. We then use the Arellano and Bond (1991) estimator to eliminate the bias related to the time dimension problem. Hence, we apply the Dynamic Fixed Effect (DFE) estimator, which is based on the Panel ARDL procedure, similar to the PMG method. For samples with large T and large N, the heterogeneous DFE technique, specifically where the units are pooled and the cross-sectional variation of the slope coefficient is allowed, can be employed to estimate short and long-run effects. While the PMG estimator allows the intercept parameter to vary across units, it does not enable the slope coefficient to vary. In contrast, the DFE estimator considers that all parameters are unchanged/fixed. In sum, we use both PMG and DFE methods to estimate the energy-growth nexus in the short and long-run period. We then use the Hausman (1979) test statistic to select the most efficient estimates between these two methods.

Contrary to other studies in Africa, we expand the analysis of the energy-growth relationship to RECMs. We seek to investigate the heterogeneous long-run impacts of REC and NREC on economic growth across African countries grouped into different RECMs. We utilise the Swamy (1970) random-coefficients linear regression model. This panel technique does not impose the assumption of constant marginal effects across countries/regions. It gives heterogeneous coefficients across countries/regions as asymptotic weighted averages. Nevertheless, examining the distribution of the marginal effects can lead to interesting insights about non-constant marginal effects. In some cases, it is possible that a covariate has fairly uniform marginal effects, while in other cases the effects might be highly heterogeneous. Consequently, we extend the RECMs analysis by empirically investigating the assumption of varying/uniform marginal effects of REC and NREC on GDP per capita. We apply the kernel-based regularized least squares (KRLS), a machine learning method described in Hainmueller and Hazlett (2014). This algorithm learns from the data and tackles regression and classification problems without strong functional form assumptions or a specification search (Ferwerda et al., 2013). It uses the Gaussian kernel function to fit GDP per capita variables of the RECMs. Each input pattern is centered, corresponding weight scaled, and summed up. Also, by imposing a penalty, a model regularisation is used to optimise the tradeoff between fit approximation and complexities of the model (Tihonov, 1963). Unlike the traditional linear regression techniques that are enormously vulnerable to misspecification bias, the KRLS estimator has several comparative advantages. First, it provides more accuracy because of initial flexibility in modeling the conditional expectation function and sub-sequent reporting of parameters as the mean derivative of the improved regressed model. Second, it avoids the over-fitting of the model by optimising the model with a penalty-attributed to optimal regularisation function. Third, the KRLS estimator controls for complex models with non-additivity, non-linearities, and interaction effects (Hainmueller and Hazlett, 2014).

5. Empirical results and discussion

5.1. Full sample results and discussion

We begin by testing whether our variables are cross-sectionally dependent across countries. Table 1 shows the Pesaran CD test results. Looking at the results in this table, it is clearly seen that the null hypothesis indicating no cross-section dependence is rejected at the 1 % level of significance for all the three variables (GDP, NREC, and REC). This result indicates that, in Africa, the economic development and electricity energy sources tend to follow similar transmission mechanisms and have strong neighboring interaction effects. According to the CD results, high economic growth in one country is likely to spillover in neighbouring countries. This shows that several African countries are strongly dependent on their neighbours in several economic activities and energy sources. Thus, this dependence has to be considered in our regressions for unbiased marginal effects.

Also, we test whether the slope coefficients are homogeneous across countries. We use the Pesaran and Yamagata (2008) slope heterogeneity test on Eq (1). We perform this test on three different models, the results of which are presented in Table 2. They indicate that the statistic of the $\tilde{\Delta}$ and $\tilde{\Delta}_{adj}$ tests reject the null hypothesis of slope homogeneity at the 1% level of significance across all the panel units and for the three different models. This signifies that panel regressions by assuming slope homogeneity restrictions may provide inaccurate inferences and misleading results. Thus, our study takes into account countries specific characteristics in the regressions between REC, NREC, and GDP per capita in Africa.

Table 2: Slope heterogeneity and dependence results

Pesaran and Yamagata (2008) slope heterogeneity		
Models	$\tilde{\Delta}$	$\tilde{\Delta}_{Adjusted}$
Model 1 (GDP=*f*(NREC))	27.390***	28.796***
Model 2 (GDP=*f*(REC))	44.596***	46.479***
Model 3 (GDP=*f*(REC, NREC))	33.427***	35.777***
Pesaran (2004) CD test		
GDP	REC	NREC
161.81***	117.68***	166.84***

Note: *** p<0.01, ** p<0.05, * p<0.1, respectively.

Given that, in this study, our empirical interest is to investigate the short and long-run impacts of REC and NREC on growth, we follow by testing for stationarity of our time series. As we highlight in the methodology section, unit root testing paves the way for panel cointegration. The CD test results indicate the presence of variables dependence across panel units. This leads to an investigation of time-series stationarity with an appropriate test that accommodates cross-section dependence. Therefore, we apply Pesaran (2007) CIPS unit root test, which is presented in Table 3. The unit root test results indicate that the null hypothesis of the unit root is not rejected for all the three variables at the level (for the model with intercept and intercept and trend). Nevertheless, when we consider the data at the first difference, the results indicate that the null hypothesis is rejected at the 1% significance level. This suggests that there is at least one cointegrating relationship between REC, NREC, and GDP per capita. Hence, the appropriate test to investigate the existing long-run equilibrium relationship among our variables is the error-correction term-based panel cointegration test proposed by Westerlund (2007), as it accounts for CD of the time series.

