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Income level and the energy consumption–GDP nexus: Evidence from Sub-Saharan Africa

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ABSTRACT

This study tests the relationship between energy consumption and economic growth in Sub-Saharan Africa, using a panel co-integration approach. Country-level time series data of energy consumption and economic growth are pooled and used to estimate the model. Sub-Saharan African countries in the sample are classified into low income and middle income countries. The findings support the neutrality hypothesis in the short-run, except for middle income countries, and a strong causation running in both directions is found in the long-run. The different results for low and middle income countries provide evidence of the importance of income level in the causal relationship. This study helps to explain the interdependence of energy consumption and economic growth in Sub-Saharan Africa. Results are critical in formulating sustainable development policies that are geared to the efficient allocation of resources which are expected to increase access to energy services in the study region.

1. Introduction

Most Sub-Saharan African (SSA) countries have been struggling with poverty and slow economic growth for years. Factors contributing to persistent poverty include war, deficient infrastructure, poor access to capital, governance, and insufficient institutional capacity (IMF, 2008). Sustained growth, job creation, and poverty alleviation have been priority development goals for SSA countries for the last two decades, but these goals can only be reached through implementation of broad-based socio-economic development policies that promote manufacturing and agricultural production, and health and education services delivery. Historically, achievement of these goals has occurred with a corresponding increase in energy use (Jakobsson, 2007), yet SSA countries have the lowest access to electricity in the world (Legros et al., 2009). Worldwide, 79% of the less developed countries' (LDCs) and 74% of SSA countries' population live without access to modern electricity, compared to 28% of all developing countries combined.[1] An International Energy Agency (IEA) study showing that energy consumption is positively related to wealth, while a lack thereof is correlated with people living on less than $2/day (IEA, 2004), provides support for the hypothesis that inadequate energy services impede SSA countries from achieving their development goals. Moreover, growing populations in both urban and rural areas, combined with rapid economic growth and rising incomes in some SSA countries, have exerted additional pressure on the already strained energy supply in the region. Therefore, unless measures are taken, energy poverty may continue to hamper economic development and poverty alleviation in the SSA region.

The energy sector in most parts of Africa is characterized by overdependence on traditional biomass and underdeveloped modern energy sectors. This state of affairs underscores the need for SSA countries to devise and implement policies aimed at increasing access to modern energy services. Africa is endowed with substantial renewable energy resources with 1100 MW of hydropower capacity, 9000 MW of geothermal potential (hot water and steam based), abundant biomass, and significant solar and wind potential (Karekezi and Ranja, 1997). In spite of massive exploitable hydropower capacity, its contribution to total power generation is relatively low, contributing only about 18% of the total power generated in Africa.

Energy plays a vital role in agriculture, manufacturing, education, trade, health, and communication. Therefore we hypothesize that increased energy consumption is a necessary condition for the growth and development of SSA economies. With support of international organizations, such as the UN, IMF, and IEA, many SSA countries have been promoting the use of renewable energy resources, such as hydro

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[1] Tables A1 and A2 in the Appendix present region and country specific information on access to electricity. They are taken from Legros et al. (2009).

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generation, geothermal, solar, and wind energy. The use of these renewable technologies has the advantage of increasing access to energy services while mitigating the effects of environmental damage. In addition, several SSA countries have undergone comprehensive energy reforms that have reduced the monopoly of state-run power companies.

Beginning with Kraft and Kraft's (1978) seminal work, economists have been intrigued by evidence that suggests a causal relationship between energy consumption and economic growth. For a comprehensive international survey of this relationship see Payne (2010a,b). Also, since the 1970s oil price shocks, economists have been interested in the relationship between energy prices and economic growth (e.g., Afrasiabi, 2008), fueled by the notion that energy prices directly affect spending decisions of households, firms, and the overall performance of the economy. There is little dispute in the literature that volatile world energy prices have significantly impacted the economic performance and achievement of development goals of SSA countries, but empirical studies of the causal relationship between energy consumption, energy prices, and economic growth have yielded mixed results. This can be attributed to a number of factors, including estimation techniques, choice of variables, study period, and level of development of the country being studied (Payne, 2010a,b).

Using a multivariate panel framework, this study examines the dynamic relationship between economic growth (GDP), energy consumption (BTU of energy), and Consumer Price Index (CPI)[2] for 40 SSA countries. We classify countries according to income level (level of development) based on the *World Development Indicators* (World Bank, 2009). In most multi-country studies, the level of income is ignored. To our knowledge, this is one of the first studies to account for countries' level of income in the relationship between energy consumption and economic growth. The recent work of Apergis and Payne (in press) is the only exception known to us. They studied 88 countries including 29 high-income, 23 upper-middle income, 25 lower-middle income, and 11 low-income countries. Their panel included 16 African countries and covered the period 1990–2006. By contrast, our panel consists of 40 Sub-Saharan African countries and covers the period 1980–2007.

