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Testing the Relationships between Energy Consumption, CO2 emissions and Economic Growth in 24 African Countries: a Panel ARDL Approach

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Abstract

This study complements existing literature by examining the nexus between energy consumption (EC), CO_2 emissions (CE) and economic growth (GDP) in 24 African countries using a panel ARDL approach. The following findings are established. First, there is a long run relationship between EC, CE and GDP. Second, a long term effect from CE to GDP and EC is apparent, with reciprocal paths. Third, the error correction mechanisms are consistently stable. However, in cases of disequilibrium only EC can be significantly adjusted to its long run relationship. Fourth, there is a long-run causality running from GDP and CE to EC. Fifth, we find causality running from either CE or both CE and EC to GDP and inverse causal paths are observable. Causality from EC to GDP is not strong, which supports the conservative hypothesis. Sixth, the causal direction from EC to GDP remains unobservable in the short term. By contrast, the opposite path is observable. There are also no short-run causalities from GDP, or EC, or EC and GDP to EC. Policy implications are discussed.

JEL Classification: C52; O40; O55; Q43: Q50
Keywords: Energy consumption; CO2 emissions; Economic growth; Africa

1. Introduction

With the transition for Millennium Development Goals (MDGs) to Sustainable Development Goals (SDGs), the literature on nexuses between energy, growth and pollution continue to be of significant interest in academic and policy-making circles. The relevance of energy as an engine of economic prosperity has been substantially documented (Ozturk, 2010). However, the efficient exploration, exploitation and development of energy within a country or region are crucial for the wellbeing of individuals, optimal usage of public commodities, inclusive growth and sustainable development (Apkan, 2012).

To the best our knowledge, the highlighted concerns are most relevant for Africa's contemporary development for at least a fivefold reason, notably: dismal poverty trends, high economic growth, energy crisis, poor energy management and consequences of climate change. First, the April 2015 World Bank report has revealed that poverty has been decreasing in all regions of the world with the exception of Africa where 45% of countries in sub-Saharan Africa (SSA) are substantially off-track from achieving the MDGs poverty target (Asongu and Kodila-Tedika, 2015). Second, the continent has enjoyed over two decades of growth resurgence (Fosu, 2015) and is currently host to seven of the ten fastest growing economies of the world (Asongu and Rangan, 2015). Third, one of the most important challenges the continent would be confronted with in the post-2015 development agenda is energy crisis (Akinyemi et al., 2015). To put this into more perspective, according to Shurig (2015), statistics from the International Energy Agency (IEA) suggest only 5% of SSA has access to energy. Moreover: (i) electricity consumption per capita in the sub-region is one-sixth of the world's average and (ii) the total consumption across the region can be compared to that of the New York state.

Fourth, the inefficient management of the underlying energy crisis in many African countries has been cause for alarm (Anyangwe, 2014). In most of these countries (e.g Nigeria), pressure on electricity demand has promoted a high demand for substitute fossil fuels that are subsidized by government to the detriment of renewable energy. It is therefore not surprising that many households on the continent's most populated country are overly relying on the burning of petroleum fuels for self-generated electricity (Apkan, 2012). Fifth, unsustainable fossil fuel consumption has been substantially documented as one of the main causes of global warming (Huxster et al., 2015). Moreover, Africa would be the hardest hit by the consequences of climate change (Kifle, 2008). In essence, emissions of carbon dioxide

(CO_2) account for more than 75% of World greenhouse gas emissions, of which approximately 80% of it is produced by the energy sector (Akpan, 2012).

As far as we have reviewed, there are two main strands in the literature on nexuses between economic growth, environmental pollution and energy. The first stream which is concerned with the relationship between economic growth and environmental pollution has most notably focused on investigating the validity of an Environmental Kuznets Curve (EKC) assumption. The EKC hypothesis postulates that in the long run, there is an inverted U-shaped nexus between per capita income and environmental degradation. Some examples of studies in this strand include: Akbostanci et al. (2009), Diao, et al. (2009) and He and Richard (2010).

The second strand entails two streams of literature: the nexus between the consumption of energy and economic growth on the one hand and on the other hand, the relationship between economic growth, energy and pollution. Whereas the former stream is well documented in the literature (Mehrara, 2007; Esso, 2010)[1], the latter stream within a multivariate setting is a relatively new research area. The studies within multivariate frameworks have produced very conflicting results in both developed and developing countries (Jumbe, 2004; Ang, 2007; Apergis and Payne, 2009; Menyah and Wolde-Rufael, 2010; Ozturk and Acaravci, 2010; Bölük and Mehmet, 2015; Begum et al., 2015).

A common denominator to above strands is that the interesting literature has been particularly skewed towards developed nations and the emerging economies of Asia and Latin America (see Ozturk, 2010), with very scarce focus on African countries. The scarce literature on Africa can be engaged in two main strands, notably: country-specific and multi-country studies.