Table 3: Pesaran (2007) CIPS unit root test results

	At level		First difference	
Variables	Intercept	Intercept and trend	Intercept	Intercept and trend
GDP	-1.966	-2.454	-5.400***	-5.628***
REN	-1.643	-2.051	-5.251***	-5.388***
NREN	-1.236	-1.658	-4.821***	-5.348***

Note: *** p<0.01, ** p<0.05, * p<0.1, respectively. The critical values of CIPS test at 10%, 5% and 1% levels of significance are -2.05, -2.25 and-2.23 for constant, and-2.55, -2.60 and-2.72 for constant plus trend, respectively.

Table 4 below presents the Westerlund (2007) cointegration results. As is presented in this table, the Westerlund test statistics reject the null hypothesis of no cointegration in favor of the alternative, for all the three models. These results confirm the presence of the long-run cointegration relationships among the selected variables. In other words, the cointegration results imply the presence of long-run equilibrium relationships between REC, NREC, and GDP per capita across African countries from 1980 to 2018.

Table 4: Westerlund (2007) cointegration test results

Test	Model (1)		Model (2)		Model (3)	
	value	p-value	value	p-value	value	p-value
P_τ	-4.156	0.103	-1.120	0.928	-3.858	0.338
P_a	-18.033***	0.000	-8.353***	0.000	-15.546***	0.000
G_τ	-2.740***	0.016	-2.196***	0.021	-2.740*	0.063
P_τ	-25.039***	0.000	-6.240***	0.000	-21.585***	0.000

Note: The estimated models include a constant in the cointegration relationship. The '***', '**' and '*' denotes the rejection of the null hypothesis of no cointegration at the 1%, 5% and 10% levels. The Akaike criterion is used to select the lags and the leads in the errors correction test.

Consequently, the PMG regression method is applied to investigate the short and long-term relationships between the series and obtain coefficients. The results are shown in Table 5, and they consist of two different parts. In the first part (the upper part of the table), we present the coefficients of the long-term relationship. In the second part (the lower part of the table), we report the coefficients of the short-term relationship. Firstly, when we consider the long-run impact, we conclude that NREC variable in Model (1) has a positive and statistically significant effect on growth at the 1% level of significance. This regression shows that a 1% increase in NREC increases growth on average by about 0.9%. However, it is also seen that the coefficient of NREC is positive but statistically insignificant in the short run. This implies that NREC does not affect growth in the short term but in the long term. Model (2) in Table 5 is the results of REC variables. We obtain a positive and statistically significant effect of REC on growth at the 1% significance level in the long-term perspective. The results show that a 1% increase in REC rises growth on average by about 1.1%. For the short-term effect, the results indicate a negative impact but is not statistically significant. As for the NREC variable, the results of REC also suggest a long-term impact only.

Lastly, Model (3) show the results of the NREC and REC variables when they are both included in the regression, as is specified in Eq. (1). The results for the long-term impact show that NREC and REC have positive and statistically significant effects on growth at the 1% significance level. Specifically, our estimations show that a 1% increase in NREC increases growth by about 0.85%, while a 1% increase in REC increases growth on average by only 0.04%.

Table 5: Pooled Mean Group (PMG) model results.

Variables	Model (1)		Model (2)		Model (3)	
	coefficient	t-statistic	coefficient	t-statistic	coefficient	t-statistic
Long-run (LR) effect						
NREN	0.851***	26.85	---		0.846***	26.12
REN	---		1.099***	9.53	0.040***	2.77
Short-run (SR) effect						
ECT(-1)	-0.138***	-8.69	-0.044***	-3.87	-0.138***	-8.91
ΔNREN	0.073	1.42	---	---	0.104	1.62
ΔREN	---		-0.001	-0.07	-0.028	-0.73
Constant	0.924***	9.42	0.286***	4.14	0.927***	9.72

Note: *** p<0.01, ** p<0.05, * p<0.1

Although both energy variables have positive impacts on growth, when comparing the magnitude of the marginal effects, it is clear that NREC is the variable with the highest marginal effect. This means that NREC plays a more critical role in driving growth in Africa compared to REC. The supremacy of NREC over REC in driving production in Africa is mainly because the transition to renewables in most African countries is more problematic since dirty technologies are more established in most African countries. This reflects the high costs of retiring existing fossil fuel-fired power stations. Large oil, gas, and mining companies have invested heavily in lobbying against implementing provisions to transition to renewables (Geels, 2014).

In terms of the average relationships, our findings of the positive long-run effects are similar to some of the findings of recent studies that document the significant role of these variables on economic growth (e.g., Aneja et al., 2017; Kahia & Aissa, 2014; Shahbaz et al., 2020; Le et al., 2020; Narayan & Doytch, 2017; Azam et al., 2021; Awodumi & Adewuyi, 2020; Ivanovski et a., 2012). For example, Azam et al. (2021) find a positive association between NREC, REC, and growth in newly industrialised countries. Awodumi & Adewuyi (2020) report that nonrenewable energy consumption enhances economic growth in the long run in several oil-producing economies in Africa[8]. Also, Ivanovski et al. (2021) show that NREC exerts a positive and significant impact on growth across OECD countries, with the coefficient function exhibiting an upward trajectory over time. They also find that the effect of REC on economic growth is statistically indistinguishable from zero in the OECD countries. In non-OECD countries, Ivanovski et al. (2021) report that NREC and REC promote economic growth.