Unlike previous studies (Akinlo, 2008; Jumbe, 2004; Odhiambo, 2009; Wolde-Rufael, 2006), but in common with Apergis and Payne (in press), we employ panel estimation techniques which have the ability to capture country-specific effects. Low, middle, and upper income countries are pooled together to create the sample. The panel approach has the advantage of providing more data points than a single time series. In addition, panel data increase the degrees of freedom and reduce the likelihood of collinearity among regressors (Apergis and Payne, 2009a,b; Levin et al., 2002). Separate equations for low income and middle income SSA countries are estimated to determine the short-run, long-run, and strong causality within a multivariate framework. We further employ dynamic panel estimation techniques which control for country-specific effects and thus overcome the problem of collinearity and endogeneity of explanatory variables.

In summary, this study contributes to the literature by testing whether or not the level of income makes a difference in the economic growth and energy consumption relationship within SSA countries. With the exception of Apergis and Payne (in press) and Lee (2005), to date, no attention has been paid to differences in income levels within developing countries. In most previous studies, comparisons are either between developed or developing countries (Mahadevan and Asafu-Adjaye, 2007) or developing and developed countries are pooled together (Sinha, 2009). Some studies also compare oil importing and exporting countries (Mahadevan and Asafu-Adjaye, 2007).

We limit the sample to African countries because of widespread perception that the African economies are structurally different from those in the rest of the world (Asiedu, 2006), and many African policymakers believe that lessons from other parts of the world do not apply to their countries. The difference in access to modern energy between developing countries in general and SSA countries (72% vs. 26%) provides evidence of structural differences between the study region and the rest of the world and also the rest of the developing world. Even within SSA countries, there are wide disparities in energy consumption between low income and middle income countries. The annual average growth rate of energy consumption in middle income SSA countries for the period of 1980–2007 is more than double that of low income countries (1.18% and 0.50% respectively, see Table 1 below).

The rest of the paper is organized as follows: Section 2 provides a review of the literature on the energy consumption–economic growth relationship. Sections 3 and 4 discuss the methodology and data sources, respectively. Finally, Section 5 provides results, conclusions, and policy recommendations.

2. Literature review

Research designed to test the causal relationships between energy consumption and economic growth is generally synthesized into four testable hypotheses (Apergis and Payne, 2009a,b). The first hypothesis states that energy consumption is a prerequisite for economic growth because energy is a direct input in the production process as well as an indirect input that complements labor and capital inputs (Ebohon, 1996; Templet, 1999; Toman and Jemelkova, 2003). Under this hypothesis, unidirectional Granger causality running from energy consumption to GDP entails that the country's economy is energy dependent; therefore, policies geared toward promoting energy consumption must be adopted in order to stimulate economic growth. In other words, inadequate provision of energy limits economic growth. Anecdotal evidence supports the theory that increased energy provision played an important role in the development process of industrialized countries (Rosenberg, 1998).

The second hypothesis is that causality runs from economic growth to energy consumption. If this hypothesis holds, the economy is less energy dependent and energy conservation policies, such as phasing out energy subsidies, will not adversely affect economic growth (EIA, 2002; Mehrara, 2007). Ferguson et al. (2000) find strong evidence that an increase in wealth is positively related to energy consumption. The third hypothesis assumes that there is no causality between energy consumption and economic growth (also known as the neutral hypothesis), and thus policies aimed at conserving energy will not harm economic growth (Asafu-Adjaye, 2000; Jumbe, 2004).

The fourth hypothesis, also known as the feedback hypothesis, assumes that there is a bidirectional relationship between energy consumption and economic growth. The implication of the bidirectional relationship is that energy consumption and economic growth are complementary. This means that an increase in energy consumption will stimulate economic growth, and conversely, an increase in economic growth will stimulate energy consumption.

Payne's (2010a) detailed survey of the literature on the causal relationship between energy consumption and economic growth

Table 1
Annual average growth rate of Sub-Saharan countries, 1980–2007.

Variables	All Sub-Saharan	Low income	Middle income
EC	0.74	0.50	1.18
GDP	3.46	3.14	4.06
CPI	12.93	13.95	11.03

[2] Even though energy prices would have been ideal, it is difficult to get comparable series for all countries and different types of energy. This is particularly evident in Sub-Saharan Africa, where traditional sources of energy and commercial energy are used side by side. Therefore, this study follows Mahadevan and Asafu-Adjaye (2007) and uses the Consumer Price Index (CPI) as a proxy for energy prices as it will capture the effect of energy prices on the economy.

finds no consensus regarding the direction of causality. Individual country studies surveyed show 29.2% of the results supporting the neutrality hypothesis, 28.2% the feedback hypothesis, 23.1% the growth hypothesis, and 19.5% support the conservation hypothesis. A survey of the empirical literature of electricity consumption and economic growth reveals similar results, with 31.15% supporting the neutrality hypothesis; 27.87% the conservation hypothesis; 22.95% the growth hypothesis; and 18.03% the feedback hypothesis (Payne, 2010b).

Prior research on the energy consumption–economic growth relationship for SSA countries includes Akinlo (2008), Jumbe (2004), Odhiambo (2009), and Wolde-Rufael (2006). Using Granger causality tests within a trivariate framework, Odhiambo (2009) examines the causal relationship between electricity consumption and economic growth in South Africa over the period 1971–2006 and finds bidirectional causality. Odhiambo's work also reveals a unidirectional causality running from employment growth to economic growth. Jumbe (2004) analyzed the causal relationship between electricity consumption and economic growth in Malawi and the results parallel Odhiambo's findings of a bidirectional relationship. The Wolde-Rufael (2006) study investigates 17 Sub-Saharan African countries and obtains mixed results: a positive unidirectional causality running from economic growth (GDP) to electricity consumption in six countries, bidirectional causality between energy consumption and economic growth in three countries, and a unidirectional causality running from energy consumption to economic growth in another three countries. Akinlo (2008) explores the causal relationship between energy consumption and economic growth for eleven Sub-Saharan African countries. Based on a vector error correction model, the test results reveal a bidirectional relationship in three countries, unidirectional causality running from economic growth to energy consumption in two countries, and support for the neutral hypothesis in five countries.