The following studies are note worthy in the first strand. First, Belloumi (2009) has examined the relationship between energy consumption and economic growth in Tunisia for the period 1971-2004 using Granger causality and Vector error correction model (VECM) to establish long-run bidirectional causality. Second, Odhiambo (2009a) has focused on South Africa using Granger causality for the period 1971 to 2006 to establish that electricity consumption leads to growth. Third, in another study, Odhiambo (2009b) targets Tanzania using the same periodicity with the Autoregressive Distributed Lag (ARDL) Bounds testing approach to conclude on bidirectional causality between economic growth and electricity consumption. Fourth, Akinlo (2009) position an inquiry on Nigeria for the period 1980 to

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[1] Also see Olusegun (2008) and Akinlo (2009).

2006 using Johansen–Juselius, co-integration and VECM approaches to find that electricity consumption causes economic growth. Fifth, Zhang et al. (2015) employ a Log Mean Divisia Index (LMDI) method to assess the contribution of factors that affect CO_2 emission related to energy in South Africa for the period 1993-2011. The authors establish that: (i) the intensity of energy play an important role in mitigating CO_2 emission, followed by effects from fossil and renewable energy structures and (ii) economic activity is critical to energy-related CO_2 emission. Sixth, using the ARDL bounds testing for cointegration and the VECM Granger causality approaches, Ben Jebli and Ben Youssef (2015) have recently investigated the nexus between per capita CO_2 emissions, Gross Domestic Product (GDP), renewable and non-renewable energy consumption in Tunisia for the period 1980-2009. The findings show short-run unidirectional causality flowing from GDP, non-renewable energy and CO_2 emissions to renewal energy while the inverted U-shaped EKC hypothesis is neither verified analytically nor graphically in the long-run.

The second strand on multi-country lines of inquiry can be summarised with the following studies. First, Wolde-Rufael (2005) has examined 19 African nations for the period 1971-2001 using the Toda–Yamamoto's Granger causality to establish the following: (i) growth causes energy consumption in Algeria, the Democratic Republic of Congo, Ghana, Egypt and Côte d'Ivoire; (ii) energy consumption causes growth in Cameroon, Nigeria and Morocco; (iii) there is a bidirectional causality in Gabon and Zambia and (iv) no causality in Benin, the Congo Republic, Senegal, South Africa, Sudan, Togo, Tunisia and Zimbabwe. Second, in a latter study, Wolde-Rufael (2006) has examined linkages between electricity consumption and economic growth in 17 African economies from 1971 to 2001, to conclude that: (i) economic growth leads to electricity consumption in Zimbabwe, Zambia, Senegal, Cameroon, Nigeria and Ghana; (ii) the opposite flow of causality in Tunisia, the Democratic Republic of Congo and Benin; (iii) bidirectional causality in Morocco, Gabon and Egypt and (iv) no causality evidence in Sudan, South Africa, Kenya, Algeria and the Congo Republic. Third, Akinlo (2008) investigates the relationship between economic growth and energy consumption in 11 African countries using an ARDL bound test to establish two main findings: (i) economic growth causes energy consumption in Senegal, Congo, Zimbabwe, Sudan, Ghana and Gambia while (ii) there is no evidence of causality in Togo, Kenya, Nigeria, Cameroon and Côte d'Ivoire. Fourth, Ozturk and Bilgili (2015) examine the long run dynamics of biomass consumption and economic growth using dynamic panel analyses in 51 SSA countries for the period 1980-2009 to conclude that biomass consumption is affected by economic growth. Fifth, using linear and hidden cointegration methodologies, Tiwari et al. (2015) examine whether asymmetric effects exist between energy (renewable and non-renewable) production and economic growth in 12 SSA for the 1971-2011 period. The empirical findings confirm and reject the growth hypothesis for some sub-samples, implying that conservation policies could adversely affect growth. Sixth, Ackah and Kizys (2015) investigate the determinants of renewable energy in Africa using fixed effects, random effects and dynamic panel models to find that the principal drivers of renewable energy in oil-rich African economies are: energy resource depletion per capita, real income per capita, energy prices and carbon emissions per capita. Seventh, Raheem and Yusuf (2015) use 15 African countries for the period 1980-2010 within the framework of a nonlinear model to find evidence of the EKC hypothesis from the energy-growth nexus in Tunisia, Togo, Egypt, Côte d'Ivoire and Benin. Moreover: (i) high regime of energy consumption boosts growth in Senegal, Morocco and Algeria; (ii) low regime of energy consumption slows growth in South Africa and Sudan whereas (iii) evidence of a neutrality hypothesis is established for Zambia and Cameroon.