However, as NREC facilitates the production of output, especially in Africa, as shown by this study's results, it is also acknowledged that NREC is a significant source of CO2 emissions (Awodumi & Adewuyi, 2020). It then leads to a dilemma in policy priority between economic growth and pollution reduction. Given that REC has a positive and statistically significant effect on growth in the long term, this signifies that African countries may play a crucial role in the transition process to renewables

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[8] This study uses the non-linear autoregressive distributed lag (NARDL) technique to study the role of non-renewable energy consumption in economic growth and carbon emission in oil producing economies in Africa. They find positive impact of the non-renewable energy consumption on economic growth.

despite several constraints related to technical progress and finances. But, the speed of transition from nonrenewables to renewables in Africa is slow. This is mainly due to weaker public regulations, policies, finances, and solid support from the running and corrupted government and policymakers (Amir & Khan, 2021). Another reason is new renewable power stations' difficulty in competing commercially against existing power stations (Ivanovski et al., 2021). For example, the shift from nonrenewable to renewable energy sources in OECD countries essentially depends on the pace of retirement of functioning power stations, which is relatively slow. In Africa, on the contrary, most countries employ more pollutant technologies and find it challenging to shift to clean energy sources. In places where the transition is happening, this shift tends to be a sluggish process. Besides, when oil prices spiked in the 1970s and 1980s, several OECD countries found alternatives by increasing R&D expenditures on renewables. In the African countries, however, government expenditures on renewable energy sources have not changed much since.

Given that the climate change effects of temperature and emissions on economic production are global and significant across climate regimes (Espoir et al., 2021), more advanced countries should financially assist African countries in the quest to achieving energy transition (Espoir et al., 2021). Looking at the current growth trajectory of most African countries, more production may result in more CO_2 emissions if governments fail to embark on energy transition by simultaneously investing in green technologies. Thus, to reach the Paris agreement on climate change through CO2 emissions reduction, the advanced nations should commit to supporting African economies in the quest to achieve energy transition without harming their economic expansion ambitions.

Furthermore, our estimations show that NREC and REC have positive and negative insignificant effects on growth in the short term, respectively. This implies that the two variables do not significantly impact economic production in Africa, at least in the short-term period. The short-run effect, especially for REC, contradicts the finding of Qudrat-Ullah & Nevo (2021), who recently found that an increase of 1% in REC drives growth in average by about 0.07% in Africa. Although the study of Qudrat-Ullah & Nevo (2021) finds a positive impact, it is also clear that the magnitude of the marginal effect is relatively weak, reinforcing our results of the insignificant short-term effect of REC in Africa.

We perform additional regressions of the three models presented in Table 5 using the Dynamic Fixed Effects (DFE) estimator. In doing so, the primary aim is to assess whether dynamic interactions help enhance the estimated marginal impacts as reported in Table 5 and control for possible endogeneity of energy variables. The results of the DFE are reported in Table 6 of the Appendix. Model (3) results in Table 6 show that only NREC has a statistically significant positive short and long-run impact on growth. REC estimate is negative but not statistically significant. Moreover, in performing the DFE estimation, the secondary aim is to check for the robustness of our PMG results as reported in Table 5 and assess which is the most efficient estimation between the two. To do this, we apply the traditional Hausman (1979) test, which is shown in Table 7 of the Appendix. The Chi2 value is 0.19 with a p-value of 0.908, suggesting that this study's PMG estimates are the most efficient. Pesaran, Shin & Smith (1999) show that the PMG model has an essential advantage over the DEF model because it allows the short-run dynamic specification to differ from country to country. Accordingly, if there is significant heterogeneity between the units, the PMG model can consider this heterogeneity and thus, minimise bias. In this study, it is evident that there are differences between the estimated marginal effects of PMG and DFE models. Nevertheless, the differences are not very critical. We strongly believe that the observed differences are due to the heterogeneity between African countries. An extension of the long-run effect analysis that explores more the countries' heterogeneities aspect may yield more insights for the interest of policy formulation. Hence, we extend the analysis to consider the RECMs by investigating the heterogeneous effect of NREC and REC on growth across African countries.

5.2. Regional Economic Communities (RECMs) results and discussion

To better understand the estimation mechanisms that drive our full sample results, we examine the heterogeneous effects of energy use (REC and NREC) on economic growth by splitting our entire sample into four different RECMs. Table 8 in the Appendix shows the different RECMs and their respective country members. As indicated earlier, we use two techniques that allow obtaining heterogeneous coefficients across the RECMs. First, we utilise the Swamy (1970) random-coefficients linear regression model. This technique does not constrain the regression to constant long-run marginal effects across panels as the PMG regression model does. The results of this regression are summarised in Figure 7. In Figure 7(a), we present the results for EAC. The estimated results demonstrate that both REC and NREC have positive and significant effects on GDP per capita at the 1% significance level. Specifically, the EAC results show that a 1% increase in REC increases growth by 0.4%, while a 1% increase in NREC rises growth on average by 1.2%. As in the entire sample, the contribution to growth from NREC is more critical than that of REC. The small contribution of REC to growth in this region is possibly due to the low level of local technological capacity in renewable energy technologies and the hitherto inadequate support for energy development initiatives (Hafner et al., 2019). Besides, it is also highlighted that information on specific energy sites that could guide potential investors, including their commercial viability, is insufficient or not readily available (Othieno & Awange, 2016). Additionally, most renewable energy resources have not been properly recognised for their commercial significance at the national level, and thus leading to an imbalance in the level of support to the development of different energy resources.