Other studies of the causal relationship between energy prices and macroeconomic performance (Burbidge and Harrison, 1984; Hamilton, 1983) find a statistically significant negative relationship between energy prices and GNP growth in five OECD member countries, suggesting that an increase in energy prices negatively affects energy consumption and economic activity. Mork (1989) and Mork et al. (1994) provide evidence of asymmetric oil price impacts; an increase in oil prices negatively affects GNP growth, but a decrease has no discernable effect. Hondroyiannis et al. (2002) analyze the link between energy consumption, GDP, and CPI for Greece. Their results show evidence of long-term bidirectional causality between energy consumption and GDP.

Past studies contribute to our understanding of the relationship between energy consumption and economic growth, but they are inconclusive regarding the direction of causality. Sample selection may be a major reason for the inconclusive results. As mentioned above, differences in income levels within developing countries have received scant attention. Lee's study estimates a trivariate relationship of energy consumption, economic growth, and gross capital formation in 18 developing countries, but his data include only two low income SSA countries (Kenya and Ghana). Similarly, the geographic and economic focus of the related work of Apergis and Payne (in press) is much wider than that of our study. Therefore, the present study adds to the scarce literature on the effect of the level of income on economic growth and energy consumption.

3. Methodology

A number of previous studies have examined the relationship between energy consumption and economic growth in SSA using country-level data and time-series techniques. Here we employ panel estimation techniques to determine the dynamic relationship between energy consumption and economic growth (GDP). To account for price effects in the process of this dynamic relationship, a price equation is included in estimating the causal relationship. The methodology adopted in this study uses a three-step procedure. First, panel unit root tests are employed to test the degree of integration between GDP, prices, and energy consumption. Second, panel cointegration techniques (Pedroni, 1999) are used to determine the long-run relationship between GDP, prices, and energy consumption. Finally, a dynamic panel error correction model is applied to determine the direction of causation in the short-run and long-run.

3.1. Panel unit root tests

Panel unit root tests have been suggested as an alternative for examining the causal relationship between energy consumption, prices, and economic growth in a panel framework. This method is becoming more popular because the asymptotic distribution is standard normal (Baltagi, 2004). We test for unit roots using three panel-based methods proposed by Levin et al. (2002), hereafter referred to as LLC, Im et al. (2003), hereafter referred to as IPS, and Hadri (2000). For each estimation technique, we test for unit roots in the panel using two types of models.[3] The first model involves estimating the variables in level form with and without a deterministic trend, while the second model involves estimating the first difference of the variables with and without a deterministic trend. The LLC test is the most widely used panel unit root test and can be specified as follows:

$$\Delta Y_{it} + \alpha_i + \delta_i Y_{it-1} + \sum\nolimits_{j=1}^{n} \rho_i \Delta Y_{it-1} + e_{it} \quad (1)$$

Δ is the first difference operator, Y_{it} is the series of observations for country i for $t=1,\ldots,T$ time periods. The panel unit root test has the following null hypothesis $H_0: \delta_i = \delta = 0$ for all i, against the alternative of $H_1: \delta_i = \delta < 0$ for all i, which presumes that all series are stationary. LLC assumes that δ is homogenous across regions and the test is based on the t-bar statistic.

The IPS test is an extension of the LLC test and based on the mean of the individual unit root statistic of the same model as used in the LLC test. Unlike the LLC test, the IPS test allows for heterogeneity in the value of δ under the alternative hypothesis. The Hadri test is an LM-based test which assumes, under the null hypothesis, that all the series in the panel are stationary.

3.2. Panel cointegration

The second step of our empirical work involves investigating the long-run relationship between energy consumption, CPI, and GDP, using Pedroni's (1999) panel cointegration technique. This technique allows for heterogeneity among individual members of the panel and is thus an improvement over conventional cointegration tests. Following Pedroni, the estimated cointegration relationship is specified as follows:

$$LGDP_{it} = \alpha_{it} + \delta_i t + \beta_1 LEC_{it} + \beta_2 LCPI_{it} + \varepsilon_{it}. \quad (2)$$

LGDP, *LEC*, and *LCPI* are the observable variables of gross domestic product per capita, energy consumption per capita, and CPI, respectively (all in log form); $t=1,\ldots,T$ are time periods; $i=1,\ldots,N$ are panel members; α_i denote country-specific effects, δ_t is the deterministic time trend, and ε_{it} is the estimated residual.