Noticeably, the above literature leaves room for improvement in two key areas, notably, the need to: (i) go beyond the scope of country-specific analysis and engage panel studies which have broader policy implications and (ii) position lines of inquiry within a trivariate analytical framework. Accordingly, with increasing calls for more economic integration in Africa within policy and academic circles (Akpan, 2014; Tumwebaze and Ijjo, 2015; Shuaibu, 2015), results on underlying issues that are relevant to a broad set of countries are more likely to enhance the harmonization of common policies in the post-2015 sustainable development agenda. Moreover, a trivariate analytical framework intuitively has more policy rewards.

In light of the above, this study aims to test the nexus between energy consumption, CO_2 emissions and economic growth in 24 African countries using a panel ARDL approach. The rest of the paper is structured as follows. Section 2 discusses the data and methodology. The empirical analysis, presentation of results and discussion of findings are covered in Section 3. Section 4 concludes with implications and future research directions.

2. Data and Methodology

2.1 Data

The variables used in this study are GDP per capita measured in constant 2005 US$, Energy Consumption (EC) measured in kg of oil equivalent per capita, and CO_2 emissions measured in metric tons per capita. These variables are obtained from the World Development Indicators (WDI, 2015). The data are annual and spanning from 1982 to 2011. This is the common period resulting from the intersection of three time spans of our variables. The countries included in this study are: Angola, Benin, Botswana, Cote d'Ivoire, Cameroon, Congo Republic, Algeria, Egypt, Ethiopia, Gabon, Ghana, Kenya, Morocco, Mozambique, Nigeria, Sudan, Senegal, Togo, Tunisia, Tanzania, South Africa, The Democratic Republic of the Congo, Zambia, and Zimbabwe.

2.2 Methodology

Pesaran et al. (1999) have introduced the pooled mean group (PMG) approach in the panel ARDL framework. According Pesaran et al. (1999), the homogeneity in the long run relationship can be attributed to several factors such as: arbitration condition, common technologies, or the institutional development which was covered by all groups. In our Analysis framework, this homogeneity may be the consequence of the remote objective of reducing energy consumption by promoting alternative sources, including renewable energies. Furthermore, and in environmental policy, the inclusion of deforestation in the United Nations Framework Convention on Climate Change (UNFCCC), as the major source of reducing CO_2 emissions, confirms that the structuring process of an international regime on forests is now set up, especially in tropical African countries (Ongolo and Karsenty (2011)). The Panel ARDL method had been used by Binder & Offermanns (2007) for the purchasing power parity analysis in Europe, by Bildirici and Kayıkci (2012) for analysing the relationship between electricity consumption and economic growth and Boubaker and Jouini (2014), who used this method in the finance area.

In lines with the Pesaran et al.' (1999) methodology, the ARDL model, including the long-run relationship between variables, may follow as:

$$\Delta GDP_{it} = \alpha_i + \sum_{j=1}^{m-1} \beta_{ij}\, \Delta GDP_{i,t-j} + \sum_{l=0}^{n-1} \varphi_{il}\, \Delta EC_{i,t-l} + \sum_{r=0}^{p-1} \gamma_{ir}\, \Delta CE_{i,t-r} + \delta_1 GDP_{i,t-1} + \delta_2 EC_{i,t-1} + \delta_3 CE_{i,t-1} + \epsilon_{1i,t}\,, \quad (1)$$

$$\Delta EC_{it} = \alpha_i + \sum_{j=1}^{m-1} \beta_{ij}\, \Delta EC_{i,t-j} + \sum_{l=0}^{n-1} \varphi_{il}\, \Delta GDP_{i,t-l} + \sum_{r=0}^{p-1} \gamma_{ir}\, \Delta CE_{i,t-r} + \omega_1 EC_{i,t-1} + \omega_2 GDP_{i,t-1} + \omega_3 CE_{i,t-1} + \epsilon_{2i,t}\,, \quad (2)$$

$$\Delta CE_{it} = \alpha_i + \sum_{j=1}^{m-1} \beta_{ij}\, \Delta CE_{i,t-j} + \sum_{l=0}^{n-1} \varphi_{il}\, \Delta GDP_{i,t-l} + \sum_{r=0}^{p-1} \gamma_{ir}\, \Delta EC_{i,t-r} + \pi_1 CE_{i,t-1} + \pi_2 GDP_{i,t-1} + \pi_3 EC_{i,t-1} + \epsilon_{3i,t}\,, \quad (3)$$

where GDP, EC, and CE are, respectively, the logarithms of the gross domestic product per capita, the energy consumption and the CO_2 emission. Δ and $\epsilon_{ki,t}$ (k=1,2,3) are the first difference operator and a white noise term. Also, α_i denotes in (1), (2), and (3), a country specific intercept. Thereupon, the subscript i denotes a specific unit and is varying from 1 to N. In order to choose the optimal lag length for each variable, we will proceed to a grid search based on the minimization of the Schwarz information criterion (SBIC).