Compared with EAC, the results of COMESA show a similar marginal effect in NREC. As seen in Figure 7(b), a 1% increase in NREC increases growth on average by 1.1% in this region. The marginal effect for REC is negative and statistically significant at the 1% significance level. We find that a 1% increase in REC reduces growth on average by about 0.43%. The is a bit surprising given the volume of REC in this region (see Figure 2). A possible explanation for this negative marginal effect is the lack of adequate distributional infrastructures. Although the region has a huge production volume of REC, the distribution networks from production centers to places of consumption are fragile. Therefore, the existing investments in the region prefer to be connected to NREC networks that are already available.

The results in Figure 7(c) further indicate that both REC and NREC have positive and statistically significant effects on growth in the SADC region. As the estimations show, a 1% increase in REC leads to a 0.55% increase in economic growth, while a 1% rise in NREC spurs growth by about 0.47%. REC's significant impact in promoting growth in this region is due principally to the share of renewables in the region's power capacity that increased from 23.5% in 2015 to nearly 38.7% in mid-2018 (Renewable Energy and Energy Efficiency Status Report, 2018). Also, a decentralised renewable energy generation and distribution network has proven to be a clean and cost-effective way of increasing energy access in remote areas of SADC.

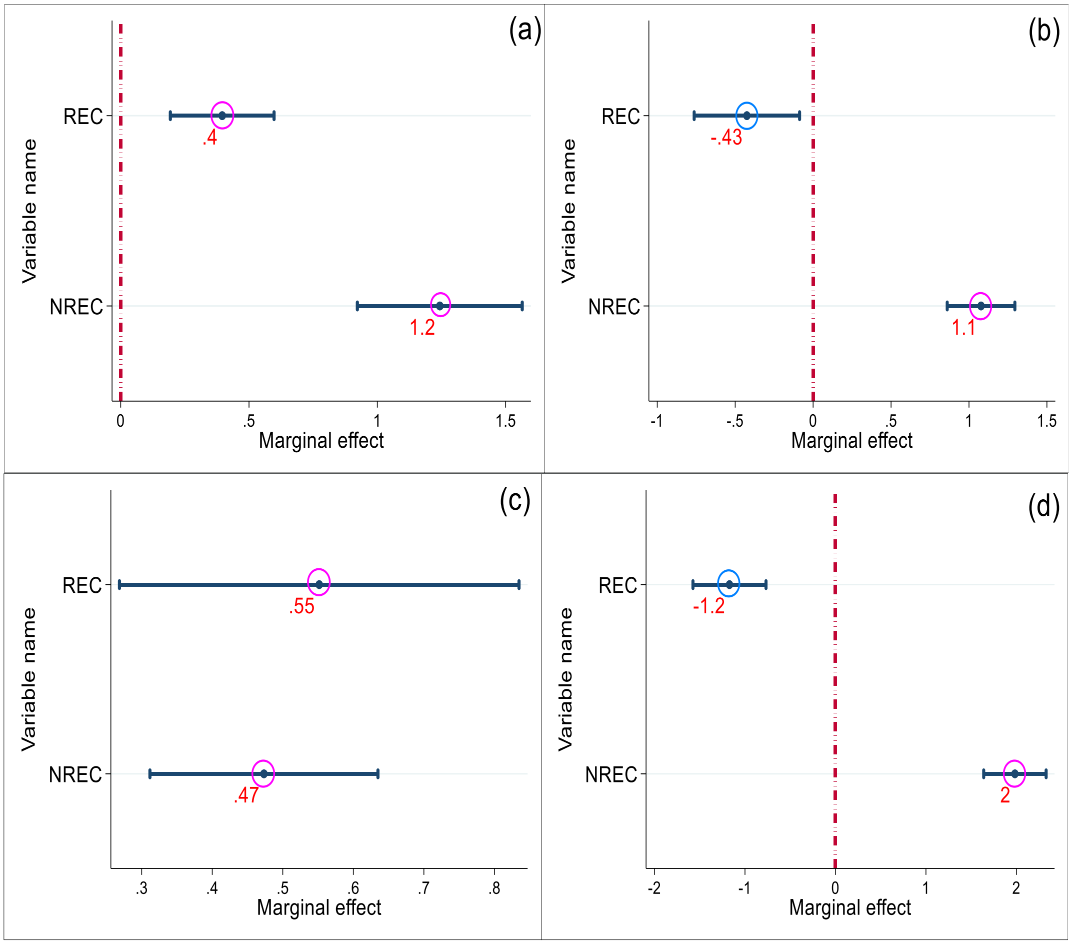

Figure 7. Heterogeneous estimation of REC and NREC on GDP (Group-specific coefficients). (a)–(d) denote the estimated coefficients for all RECMs (EAC, COMESA, SADC, and ECOWAS). Dots are color coded as Magenta hollow circle (positive coefficients), and Blue hollow circle (negative coefficients at the 0.05 level). 95% confidence intervals of each variable are shown. The red dashed lines represent estimated values equal to 0.