The estimated residual indicates the deviation from the long-run relationship. With the null hypothesis of no cointegration, the panel cointegration is essentially a test of unit roots in the estimated residuals of the panel. Pedroni (1999) shows that there are seven different statistics for the cointegration test. They are the panel v-statistic, panel ρ-statistic, Pedroni Panel (PP)-statistic, panel Augmented Dickey–Fuller (ADF)-statistic, group *rho*-statistic, group PP-statistic, and group ADF-

[3] For a detailed discussion on panel unit root tests, see Levin et al. (2002), Hadri (2000), and Im et al. (2003).

statistic. The first four statistics are known as panel cointegration statistics and are based on the within dimension approach. The last three statistics are group panel cointegration statistics and are based on the between dimension approach. In the presence of a cointegrating relationship, the residuals are expected to be stationary. The panel v-test is a one-sided test, with the null of no cointegration being rejected when the test has a large positive value. The other tests reject the null hypothesis of no cointegration when they have large negative statistics.

3.3. Panel Granger causality tests

Cointegration of the three variables (*GDP*, *CPI*, and *EC*) implies that causality exists between the three series, but does not indicate the direction of causality. To test for Granger causality in the long-run relationship, we employ a two-step process that first estimates the residuals from the long-run model (Eq. 2), and in the second step fits the estimated residuals as a right-hand variable in a dynamic error correction model. The dynamic error correction model is specified as follows:

$$\begin{aligned}\Delta LGDP_i &= \alpha_1 + \beta_1 ECT_{t-1} + \beta_2 \Delta LGDP_{t-1} + \beta_3 \Delta LGDP_{t-2} \\ &\quad + \beta_4 \Delta LEC_{t-1} + \beta_5 \Delta LEC_{t-2} + \beta_6 \Delta LCPI_{t-1} \\ &\quad + \beta_7 \Delta LCPI_{t-2} + \varepsilon_1\end{aligned} \tag{3}$$

$$\begin{aligned}\Delta LEC_i &= \alpha_2 + \delta_1 ECT_{t-1} + \delta_2 \Delta LGDP_{t-1} + \delta_3 \Delta LGDP_{t-2} + \delta_4 \Delta LEC_{t-1} \\ &\quad + \delta_5 \Delta LEC_{t-2} + \delta_6 \Delta LCPI_{t-1} + \delta_7 \Delta LCPI_{t-2} + \varepsilon_2\end{aligned} \tag{4}$$

$$\begin{aligned}\Delta LCPI_i &= \alpha_3 + \gamma_1 ECT_{t-1} + \gamma_2 \Delta LGDP_{t-1} + \gamma_3 \Delta LGDP_{t-2} \\ &\quad + \gamma_4 \Delta LEC_{t-1} + \gamma_5 \Delta LEC_{t-2} + \gamma_6 \Delta LCPI_{t-1} \\ &\quad + \gamma_7 \Delta LCPI_{t-2} + \varepsilon_3.\end{aligned} \tag{5}$$

Δ denotes the difference operator; *ECT* is the lagged error correction term derived from the long-run cointegrating relationship; β_1, δ_1, and γ_1 are adjustment coefficients; and ε_1, ε_2, and ε_3 are disturbance terms.

We can identify the sources of causation by testing for the significance of the coefficients on the lagged dependent variables in Eqs. (3), (4), and (5). To evaluate weak Granger causality (short-run), we first test $H_0: \beta_4 = \beta_5 = \beta_6 = \beta_7 = 0$ for all i in Eq. (3), $H_0: \delta_2 = \delta_3 = \delta_6 = \delta_7 = 0$ for all i in Eq. (4), and $H_0: \gamma_2 = \gamma_3 = \gamma_4 = \gamma_5 = 0$ in Eq. (5). Masih and Masih (1996) interpret weak Granger causality as the short-run causality in the sense that the dependent variable responds only to the short-term shocks to the stochastic environment. On the other hand, long-run causality can be tested by looking at the significance of the coefficient of the error correction term in Eqs. (3), (4), and (5). In each equation, a change in the endogenous variable is caused not only by its lags, but also by the previous period's disequilibrium level.

The coefficients on *ECT* represent how fast deviations from the long-run equilibrium are eliminated following changes in each variable. The significance of β_1, δ_1, and γ_1 indicates the long-run relationship of the cointegrated process; hence movements along this path are considered permanent. To examine the long-run causality relationship, we test $H_0: \beta_1 = 0$ for all i in Eq. (3), $H_0: \delta_1 = 0$ for all i in Eq. (4), and $H_0: \gamma_1 = 0$ for all i in Eq. (5).

If $\beta_1 = \delta_1 = \gamma_1 = 0$ for all i then there is no Granger causality in the long-run. The sources of causation will be determined by testing the joint hypothesis of $H_0: \beta_1 = \beta_4 = \beta_5 = \beta_6 = \beta_7 = 0$ for all i in Eq. (3), $H_0: \delta_1 = \delta_2 = \delta_3 = \delta_6 = \delta_7 = 0$ for all i in Eq. (4), and $H_0: \gamma_1 = \gamma_2 = \gamma_3 = \gamma_4 = \gamma_5 = 0$ for all i in Eq. (5). This test is referred to as the strong Granger causality test and is used for determining the variables which bear the burden of short-run adjustment to re-establish long-run equilibrium, following a shock to the system (Asafu-Adjaye, 2000). A result of no causality in either direction indicates that the variables have a neutral effect on each other.