A reasonable generalization of cointegration test Pesaran et al. (2001) from time series to panel data may formulate the null hypothesis of no co-integration between the three variables in Eq. (1) as follows: $H_0: \delta_1 = \delta_2 = \delta_3 = 0$ against the alternative hypothesis $H_1: at\ least\ one\ \delta_k \neq 0\ (k = 1,2,3)$. Likewise, the null hypothesis of no co-integration between the three variables may be written as $H_0: \omega_1 = \omega_2 = \omega_3 = 0$. However, in Eq. (3), the null hypothesis of no co-integration between the three variables may be formulated as $H_0: \pi_1 = \pi_2 = \pi_3 = 0$. Even though the generalization of this test is possible in this way, we have not yet encountered in the literature the determination of its critical values in panel data context. Logically, when we have 'large' values of the Fisher statistics, associated with the above tests, we reject the no-cointegration null hypothesis. It is for this reason that the majority of works, resorting to the panel ARDL approach, have made use of the cointegration test of Pedroni (2004) given that the tests with null hypotheses presented above were not well specified in applied works.

In the second step, if the null hypothesis of co-integration is not rejected, we estimate the long run relationship between the three variables. For example, this long run relationship for the first ARDL model described by Eq. (1) is written as follows:

$$GDP_{it} = \mu_i + \sum_{j=1}^{m-1} \lambda_{1j}\, GDP_{i,t-j} + \sum_{l=0}^{n-1} \lambda_{2j}\, EC_{i,t-l} + \sum_{r=0}^{p-1} \lambda_{3j}\, CE_{i,t-r} + v_{1i,t} \,. \quad (4)$$

In doing so, we have respected the assumption imposed by the PMG approach, namely the coefficients of the long run relationship are the same for each country. Moreover, this assumption has been also respected in the specification of the no co-integration null hypotheses associated with the three above-described ARDL models. Likewise, the long-run relationships corresponding to the two remaining ARDL models are established in the same way. The error correction terms are derived accordingly from these relationships, and they will be used in the following.

Next, the Error Correction models, used to consider the short run relationships between the variables, are constructed as follows:

$$\Delta GDP_{it} = \alpha_i + \sum_{j=1}^{m-1} \beta_{ij}\, \Delta GDP_{i,t-j} + \sum_{l=0}^{n-1} \varphi_{il}\, \Delta EC_{i,t-l} + \sum_{r=0}^{p-1} \gamma_{ir}\, \Delta CE_{i,t-r} + aECT_{t-1} + e_{1i,t} \,, \quad (5)$$

$$\Delta EC_{it} = \alpha_i + \sum_{j=1}^{m-1} \beta_{ij}\, \Delta EC_{i,t-j} + \sum_{l=0}^{n-1} \varphi_{il}\, \Delta GDP_{i,t-l} + \sum_{r=0}^{p-1} \gamma_{ir}\, \Delta CE_{i,t-r} + bECT_{t-1} + e_{2i,t} \,, \quad (6)$$

$$\Delta CE_{it} = \alpha_i + \sum_{j=1}^{m-1} \beta_{ij}\, \Delta CE_{i,t-j} + \sum_{l=0}^{n-1} \varphi_{il}\, \Delta GDP_{i,t-l} + \sum_{r=0}^{p-1} \gamma_{ir}\, \Delta EC_{i,t-r} + cECT_{t-1} + e_{3i,t} \,, \quad (7)$$

where the residual $e_{ki,t}$ (k=1,2,3) is independently and normally distributed with zero mean and constant variance, and ECT_{t-1} is the error correction term defined from the long-run equilibrium relationship. The parameters a, b and c indicate the speed of adjustment to the equilibrium level. As mentioned above, the estimators of all these parameters are obtained by having recourse to the PMG method. More specifically, following Pesaran et al. (1999), the parameters of each Error correction model are estimated using the nonlinear algorithm of Newton-Raphson. The PMG estimators obtained are consequently consistent and asymptotically distributed normally, according to Pesaran et al. (1999). Moreover, they are intermediate estimators involving both pooling and averaging. Inasmuch as the PMG approach allows short-term dynamic specifications which differ from country to country while long-term coefficients are constrained to be the same, it has some advantages compared to the dynamic OLS (DOLS) and fully modified OLS (FMOLS) methods. Note that we do not include any control variables in the three specifications of the ARDL models following Pesaran and Smith (2014), who reason in support of parsimonious models when the object of interest is not the impact "ceteris paribus" of an explanatory variable.

In the last stage, the Granger causality tests are used in three ways following Bildirici and Kayikçi (2012). First, short run causalities are tested by considering $H_0: \varphi_{il} = 0$ for all i and $l \geq 1$ if we focus, for example, on testing in (5) the short run causality running from EC to GDP. The other short run causality directions follow in the same way in (5), (6) and (7). Second, long run causalities are tested from the ECTs in those equations. More specifically, the corresponding null hypotheses are $H_0: a = 0$, $H_0: b = 0$ and $H_0: c = 0$. Finally, if we focus on the strong causality running, in (5), from EC to GDP, the null hypothesis is $H_0: \varphi_{il} = a = 0$ for all i and $l \geq 1$. In the same way, the null hypotheses are specified for testing the other strong causality directions in (5), (6) and (7). For further details, see Bildirici and Kayikçi (2012).