Finally, in Figure 7(d), the results indicate that REC and NREC have a negative and positive significant effect on growth, respectively. They show that a 1% increase in REC leads to a decrease in economic growth by about 1.2%, while a 1% increase in NREC boosts growth by 2%. The current outcome of the negative marginal effect of REC on growth in ECOWAS is highly supported by Maji et al. (2021), who investigate the impact of renewable energy on economic growth in 15 ECOWAS using panel dynamic ordinary least squares over the 1995-2014 period. These authors conclude that renewable energy consumption slows down economic growth in these countries. They attributed the adverse effect to the nature and source of renewable energy used in ECOWAS, mainly wood biomass.

This type of energy source used in ECOWAS is usually unclean and highly polluting when burnt. Given the current alarming climate change situation, it is recommended that cleaner technologies be used to optimise the benefits of wood biomass as a renewable source of energy while minimizing its adverse effects. This can be achieved through investing in R&D technologies that are easy to utilise by local communities involved in this energy sector. Also, the share of other renewable energy components such as wind, solar, and geothermal must be increased in the renewable energy mix of the ECOWAS region. In sum, our estimations show that REC has a negative marginal effect on growth in COMESA and ECOWAS and a positive impact in EAC and SADC. Concerning NREC, the results indicate positive effects in all the RECMs. Also, it is seen that the estimated marginal effects for both variables are heterogeneous across the RECMs. This suggests that a one-fit-all policy designed to increase growth through REC may not yield the same outcome in Africa. Therefore, policymakers should consider the heterogeneities of each country and region in designing policies that effectively promote growth through renewable energy sources in Africa.

Second, to further strengthen the arguments presented from the Swamy (1970) random-coefficients linear regression model results, we use a machine learning regression technique to assess and determine the relationships among the energy variables and growth across different RECMs. This analysis estimates pointwise derivatives using KRLS to determine the relationship between the explanatory variables and GDP per capita. The overall predicting power of the models, as is in Table 9, is 0.978, 0.950, 0.983, and 0.972, indicating that explanatory variables explained 97.8, 95, 98,3, and 97, 2% of the variation in GDP per capita for EAC, COMESA, SADC, and ECOWAS, respectively.

Table 9: Pointwise derivatives using KRLS

Region	GDP	Avg	SE	T-statistic	P-value	P-25	P-50	P-75
	NREC	1.329	0.140	9.431	0.000	0.926	1.465	2.005
EAC	REC	0.251	0.094	2.660	0.011	-0.225	0.176	0.794
	Lambda	0.133	Sigma.	2.000	R^2	0.978	Obs.	39
	Tolerance	0.718	Eff. DF	7.630	Looloss	0.718	F-test	-
	NREC	0.405	0.094	4.288	0.000	-0.340	0.010	1.365
COMESA	REC	-0.184	0.169	-1.091	0.282	-0.700	-0.353	0.279
	Lambda	0.103	Sigma	2.000	R^2	0.950	Obs.	39
	Tolerance	0.039	Eff. DF	9.203	Looloss	1.594	F-test	-
	NREC	0.473	0.054	8.640	0.000	0.307	0.507	0.762
SADC	REC	0.236	0.116	2.031	0.049	-0.059	0.081	0.456
	Lambda	0.101	Sigma.	2.000	R^2	0.983	Obs.	39
	Tolerance	0.039	Eff. DF	7.229	Looloss	0.462	F-test	-
	NREC	0.965	0.112	8.575	0.000	0.340	1.207	1.588
ECOWAS	REC	-0.267	0.132	-2.029	0.050	-0.717	-0.348	0.161
	Lambda	0.081	Sigma	2.000	R^2	0.972	Obs.	39
	Tolerance	0.039	Eff. Df	8.071	Looloss	0.850	F-test	-

Note: Avg. is the average marginal effect; SE is the standard error; P-25, P-50, and P-75 are the 25th, 50th, and 75th percentile.

Looking at the average marginal effect, it is seen that the mean pairwise marginal effects of NREC and REC are 1.33% and 0.25% for EAC; 0.41% and -0.18% for COMESA; 0.47% and 0.24% for SADC; and 0.97% and -0.27% for ECOWAS. We also notice that the probability value of each explanatory variable is significant at a 1% significance level, except for REC in COMSEA. This signifies that only REC marginal effect is not substantial in the COMESA region. Additionally, the long-run impacts of NREC and REC on GDP per capita and their variabilities are analysed by plotting the pointwise derivative of the two explanatory energy variables against GDP per (Figure 8a – 8d).

Figure 8(a) shows the varying marginal effects of NREC and REC in EAC. In this plot, we observe that the lower level of NREC increases growth at a higher level until it reaches a point where increasing NREC decreases growth. This connotes the negative impacts of NREC energy sources on the environment. Concerning REC, we notice that lower-level decreases growth to negative values until it reaches a level where increasing REC increases growth and the cycle of decreasing effect restarts again. Similarly, Figure 8(b) reveals the varying marginal effects of NREC and REC on growth. It shows that a higher level of NREC increases growth at a higher level, while a higher level of REC decreases growth. In other words, the NREC marginal effect implies that the association between nonrenewable energy and growth first moves at the same pace until a threshold point is reached. Then the lower level of nonrenewable energy increases growth.

Figure 8(c) exhibits the varying marginal effects of NREC and REC in SADC. In this plot, we observe that higher levels of both NREC and REC increase growth at a higher level until a turning point is reached where an additional increase in both variables reduces growth.