The methodologies reviewed above will be applied to test whether the level of income matters in the energy consumption and economic growth relationship. Separate equations for low income and middle income SSA countries will be estimated to determine the short-run, long-run, and strong causality discussed above.

Table 2
Annual average growth rate, 1980–2007.

Lower income countries				Middle income countries			
Country	*EC*	*GDP*	*CPI*	Country	*EC*	*GDP*	*CPI*
Benin	4.10	3.31	3.95	Cameroon	−0.32	2.67	5.03
Burkina Faso	1.64	4.66	3.60	Cape Verde	−2.66	6.69	6.71
Burundi	2.92	2.26	10.25	Congo, Brazzaville	0.32	3.72	3.27
Central African Republic	0.36	1.94	3.78	Cote d'Ivoire	−0.99	1.52	4.78
Chad	−3.32	5.42	3.57	Lesotho	3.05	4.92	10.64
Comoros	1.42	2.73	3.68	Nigeria	0.60	4.07	21.01
Ethiopia	2.01	4.18	5.86	Sao Tome and Principe	1.91	2.30	23.29
Gambia	−0.87	3.32	9.88	Sudan	2.33	4.49	40.86
Ghana	−1.19	3.91	29.47	Swaziland	−0.52	5.09	10.34
Guinea	−1.03	3.00	18.32	Botswana	4.10	3.31	3.95
Guinea-Bissau	2.95	1.31	31.06	Gabon	−1.04	2.32	4.20
Kenya	0.21	3.47	12.33	Mauritius	4.42	7.01	7.78
Madagascar	0.62	2.16	15.27	Seychelles	4.62	5.27	2.52
Malawi	0.50	3.04	20.96	South Africa	0.68	3.47	10.05
Mali	−0.55	4.27	3.27				
Mauritania	3.40	3.71	6.96				
Mozambique	−1.89	5.48	28.57				
Niger	−0.80	1.45	3.37				
Rwanda	2.83	3.65	9.40				
Senegal	0.41	3.44	4.24				
Sierra Leone	−0.31	1.07	36.98				
Tanzania	1.02	4.21	19.42				
Togo	2.11	1.46	4.21				
Uganda	0.56	5.13	39.06				
Zambia	−2.81	1.76	42.59				
Zimbabwe	−1.22	1.23	−7.42				

4. Data

Data used in this study are pooled annual time series for gross domestic product per capita (*GDP*), *CPI* as a proxy for prices, and energy consumption per capita (*EC*) for 40 Sub-Saharan African countries for the period 1980 to 2007. BTU of energy is used as a proxy for energy consumption (*EC*); this data is obtained from the Energy Information Administration (EIA) of U.S. Department of Energy. Gross domestic product (*GDP*) per capita and *CPI* data come from the IMF, World Economic Outlook (2009). The length of the period is dictated by the availability of a consistent time series data for all the countries. Seven Sub-Saharan countries (Angola, Democratic Republic of Congo, Djibouti, Eritrea, Liberia, Namibia, and Somalia) are dropped from the study due to a lack of consistent time series data.

Table 3
Panel unit root results for *LGDP*, *LEC* and *LCPI*, 1980–2007.

Variable	IPS test		LLC test		Hadri test	
	No trend	Trend	No trend	Trend	No trend	Trend
LGDP	9.393	2.791	2.004	2.889	20.638[a]	10.855[a]
LEC	0.232	0.608	−0.989	0.351	12.343[a]	14.379[a]
LCPI	0.851	1.817	−6.928[a]	0.319	19.882[a]	14.250[a]
ΔLGDP	−13.267[a]	−11.758[a]	−8.254[a]	−7.579[a]	3.518[a]	8.647[a]
ΔLEC	−18.909[a]	−17.300[a]	−15.193[a]	−12.789[a]	7.575[a]	9.929[a]
ΔLCPI	−8.050[a]	−6.566[a]	−7.007[a]	−7.190[a]	9.850[a]	8.834[a]

[a] Indicate rejection of the null hypothesis at the 1% significance level.

Table 4
Panel co-integration panel results for *LGDP*, *LEC* and *LP*, 1980–2007.

Statistic	All countries		Low income		Middle income	
	Intercept and no time trend	Intercept and time trend	Intercept and no time trend	Intercept and time trend	Intercept and no time trend	Intercept and time trend
Panel v-stat	2.347[a]	−1.744	1.995[b]	−1.577	1.207	−0.685
Panel Rho-stat	−3.570[a]	−0.403	−2.872[a]	−0.050	−2.123[b]	−0.797
Panel PP-stat	−6.458[a]	−5.454[a]	−5.576[a]	−4.707[a]	−3.23[a]	−2.809[a]
Panel ADF-stat	−6.388[a]	−5.602[a]	−5.500[a]	−4.813[a]	−3.23[a]	−2.812[a]
Group Rho-stat	−1.636[c]	0.966	−1.432[c]	0.723	−0.813	0.647
Group PP-stat	−6.809[a]	−6.132[a]	−5.991[a]	−5.590[a]	−3.345[a]	−2.747[a]
Group ADF-stat	−7.539[a]	−6.742[a]	−6.816[a]	−6.259[a]	−3.346[a]	−2.866[a]
Panel v-stat	2.347[a]	−1.744	1.995[b]	−1.577	1.207	−0.685

[a] Indicates significance at 1% level.
[b] Indicates significance at 5% level.
[c] Indicates significance at 10% level.