3. Empirical Results

3.1 Unit root tests

To test the stationarity of the data, we used a variety of panel unit root tests. Particularly, we have used the tests of: Levin, Lin and Chu (2002) [henceforth LLC], Im, Pesaran and Shin (2003) [henceforth IPS], Breitung (2000) and Hadri (2000). All these tests are considered first generation panel unit root tests because they assumed the independence between cross section units. The IPS test had the objective of rectifying the restrictive LLC hypothesis, namely the homogeneous nature of the autoregressive root under the alternative hypothesis. On the other hand, Breitung (2000) suggested a statistic without a bias adjustment to avoid the dramatic loss of power, observed for the LLC and IPS tests if individual-specific trends are included. We still have to mention the null hypothesis of Hadri’s (2000) test is stationarity. In contrast, the null hypotheses of the other tests are the unit root ones. The use of both types of tests can be advantageous to avoid the loss a power noted when each cross section alternative is near the unit root. Finally, we chose from the second generation tests, that of Choi (2001). In particular, we used the Z and the modified Fisher statistics.

From Tables 1 and 2, we can conclude that GDP and EC are integrated variables , while the variable CE is stationary, so that we could use the panel ARDL model. This finding is deduced from the conclusions drawn from the majority of panel unit root tests.

Table 1: Panel unit root results: series in level

	GDP		EC		CE	
	Intercept	Trend	Intercept	Trend	Intercept	Trend
LLC	2.63 (0.99)	0.75(0.77)	0.50(0.69)	-0.66(0.25)	-1.38(0.08)	-6.64(0.00)
IPS	5.74 (1.00)	3.44 (0.99)	2.82(0.99)	1.68(0.95)	-0.42(0.34)	-4.35(0.00)
Breitung	--------------	4.67(1.00)	-------------	1.69(0.95)	-------------	0.38(0.65)
Hadri	13.26(0.00)	11.90(0.00)	14.01(0.00)	11.10(0.00)	14.38(0.00)	10.02(0.00)
Choi:Z statistic	5.54(1.00)	3.67(0.99)	2.78(0.99)	1.79(0.96)	73.92(0.009))	-3.88(0.00)
Choi: Fisher	28.98(0.98)	42.10(0.71)	30.41(0.97)	36.70(0.88)	-0.25(0.40)	103.08(0.00)

Notes: Table 1 show the statistics of the panel unit root tests. The values in brackets are the corresponding p values.

Table 2: Panel unit root test results: series in first difference

	ΔGDP		ΔEC		ΔCE	
	Intercept	Trend	Intercept	Trend	Intercept	Trend
LLC	-11.14(0.00)	-8.54(0.00)	-20.57(0.00)	-18.87(0.00)	-22.59(0.00)	-18.59(0.00)
IPS	-12.82(0.00)	-12.60(0.00)	-21.66(0.00)	-20.87(0.00)	-24.44(0.00)	-21.13(0.00)
Breitung	------------	-3.88(0.0001)	-------------	-12.29(0.00)	------------	-10.27(0.00)
Hadri	5.75(0.00)	5.29(0.00)	3.55(0.00)	4.97(0.00)	3.68(0.0001)	10.6821(0.00)
Choi:Z statistic	-10.73(0.00)	-10.52(0.00)	-17.34(0.00)	-16.48(0.00)	-19.25(0.00)	-16.66(0.00)
Choi: Fisher	252.57(0.00)	288.88(0.00)	435.87(0.00)	398.00(0.00)	493.31(0.00)	400.45(0.00)

Notes: Table 2 show the statistics of the panel unit root tests. The values in brackets are the corresponding p values.

3.2 Cointegration resuts

Table 3 reports the results of Pedroni's (2004) cointegration test. We have only three statistics, from seven, indicating the rejection of the no cointegration null hypothesis. Within this set of the three statics, we find the panel ADF and group ADF statistics, considered as the more reliable statistics by Pedroni (2004). In our results, the null hypothesis of no cointegration is rejected at 5% level and 10% level by the panel-ADF statistic while the group-ADF statistic rejects this null hypothesis at 1% level. Therefore, we can conclude that there is a long run relationship between energy consumption, CO_2 emissions and GDP in our 24 African countries.