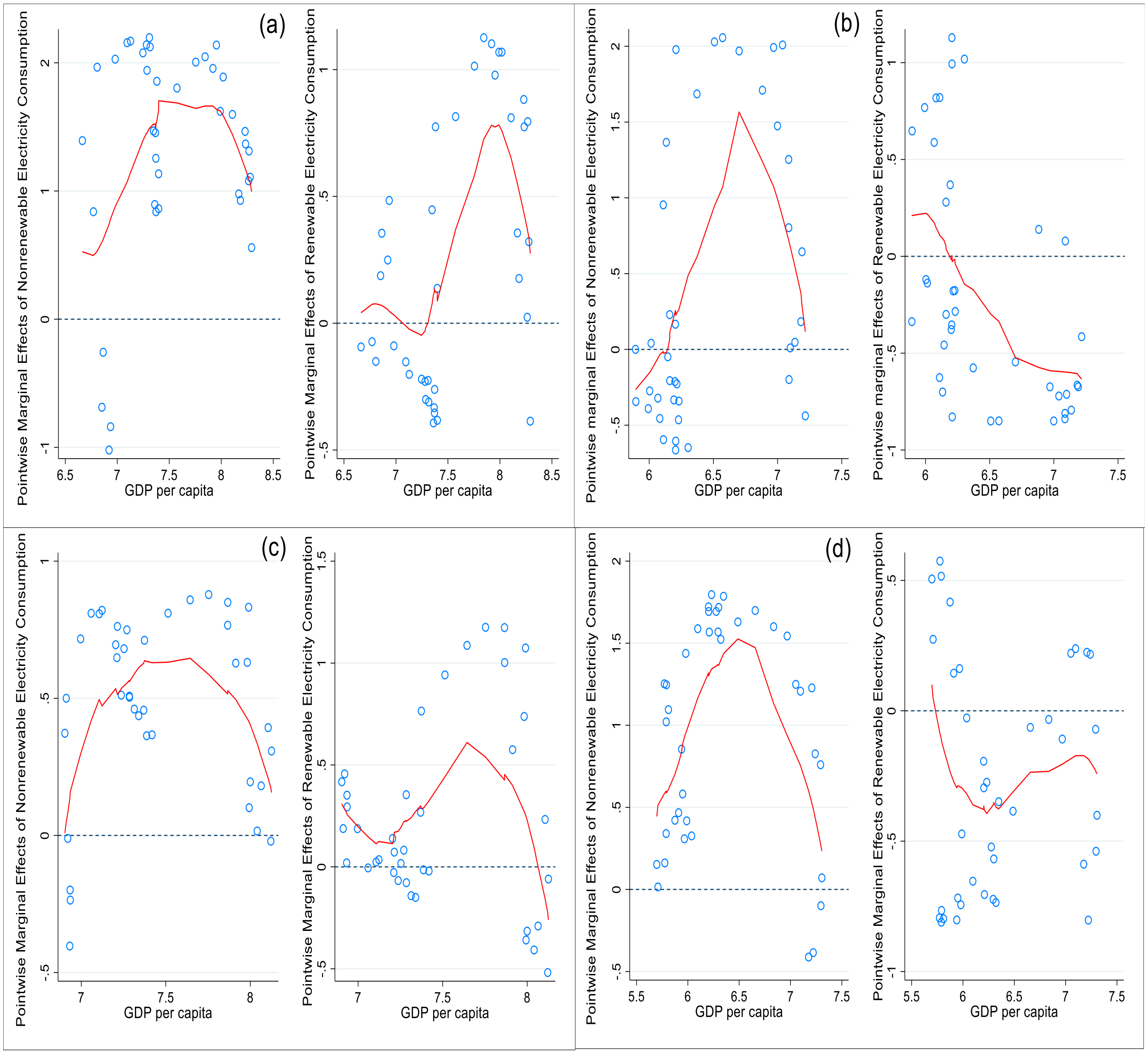

Figure 8. Representation of Pointwise marginal effect of renewable and nonrenewable electricity consumption across RECMs. (a), (b), (c), and (d) denote the estimated coefficients for EAC, COMESA, SADC, and ECOWAS, respectively.

Finally, Figure 8(d) presents the varying marginal effects of NREC and REC in ECOWAS. We notice that a higher level of NREC increases growth at a higher level up to a level where an additional increase negatively affects growth. Concerning REC, we observe that lower-level decreases growth until another level moves growth to a high level even though the marginal effect remains on average at a negative path. In sum, the results of these regressions confirm the validity of the Swamy (1970) results and the corresponding policy implications.

6. Conclusion and summary of the policy implications

Energy services are required for human development and well-being and healthy economic growth and employment generation. Africa urgently needs to address access to energy by rapidly and widely expanding both on-grid and off-grid power generation capacity, as well as the provision of alternative sources of energy. There is increasing confidence that the energy access gap may be overcome without aggravating climate change, which would jeopardize Africa's growth. In light of the foregoing, Africa has experienced a 60% increase in renewable energy capacity (IRENA, 2015). However, the most critical question that arises is whether the tremendous increase in renewables in the energy mix has had any major influence on economic growth in Africa?

This study investigates the effect of electricity consumption (renewable and non-renewable) on economic growth for 51 African countries over the period 1980 to 2018. First, we test whether the energy and growth variables (GDP, NREC, and REC) are cross-sectionally dependent across countries We conclude that in Africa, economic development and electricity energy sources tend to follow similar transmission mechanisms and have strong neighboring interaction effects. Additionally, we test whether the slope coefficients are homogeneous across countries. Contrary to existing studies that impose country homogeneity on the relationship between GDP, REC and NREC, our results of slope heterogeneity reject this hypothesis across all the panel units. We conclude that by assuming slope homogeneity, studies on energy-growth nexus provide inaccurate inferences and misleading results.