The World Bank uses gross national income (GNI) per capita as the main economic criteria to classify countries as low, middle, and upper income countries. The current classification uses 2008 GNI per capita calculated using the Atlas method (World Bank, 2010). The groups are: low income, \$975 or less; middle income, \$975–\$11,905 (subdivided into lower middle income, \$975–\$3855 and upper middle income \$3856–\$11,905); and high income countries, \$11,906 or more. In this study, there are 26 countries classified as low income and 14 countries classified as middle income countries (9 lower middle income and 5 upper middle income).

Table 1 presents the average annual growth rates of the three variables used in the study. Middle income countries perform relatively better than the rest of the region. They have a higher level of growth in energy consumption and *GDP* and a somewhat lower level of inflation. In this group, Mauritius, with an average economic growth of 7.01%, has the best performance, while Ivory Coast at 1.52% has the slowest growth rate. Mozambique leads the low income countries with a 5.48% average growth rate, while Sierra Leone, with 1.02%, brings up the end. Table 2 presents the average annual growth rates from 1980 to 2007 of *GDP*, *EC*, and *CPI* by country.

Table 5
Fully modified OLS estimates.

Country	EC	CPI	Country	EC	CPI
Benin	0.599[a]	0.242	Malawi	0.335	0.185[a]
Botswana	0.385[b]	0.812[a]	Mali	1.104[a]	1.458[a]
Burkina Faso	0.516[c]	1.153[b]	Mauritania	0.009	0.859[a]
Burundi	0.47[a]	0.073[c]	Mauritius	0.477[a]	0.712[a]
Cameroon	0.488	0.678[a]	Mozambique	0.303[a]	0.224[a]
Cape Verde	0.424[a]	1.203[a]	Niger	0.863[a]	0.762[a]
Central African Republic	0.972[a]	0.39[b]	Nigeria	1.298[c]	0.098
Chad	0.611[b]	2.1[a]	Rwanda	0.549	0.307[a]
Comoros	0.464[a]	0.729[a]	Sao Tome and Principe	−0.099	0.188[a]
Congo (Brazzaville)	0.961[a]	1.121[a]	Senegal	0.772[a]	0.589[c]
Ivory Coast	−0.048	0.933[a]	Seychelles	0.477[c]	1.539[b]
Ethiopia	0.661[a]	0.649[a]	Sierra Leone	1.583[a]	−0.027
Gabon	0.499[b]	0.997[a]	South Africa	1.656[a]	0.099
Gambia	1.720[a]	0.162[b]	Sudan	0.652[a]	0.08[a]
Ghana	0.372[a]	0.227	Swaziland	−0.303[c]	0.839[a]
Guinea	1.493[b]	0.164[c]	Tanzania	0.958[a]	0.189[a]
Guinea–Bissau	0.169	0.091[a]	Togo	0.203	0.763[a]
Kenya	0.586[b]	0.305[a]	Uganda	1.753[a]	−0.032
Lesotho	0.101[b]	0.579[a]	Zambia	1.421[a]	0.103[a]
Madagascar	0.221[b]	0.257[a]	Zimbabwe	2.01[a]	−0.162[c]
Panel (with time dummies)	0.212[a]	−0.015[a]			

[a] Significant at 1%.
[b] Significant at 5%.
[c] Significant at 10%.

5. Empirical results

5.1. Panel unit root results

The results of the IPS, LLC and Hadri panel unit root tests for the series *LGDP*, *LEC*, and *LCPI* are shown in Table 3. The unit root statistics reported are for the level and first differenced series of these variables. For the variables in level form, the null hypothesis of a unit root cannot be rejected for the IPS and LLC tests, while the Hadri test rejects the null hypothesis at the 1% significance level for all three variables. When taking the first difference, all three tests reject the null hypothesis at the 1% level for the variables in level form. These results are similar to the IPS test results of Mahadevan and Asafu-Adjaye (2007) and Lee (2005). In both studies, the first difference gives conclusive evidence of a panel unit root. Therefore, we conclude that all the series are nonstationary and integrated of order one.

5.2. Panel cointegration results

Table 4 reports the within and between dimension results of the panel cointegration tests. The tests reject the null hypothesis of no cointegration at the 1% significance level and thus conclude that *GDP*, *CPI*, and *EC* move together in the long-run.

We also estimated the long run Eq. (2) for each country using FMOLS to check the long-run cointegrating relationship. As shown in Table 5, both coefficients are statistically significant at the 1% level. Since all variables are expressed in natural logarithms, the coefficients can be interpreted as elasticity estimates. They indicate that a 1% increase in energy usage increases real *GDP* by 0.21%, and that a 1% increase in *CPI* decreases *GDP* by 0.015%.[4]

Table 5 also reports the results of the estimation of individual FMOLS for the cointegrating relationship. Except for eight countries for *EC* and six countries for *CPI*, the estimates for all other countries show a significant long run relationship with *GDP*. Within the group of countries with significant relationships, Zimbabwe has the highest elasticity of energy consumption (2.01) and the Seychelles has the highest elasticity for prices.

[4] Although the result indicates that a 1% increase in the CPI caused by an increase in energy prices decreases GDP by 0.015%, we cannot conclude that this is the elasticity of GDP with respect to energy prices, since the GDP incorporates the primary effect of energy price changes as well as secondary effects via other consumption goods.