The evidence on cointegration is consistent with country-specific and multi-country studies engaged in the literature, notably in: Tunisia (Belloumi, 2009), South Africa

(Odhiambo, 2009a), Tanzania (Odhiambo, 2009b) and Akinlo (2009). Whereas these studies have employed the VECM for the most part, what is apparent is that the underlying methodology is contingent on the presence of cointegration. While findings of underlying studies may not be directly comparable with the present line of inquiry, owing to differences in data structure, what is quite apparent as common denominator among them is the presence of a long-run equilibrium between energy consumption, CO_2 emissions and GDP. We may therefore reasonably infer that the documented country-specific evidence of cointegration may well be extended to regional and continental levels for broader policy implications.

Table 3: Results of Pedroni's (2004) cointegration test

	Statistics	**Probabilities**
Panel v-Statistic	-0.308735	0.6212
Panel rho-Statistic	0.929805	0.8238
Panel PP-Statistic	-1.075333	0.1411
Panel ADF-Statistic	-1.980038**	0.0238
Group rho-Statistic	1.660957	0.9516
Group PP-Statistic	-1.361107*	0.0867
Group ADF-Statistic	-2.809234***	0.0025

Notes: ***, ** and * imply significance levels at the 1%, 5% and 10% levels, respectively.

3.3 Panel ARDL results

3.3.1 PMG long-run estimates

We can deduce from Table 4 that there is great evidence that the variable CE has long run effects on GDP and EC. Note that the reciprocal paths of these long-run effects are observed with as much evidence. However, the long-run effects of EC on GDP (and vice versa) are only significant at the 10% level.

Table 4: PMG long run estimates

		Dependent variable		
		GDP	EC	CE
Independent variable	GDP	----------------	-0.0350* (-1.837)	0.257*** (21.852)
	EC	-0.138* (-1.837)	----------------	0.549*** (25.707)
	CE	1.558*** (21.852)	0.873*** (25.707)	---------------

Notes: The values in parentheses are the standard errors. *** and * indicate significance levels 1 % and 10%, respectively.

3.3.2 PMG short-run estimates

This section presents short-run estimates and describes the error correction model corresponding to the established cointegration relationships or long-run equilibriums. While at equilibrium the error correction term (ECT) is zero, a non-zero ECT implies that pairs of linkages have deviated from the long-term equilibrium. Hence, the ECT helps in the adjustment and partial restoration of the cointegration relationship. The underlying restoration of the equilibrium requires that the ECT: (i) has an expected sign and (ii) is within the right interval. In essence, a negative ECT within the interval of 0 and 1 is necessary for a stable error correction mechanism (Asongu, 2014ab). A positive ECT denotes deviation from the equilibrium. It follows that a negative ECT sign is necessary for the restoration of equilibrium following an exogenous shock. In the determination of the speed with which the equilibrium is restored, 0 indicates no adjustment whereas one period later, 1 suggests full adjustment.

Tables 5, 6 and 7 present the feedback coefficients for the cointegrating vectors for respectively GDP, EC and CE. We first notice that irrespective of tables, the signs and intervals of ECTs are consistent with theory, though only the ECT corresponding to EC is significant. This implies that in the presence of a shock, only EC can significantly be restored to its long-run equilibrium. This is an unfortunate scenario because the fundamentals of all ECTs are not weakly exogenous, with slight exceptions from 'Δ (EC(-1))', 'Δ (GDP(-1)) and Δ (CE(-1))' and 'Δ (GDP(-1))' in Table 5, Table 6 and Table 7 respectively. To put this technical insight into more perspective, adjustment of imbalances (i.e deviations from equilibrium) to restore a cointegration or a long-term relationship depends on fundamentals of Error Correction Terms (ECTs). The highlighted fundamentals or lagged variables are not significant; thus display weak exogeneity relative to corresponding ECTs. Hence they do not significantly contribute to adjusting underlying imbalances (or deviations) to corresponding cointegration relationships.

Table 5: PMG short-run estimate, ΔGDP is the dependent variable

	Estimate	t-student	p-value
constant	0.006^{***}	3.473302	0.0005
Δ (GDP(-1))	0.332^{***}	9.313	0.0000
Δ (CE(-1))	0.072823^{***}	2.942653	0.0034
Δ (CE)	0.052951^{**}	2.113089	0.0350

Δ (EC(-1))	-0.017509	-0.397408	0.6912
Δ (EC)	0.158681***	3.606315	0.0003
ECT (-1)	-0.004820	-1.586915	0.1130

Notes: The values in parentheses are the standard errors. *** and ** indicate significance levels 1 % and 5%, respectively. GDP: Gross Domestic Product. EC: Energy Consumption. CE: CO_2 emissions. GDP (-1) refers to GDP_{t-1}. Δ ( ) is the first difference operator.

Table 6: PMG short-run estimate, ΔEC is the dependent variable

	Estimate	t-student	pvalue
constant	0.003183**	2.073367	0.0385
Δ (EC(-1))	-0.070091*	-1.847755	0.0651
Δ (GDP)	0.118202***	3.569916	0.0004
Δ (GDP(-1))	0.032823	1.005280	0.3151
Δ (CE)	0.099936***	4.674685	0.0000
Δ (CE(-1))	-0.019157	-0.888379	0.3747
ECT (-1)	-0.019888***	-3.871489	0.0001

Note: ***, ** and * indicate significance levels 1%, 5% and 10%, respectively. GDP: Gross Domestic Product. EC: Energy Consumption. CE: CO_2 emissions.