The second unique feature of our study is that we adopt the Pooled Mean Group (PMG) estimator to estimate our explanatory variables' short and long-run slope coefficients. The PMG estimate the long-run slope coefficient as the weighted average for the entire panel but allows heterogeneity and the exchange of error correction terms between groups in the short-term period. Considering the long-run impact, we find that NREC has a positive and statistically significant effect on growth. However, the coefficient of this variable is positive but statistically insignificant in the short-run. Hence, we conclude that NREC does not affect growth in the short-term but rather, in the long-term. Regarding REC, we obtain a positive and statistically significant effect on growth in the long-term. Similarly, we find no short-term effect, between REC and growth. Although both REC and NREC have positive effects on growth, we conclude that NREC exerts the highest marginal effect when comparing the magnitude of the marginal effects between the two variables. Therefore, NREC plays a more important role in driving growth in Africa compared to REC.

Subsequently, we check for robustness of our PMG results and assess whether dynamic interactions help enhance our estimated marginal effect. We do so by using the Dynamic Fixed Effects (DFE) estimator, which controls endogeneity among our variables. The DFE results show that only NREC has a statistically significant positive effect on growth within both the short and long-run. However, it should be noted that our PMG estimator has an important advantage over the DEF in the sense that it allows the short-run dynamic specification to differ from country to country. By means of the Hausman test, we conclude that the PMG estimator fitted the best our data.

We take a step further and explore the long-run effects of our variables by considering regional economic communities (RECMs) within Africa. We pursue exploring the heterogeneities that may exist among countries and regions. We employ an econometric technique that allows us to obtain heterogeneous coefficients across the RECMs. Specifically, we use the Swamy (1970) random-coefficients linear regression model, which does not impose the assumption of constant long-run marginal effects across panels as in the PMG estimator's case. Our results show that both REC and NREC have positive and significant impacts on growth. Regional regressions show that, in EAC, the contribution of NREC to growth is more important than that of REC. We argue that the low contribution of REC to growth in the EAC area is possibly due to the low level of local technological capacity in renewable energy technologies coupled with inadequate support for energy development initiatives. Similarly, our results of the COMESA area show that NREC increases growth. However, REC is found to exert a negative impact on growth. We show that the lack of adequate distributional infrastructures is at the center of the negative marginal effect in this region. Although the region has an important production volume of REC, the distribution networks from production centers to places of consumption are fragile. Therefore, the existing investments in the region prefer to be connected to NREC networks that are already available. Our results further indicate that both REC and NREC have positive and statistically significant effects on growth within the SADC area. REC is found to enormously increase growth compared to NREC. We conclude that the considerable impact of REC on growth in the SADC region is due to the high share of renewables in the region's power capacity that has seen an increased volume in recent years. Finally, our results indicate that REC and NREC have a negative and positive significant effect on growth in the ECOWAS area. REC is found to decrease growth while NREC is found to boosts growth in the region.

Furthermore, to corroborate our results from the random-coefficients estimator, we also use a machine learning regression technique to assess and determine the relationships among our energy variables and growth within the RECMs. In summary, the results from this algorithm confirm our findings of the region-specific coefficients.

Based on our findings, policy implications are addressed to multilateral, continental, regional and country policymakers as follows. Firstly, our findings indicate that REC and NREC increase growth at the global level in Africa. But the positive impact is enormous for NREC compared to REC. NREC facilitates output production but it is also a major source of CO_2 emission, leading to a dilemma in policy choice between growth and pollution abatement. Therefore, we recommend an intensive public-private investment in existing and planned renewable energy projects coupled with economic activity management. This approach can lead to significant CO_2 emissions reduction without posing a drag to several African countries' current economic growth trajectory. Secondly, the RECMs analysis shows heterogeneous effects of REC and NREC. While our regressions provide positive but heterogeneous significant marginal effects of NREC in all the RECMs, the REC variable results indicate a negative impact in COMESA and ECOWAS. Given the negative marginal effects of REC in these two regions, we recommend that cleaner technologies be used to optimise the benefits of wood biomass as a renewable source of energy at the regional economic community level. This will minimize the adverse effect of such energy on growth. Policymakers are therefore encouraged to invest in energy technologies that local communities can efficiently utilise. It is also important that the share of other renewable energy components such as wind, solar, and geothermal be increased in the renewable energy mix within the Africa region. Also, the heterogeneity suggests that a one-size-fit-all policy designed to boost growth through REC may not yield the same outcome in Africa. Therefore, while policies should speak to the common global agenda, there is a need to internalise and localise the strategies in each country and/or region.

Appendix

Table 6: Dynamic fixed effect (DFE) model results.