Table 6
Results of panel causality tests for all SSA, low, and middle income countries.

Dependent variable	Sources of causation						
	Short-run			Long-run	Test for short-run and long-run causality (strong causality)		
	ΔLGDP	ΔLEC	ΔLCPI	ECT(−1)	ΔLGDP, ECT(−1)	ΔLEC, ECT(−1)	ΔLCPI, ECT(−1)
All SSA countries							
ΔLGDP	–	2.28 [0.034][a]	0.18 [−0.0004]	28.3[b](−)	–	11.01[b]	9.55[b]
ΔLEC	0.83 [0.15]	–	0.61 [−0.04]	19.49[b](+)	8.46[b]	–	6.99[b]
ΔLCPI	2.59[c] [−0.214][a]	0.85 [−0.01]	–	0.97(+)	1.82	0.86	–
Low income							
ΔLGDP	–	1.57 [0.04][c]	0.04 [−0.003]	8.98[b](−)	–	4.06[b]	3.02[a]
ΔLEC	0.64 [0.16]	–	0.39 [−0.03]	20.32[b](−)	9.7[b]	–	7.13[b]
ΔLCPI	1.82 [−0.23]	0.47 [−0.01]	–	0.57(−)	1.23	0.48	–
Middle income							
ΔLGDP	–	1.35 [0.04]	2.47[c] [0.008]	23.98[b](−)	–	9.05[b]	9.88[b]
ΔLEC	3.31[a] [−0.015]	–	0.14 [−0.04]	1.89(−)	2.72[a]	–	0.8
ΔLCPI	0.58 [−0.14]	0.31 [−0.03]	–	0.003(−)	0.40	0.20	–

Notes: F-statistics for short-run, long-run, and strong causality tests. The sums of lagged coefficients for the short-run cases are denoted in brackets.
[a] Indicates significance at 5% level in all cases.
[b] Indicates significance at 1% level in all cases.
[c] Indicates significance at 10% level in all cases.

The implication of the estimation results of the two cointegration tests is that there is a long-run relationship between *GDP*, *CPI*, and energy consumption for a cross section of the countries. Having determined that the three variables have a long-run relationship, or are cointegrated, we perform the Granger causality tests by employing the panel error correction model (ECM).

5.3. Granger causality results

Table 6 summarizes the causality estimates for all SSA countries, and separately for low and for middle income SSA countries, respectively. The optimal lag structure is set to two and the significance of the causality tests is determined by the Wald F-test. For the panel of 40 SSA countries, there is no short-run relationship running from energy consumption to economic growth (*GDP*) or from *GDP* to energy consumption. Based on the negative coefficient of *GDP* in the price equation, we conclude that there is a short-run transitory relationship running from *GDP* to the *CPI*. With the exception of the *CPI* equation, the coefficient of the error correction term in the *GDP* and energy consumption equations is significant. This provides evidence of a long-run permanent relationship between *GDP* and energy consumption for the panel of countries in this study. The strong causality test (joint short-run and long-run) also supports the existence of a strong bidirectional relationship between energy consumption and economic growth.

Table 6 shows that the results for the low income countries are not different from the results of all SSA countries, except that *GDP* is not significant in the *CPI* equation. In the short-run, there is no causation running in any direction. The long-run and strong causality tests confirm the strong interdependence between energy consumption and economic growth for low income countries. In the price equation, none of the lagged explanatory variables is significant. The consumer price index (*CPI*) is not affected by energy consumption[5] and economic growth in both the short-run and the long-run.

For middle income countries, the relationship between energy consumption and economic growth is somewhat different from that of the low income SSA countries. Table 6 shows unidirectional causality running from *GDP* to energy consumption and from prices (*CPI*) to *GDP* in the short-run. Further, the results reveal that a change in *GDP* responds to deviations from the long-run equilibrium in the previous period. The significance of the error correction in the *GDP* equation implies that there is a long-run permanent relationship between *GDP*, energy consumption, and price (*CPI*), but the same is not true for energy consumption and *CPI*. In both cases, the error correction term is not significant. With regard to the strong causality test, we find a bidirectional relationship between energy consumption and economic growth and unidirectional Granger causality from prices to economic growth.

These results imply that as the level of income increases the demand for energy simultaneously increases. An increase in *GDP* can affect energy consumption in several ways. At the household level, it can encourage households to spend the extra income on additional energy services. *GDP* growth can also induce higher demand for energy inputs in the production system. As *GDP* increases, the distribution of energy services can expand to remote areas and this can subsequently increase energy consumption in the country. The lack of a long-run causality running from *GDP* to energy consumption implies that for middle income countries *GDP* has a neutral effect in the long-run.

In general, the findings support the neutrality hypothesis in the short-run, except for middle income countries, but support the bidirectional interdependence of energy consumption and economic growth in Sub-Saharan Africa in the long run. The results obtained for low income countries in this study are different from those of Nondo et al. (2010). For low income Common Market for Eastern and Southern Africa (COMESA) countries, they find causation running from energy consumption to *GDP* in the short-run. In almost all empirical estimations, prices are not affected by the level of energy consumption and economic growth. This is because SSA is not a significant player in the global economy and thus does not possess the power to influence prices. Notably, most SSA countries are net importers and their domestic prices are highly influenced by the global market.