Table 7: PMG short-run estimate, ΔCE is the dependent variable

	Estimate	t-student	pvalue
constant	-0.002692	-0.968138	0.3333
Δ (CE(-1))	-0.183101***	-4.754889	0.0000
Δ (CE(-2))	-0.189149***	-5.012503	0.0000
Δ (GDP)	0.142863**	2.395874	0.0169
Δ (GDP(-1))	0.056942	0.922606	0.3566
Δ (GDP(-2))	-0.168862***	-2.911800	0.0037
Δ (EC)	0.308355***	4.572995	0.0000
Δ (EC(-1))	0.255527***	3.750215	0.0002
Δ (EC(-2))	0.274120***	4.085150	0.0000
ECT(-1)	-1.65×10^{12}	-0.672525	0.5015

Notes: The values in parentheses are the standard errors. *** and ** indicate significance levels 1 % and 5%, respectively. GDP: Gross Domestic Product. EC: Energy Consumption. CE: CO_2 emissions. GDP (-1) refers to GDP_{t-1}. Δ ( ) is the first difference operator.

3.4 Causality tests

We have resorted to the Wald statistics, besides the F ones, in doing the causality tests. Indeed, the usual t- and F-statistics are still valid in the context of non-linear estimation, but they are no flexible enough; see Brooks (2008). This is all the more reason why we have added the Wald statistics.

3.4.1 Long run causalities

In view of Table 8, we can conclude that there is only one long-run causality running from GDP and CE to EC. Two insights may result from this finding. CE and EC may not be causing GDP in the long-term because: (i) EC is low owing to relative low access to energy and (ii) CE emissions are associated with activities of subsistence (e.g farming) instead of mainstream industrial or mechanized farming processes. This is broadly consistent with the conservative hypothesis which we engage to elaborate detail in the next section.

Table 8: Long-run causality statistics

		Statistics			
		Wald	p-value	Fisher	p-value
Dependent variable	GDP	2.518301	0.1125	2.518301	0.1130
	EC	14.98843***	0.0001	14.98843***	0.0001
	CE	0.452289	0.5012	0.452289	0.5015

Notes: *** indicates a significant long-run causality statistic at the 1% level. GDP: Gross Domestic Product. EC: Energy Consumption. CE: CO_2 emissions.

3.4.2 Strong causalities

We can conclude from Table 9 that there is great evidence of a strong causality running from either CE or both of CE and EC to GDP. Note that the inverse causal paths are also observable. It is not surprising that there is no strong causality from energy consumption to GDP for the whole considered panel. This supports the conservative hypothesis which assumes a unidirectional causality running from economic growth to energy consumption. Accordingly, the conservative hypothesis is in favor of the fact that energy conservation policies may have little or no impact on economic growth.

The established evidence of growth leading to energy consumption is broadly consistent with some studies in the literature that have found similar outcomes, notably: (i)

Ben Jebli and Ben Youssef (2015) in Tunisia within the framework of renewable energy; (ii) Wolde-Rufael (2006) in 17 African countries in the perspective of electricity consumption; (iii) Akinlo (2008) with regard to energy consumption in Senegal, Congo, Zimbabwe, Sudan, Ghana and Gambia; (iv) Ozturk and Bilgili (2015) within the framework of biomass consumption in 51 African countries and (v) Ackah and Kizys (2015) who have recently shown that GDP per capita is a main driver of energy consumption in oil-rich African countries.

Conversely, there is also evidence against the established hypothesis in the engaged literature. Such is apparent in studies that have found that energy consumption causes growth. These include: (i) Wolde-Rufael (2005) in Cameroon, Nigeria and Morroco; (ii) Wolde-Rufael (2006) for Tunisia, the Democratic Republic of Congo and Benin and (iii) Raheem and Yusuf (2015) with Senegal, Morocco and Algeria.

While the findings may be conflicting based on country-specific studies, the interest of using a panel data structure somehow helps to provide a broad or more general view. Hence, from a panel perspective, we might reasonably infer that the conservative hypothesis is broadly relevant. This is logical because African economies are not based on industrial activities.