Variables	Model (1)		Model (2)		Model (3)	
	coefficient	t-statistic	coefficient	t-statistic	coefficient	t-statistic
Long-run (LR) effect						
NREN	0.750***	11.70	---		0.752***	11.65
REN	---		0.063	0.59	-0.006	-0.18
Short-run (SR) effect						
ECT(-1)	-0.089***	-8.74	-0.028***	-4.31	-0.089***	-8.76
ΔNREN	0.047*	1.92	---	---	0.051***	2.04
ΔREN	---		-0.003	-0.56	-0.006	-0.93
Constant	0.628***	9.11	0.224***	4.94	0.628***	9.12

Note: *** p<0.01, ** p<0.05, * p<0.1

Table 7: Hausman test results

Model estimated	Chi2 statistic	Probability
Model (3)	0.19	0.908

Note: Under the null hypothesis PMG is consistent

Table 8: List of countries classified into regional economic communities (RECs)

EAC (5)	COMESA (16)	SADC (16)	ECOWAS (14)
Kenya	Burundi	Angola	Benin
Uganda	Rwanda	Botswana	Burkina Faso
Burundi	DRC	Comoros	Cabo Verde
Rwanda	Comoros	DRC	Côte d'Ivoire
Tanzania	Egypt	Eswatini	Gambia
	Ethiopia	Lesotho	Ghana
	Kenya	Madagascar	Guinea
	Libya	Malawi	Guinea-Bissau
	Madagascar	Mauritius	Mali
	Malawi	Mozambique	Niger
	Mauritius	Namibia	Nigeria
	Seychelles	Seychelles	Senegal
	Eswatini	South Africa	Sierra Leone
	Uganda	Tanzania	Togo
	Zambia	Zambia	
	Zimbabwe	Zimbabwe	

Source: Authors' own presentation

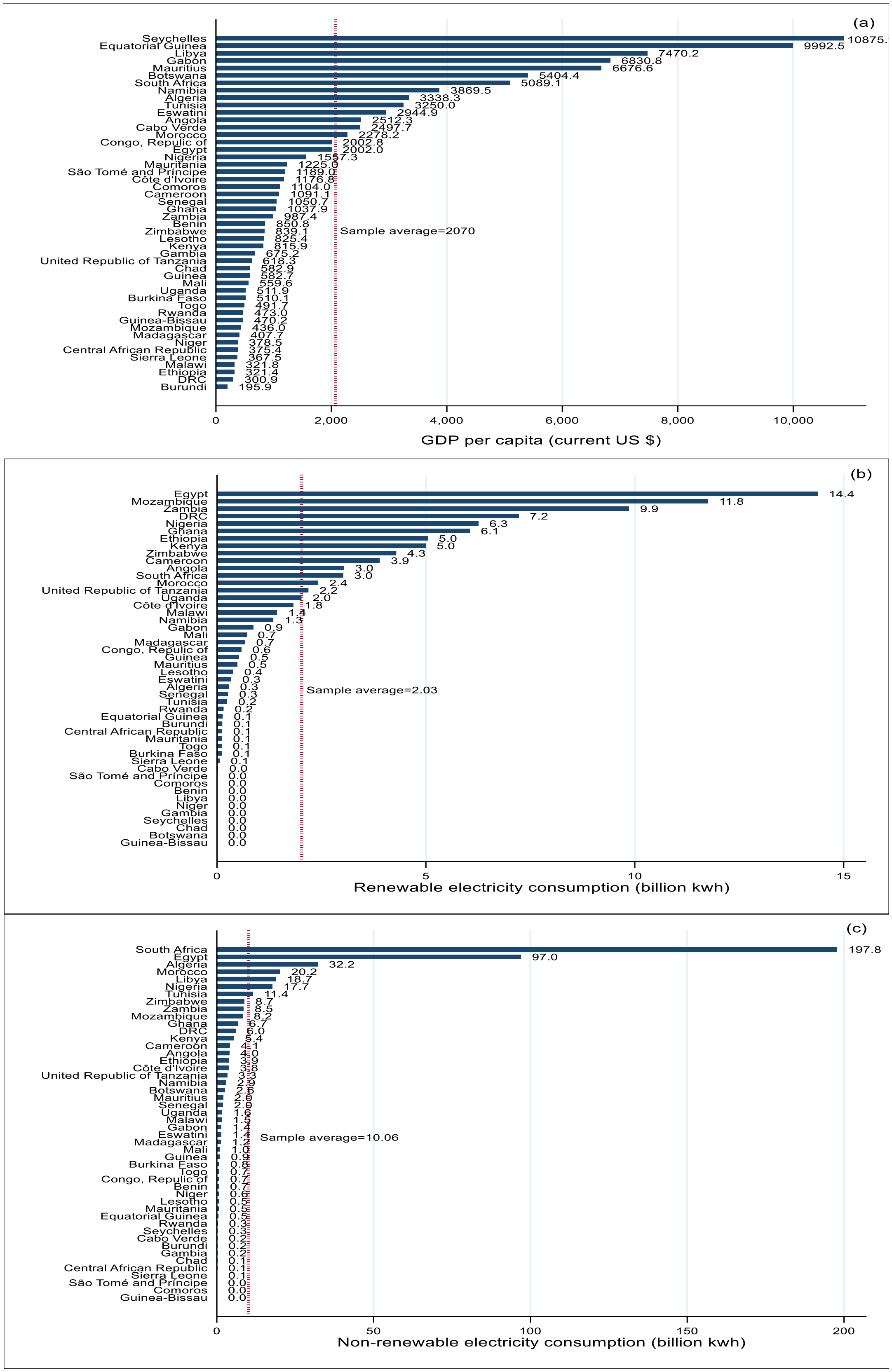

Figure 4: Period average value of: (a) GDP per capita (current US $), (b) renewable electricity consumption (billions kwh), and (c) non-renewable electricity consumption (billion kwh), 1980-2018.

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