6. Conclusions and policy recommendations

This study tests for Granger causality between energy consumption, price level (*CPI*), and *GDP* for 40 SSA countries. For a panel of 40 SSA and a subset of low income countries, we find that energy consumption and economic growth have a neutral short-run effect on each other. The results also reveal a short-run transitory relationship running from *GDP* to prices for all SSA countries. The results also provide evidence of a long-run permanent relationship between *GDP*

[5] This is plausible since energy prices are set in the world market and the individual countries' consumption is small relative to total demand.

and energy consumption and bidirectional causality between energy consumption and *GDP*.

The panel estimation did not provide evidence of a long-run relationship between *GDP* and energy consumption for middle income countries, but only evidence of short-run and strong causality. However, the strong causality test shows bidirectional causality between *GDP* and energy consumption, and a unidirectional Granger causality from *CPI* to *GDP*. With the exception of middle income countries, we find that the *CPI* is exogenous to energy consumption and economic growth. In terms of strong causation, we find unidirectional Granger causality from *CPI* to *GDP* for the panel of 40 SSA countries as well as for the subset of low and middle income countries. There is also a strong unidirectional Granger causality from prices to energy consumption for the panel of 40 SSA and low income countries. This suggests that high price levels which in many cases are related to high energy prices may impede development goals for SSA countries, particularly in countries that are net oil importers.

Overall, the different results for low and middle income countries among SSA countries provide evidence for the hypothesis that the level of income matters in the causal relationship between energy consumption and economic growth and suggest that economic growth and energy consumption are an integral part of the development process. This relationship seems to be consistent with the development stage of SSA countries. Therefore, regional policy measures that ignore this fact are unlikely to lead to effective solutions for energy poverty. The low levels of development for a majority of SSA reflect the importance of energy supplies for the development process.

Energy policies in the region should focus on minimizing the dependence on volatile energy markets to guarantee sustainable development and, therefore, greater regional energy self-sufficiency should be one of the objectives of SSA countries. They have significant solar, wind, hydro-electric, and geothermal potentials, which, together with proven oil and gas reserves, can be tapped to reliably supply energy to the region and improve the energy supply, in general. The lack of adequate financial, physical, and human capital is an obstacle, if countries pursue energy-related policies individually. But the prospects are brighter, if SSA countries harmonize and coordinate energy policies within the context of regional economic integration.

Regional economic communities are expected to promote unity, enhance sustainable development, increase competitiveness, and integrate African countries into the global economy. All SSA countries are members of the African Economic Community (AEC) and one or more sub-continental organizations such as the Economic Community of West African States (ECOWAS), Economic Community of Central African States (ECCAS), Southern African Development Community (SADC), East African Community (EAC), and Common Market for East and Southern Africa (COMESA). These organizations can provide forums to be used for coordinating policies toward sustainable economic development and regional energy integration.

Appendix A

Table A1
Access to electricity in the world, 2008.
Source: Legros et al. (2009).

	Total population (mil)	Electrification rate (%)	Total population without electricity (mil)
World	6692	78.2	1456
OECD and transition economies	1507	99.8	3
Developing countries	5185	72	1453
LDCs	824	21	635
Sub-Saharan Africa	777	26	561

Table A2
Electricity access of Sub-Saharan Africa by country.
Source: Legros et al. (2009).

Country	% of population with electricity access		
	National	Urban	Rural
Angola	26.2	10.7	38
Benin	24.8	8.5	48
Botswana	45.4	12	68
Burkina Faso	10	6.3	25
Burundi	2.8	0.1	25.6
Cameroon	29.4	9	45
Cape Verde	70.4	44.9	87.5
Central African Rep.	5.1	0.3	14.7
Chad	3.5	0.3	16.4
Comoros	40.1	–	–
Congo	30	15	39.5
Congo (DR)	11.1	25	4
Côte d'Ivoire	47.3	18	78
Djibouti	49.7	10.2	56.9
Equatorial Guinea	27	6.2	71.2
Eritrea	32	5	86
Ethiopia	15.3	2	80
Gabon	36.7	18	40
Gambia	8.3	2.8	45.9
Ghana	54	23	85
Guinea	20.2	2.8	63.8
Guinea-Bissau	11.5	<1	30.7
Kenya	15	5	51.3
Lesotho	16	6	44
Liberia	3.3	1	7
Madagascar	19	5	53
Malawi	9	5.3	25
Mali	17.4	3.7	48.7
Mauritania	30.1	2	47
Mauritius	99.4	99	100
Mozambique	11.7	6.3	21
Namibia	34	13	70
Niger	9.3	1.5	47.2
Nigeria	46.8	26	69
Rwanda	4.8	1.3	25.1
Sao Tome and Principe	48.5	33.7	61.6
Senegal	42	18	74.7
Seychelles	96	–	–
Sierra Leone	5.1	0.1	12.7
South Africa	75	55	88
Sudan	31.4	19	47.5
Swaziland	29.7	20.2	65.2
Tanzania	11.5	2	39
Togo	20	4	42
Uganda	9	4	42.5
Zambia	18.8	3.3	47
Zimbabwe	41.5	19	79

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