Table 9: Strong causalities

	Statistics			
Causality directions	Wald	p-value	Fisher	p-value
EC→GDP	2.736432	0.2546	1.368216	0.2553
CE→GDP	12.45258***	0.0020	6.226288***	0.0021
EC,CE→GDP	12.46104***	0.0060	4.153681***	0.0063
GDP→EC	16.01086***	0.0003	8.005432***	0.0004
CE→EC	15.13461***	0.0005	7.567303***	0.0006
CE,GDP→EC	16.13689***	0.0011	5.378963***	0.0012
GDP→ CE	8.746027**	0.0329	2.915342**	0.0337
EC→ CE	29.64075***	0.0000	9.880250***	0.0000
GDP,EC→CE	34.64535***	0.0000	6.929070***	0.0000

Notes : *** and ** imply significance levels at the 1% and 5% levels, respectively. '→' refers to the direction of causality. GDP: Gross Domestic Product. EC: Energy Consumption. CE: CO_2 emissions.

3.4.3 Short-run causalities

The causal direction from EC to GDP remains unobservable in the short term. By contrast, the opposite path is observable. There are also no short-run causalities from GDP, or CE or CE and GDP to EC. Based on the findings, we can neither confirm nor reject the conservative hypothesis because whereas EC does not significantly cause GDP, the reverse path is not also significantly apparent. This scenario is broadly in accordance with engaged studies that have established evidence of no causality, especially within the framework of short-run Granger causality, namely: (i) Wolde-Rufael (2006) for South Africa, Kenya, Algeria and the Congo Republic from the angle of electricity consumption; (ii) Akinlo (2008) on the absence of causality evidence in Togo, Kenya, Nigeria, Cameroon and Côte d'Ivoire and (iii) Raheem and Yusuf (2015) on the confirmation of a neutrality hypothesis established for Zambia and Cameroon.

Table 10: Short-run causalities

	Statistics			
Causality directions	Wald	p-value	Fisher	p-value
EC→GDP	0.157933	0.6911	0.157933	0.6912
CE→GDP	8.659204***	0.0033	8.659204***	0.0034
EC,CE→GDP	8.677822**	0.0131	4.338911**	0.0134
GDP→EC	1.010588	0.3148	1.005280	0.3151
CE→EC	0.789217	0.3743	0.789217	0.3747
CE,GDP→EC	1.753318	0.4162	0.876659	0.4167
GDP→ CE	8.490847**	0.0143	4.245423**	0.0147
EC→ CE	28.68906***	0.0000	14.34453***	0.0000
GDP,EC→CE	33.87522***	0.0000	8.468806***	0.0000

Notes : *** and ** imply significance levels at the 1% and 5% levels, respectively. '→' refers to the direction of causality. GDP: Gross Domestic Product. EC: Energy Consumption. CE: CO_2 emissions.

4. Concluding implications and further directions

The study has complemented existing literature in two key areas, notably the need to: (i) engage panel studies by positioning lines of inquiry beyond the scope of country-specific literature and (ii) steer clear of substantially documented bivariate studies by modeling within a trivariate framework. To these ends, we have investigated the nexus between energy consumption (EC), CO_2 emissions (CE) and economic growth (GDP) in 24 African countries using a panel ARDL approach. The following findings have been established. First, there is a long run relationship between EC, CE and GDP. Second, a long term effect from CE to GDP and EC is apparent, with reciprocal paths. Third, the error correction mechanisms are consistently stable. However, in cases of disequilibrium only EC can be significantly adjusted to its long run relationship. Fourth, there is a long-run causality running from GDP and CE to EC. Fifth, we find causality running from either CE or both CE and EC to GDP and inverse causal paths are observable. Causality from EC to GDP is not strong, which supports the conservative hypothesis. Sixth, the causal direction from EC to GDP remains unobservable in the short term. Likewise, the opposite path isn't observable in the short term. There are also no short-run causalities from GDP, or CE or CE and GDP to EC.

Policy implications can be discussed along three main strands, notably on the: long-run relationships, feedbacks to restore the long term relationships in event of disequilibrium and the unsurprising absence of causality flowing from EC to GDP. First, the long run linkages imply that it would require policy to carefully tailor EC, CE and GDP in the post-2015 development agenda. However, the nexuses would have to be tailored so that, *inter alia*: (i) GDP is not compromised by CE, (ii) the responsiveness of CE to GDP is maintained at minimum, which would require, (iii) more dependence on renewable EC and less dependence on fossil fuels that are the main drivers of CE. Second, the evidence that in the presence of disequilibrium only EC can be significantly adjusted to restore the long term relationship implies the fundamentals of ECTs corresponding to GDP and CE need to be consolidated. Third, the unsurprising finding of no strong causality flowing from EC to GDP has at least a twofold implication, notably: (i) confirmation of the conservative hypothesis which we have engaged substantially in the preceding sections and (ii) an articulation of the energy crisis that most of the sampled countries are facing. The overall implication is that, African countries can substantially increase current GDP growth rates if access to energy is improved, especially (renewable energy).

The overwhelming evidence of causality flowing from one variable to another may not be exhaustive for drawing economic inferences. The scale and timing of shocks from one variable on the one hand and responses to shocks by corresponding variables on the other hand, may be required for more policy options. It would be interesting if further research devoted to improving the extant literature moves towards these directions.

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