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Energy Consumption and Economic Growth Revisited in African Countries

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Abstract

The aim of this paper is to provide new empirical evidence on the relationship between energy consumption and economic growth for 21 African countries over the period from 1970 to 2006, using recently developed panel cointegration and causality tests. The countries are divided into two groups: net energy importers and net energy exporters. It is found that there exists a long-run equilibrium relationship between energy consumption, real GDP, prices, labor and capital for each group of countries as well as for the whole set of countries. This result is robust to possible cross-country dependence and still holds when allowing for multiple endogenous structural breaks, which can differ among countries. Furthermore, we find that decreasing energy consumption decreases growth and vice versa, and that increasing energy consumption increases growth, and vice versa, and that this applies for both energy exporters and importers. Finally, there is a marked difference in the cointegration relationship when country groups are considered.

JEL-Code: C230, O400, Q430.

Keywords: Africa, energy consumption, economic growth, panel cointegration, panel causality.

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1. Introduction

Although 14.1 percent of the world's total population lives in Africa, the continent consumes only 4.2 percent of world delivered energy for industrial uses in 2007 (International Energy Agency - IEA, 2010). According to the prediction of the IEA, Africa's total industrial energy use and the demand for electricity grow at an average annual rate of 1.4 and 2.6 percent, respectively, whilst the sub-Saharan Africa region grows by an average of 3.6 percent per year. In Africa, natural gas consumption has grown substantially in recent years, stimulated by increased economic activity, large investments in new infrastructure, and domestic price subsidies.

Since the Earth Summit of Rio de Janeiro in 1992 and the Kyoto Protocol in 1997, which state that environmental degradation and climate changes are related to fossil energy consumption, some experts suggest a lowering of the world energy use. Developed countries fear a reduction in their lifestyle due to lower energy consumption, while developing countries, namely those emerging ones perceive this as a brake on growth.

Economic growth is among the most important factors to be considered in projecting changes in world energy consumption. In this regard, the analysis of the relationship between energy consumption and economic growth has received a great deal of attention during last years. Indeed, whether the economic growth promotes energy consumption or whether energy itself is a stimulus for economic growth has motivated interest among economists and policy-makers. Over the two last decades, there has been a large body of published research investigating the causality links between energy consumption and economic growth. This is because the direction of causality has significant policy implications. For instance, if energy consumption is a vital component in economic growth, energy conservation policies which reduce energy consumption may adversely affect real GDP. However, a unidirectional causality running from economic growth to energy consumption signifies a less energy dependent economy such that energy conservation policies may be implemented with little or no adverse effect on economic growth.

Recent empirical studies on the relationship between energy consumption and economic growth in African countries failed to reach a consensus as to the direction of causation. Most of these studies have mainly used time series approaches (*e.g.* Wolde-Rufael, 2005, 2006; Odhiambo, 2009, 2010; Belloumi, 2009; Ouedraogo, 2010). However, one problem with the results for individual countries studies is that they are often impaired by a short data span that lowers the power of the unit root and cointegration tests. Time series analyses also have the drawback to occult structural breaks.[1] It is well-known that erroneously omitted breaks can cause deceptive in time series testing and the effects of structural breaks do not disappear simply because one uses panel data. Lack of careful investigation of these potential structural breaks may thus lead to misspecification of the long-run properties of a dynamical system and inadequate estimation and testing procedures (see for example Lee and Chiu, 2011; Esso, 2010; Narayan and Smith, 2008; 2009). Indeed, the occurrence of certain events such as economic crisis, energetic crisis, and structural adjustment could have affected the trend behaviour of the energy consumption and real GDP. Unfortunately, the existing literature on the relationship between energy consumption and economic growth in Africa using panel cointegration ignored this aspect. This paper tries to fill this gap.

[1] Gregory et al. (1994) show that, the power of conventional cointegration tests falls sharply when cointegrating relationships are subject to structural changes.

The contributions of this study are fourfold. First, we employ recently developed panel methods to test for unit roots, cointegration and Granger causality. Specifically, we employ Westerlund (2007) panel cointegration tests which do not impose common factor restriction and solve on the problems of Pedroni's (1999) residual-based tests, being also robust to possible cross-country dependence. We also make use of Westerlund (2006) panel cointegration allowing for multiple endogenous structural breaks, which can differ among series. This last test generalizes Im et al. (2005) and assumes that the individual series are not cross-correlated. However, given that this is an overly restrictive assumption in macroeconomics, we draw our empirical conclusions using bootstrap-based critical values. This method allows us to solve another problem of Pedroni's (1999) cointegration test that cannot accommodate structural breaks.

To the best of our knowledge, such an analysis has not been performed to study the relationship between energy consumption and economic growth in African countries. Adoption of such new panel data methods within the macropanel setting is preferred to the usual time series techniques to circumvent the well-known problems associated with the low power of traditional unit root and cointegration tests in small sample sizes (as it is the case here with just over thirty five observations). Adding the cross-sectional dimension to the usual time dimension is indeed very important in the context of non-stationary series in order to increase the power of such tests. As noted by Baltagi and Kao (2000), 'the econometrics of non-stationary panel data aims at combining the best of both worlds: the method of dealing with non-stationary data from the time series and the increased data and power from the cross-section'.

The second contribution of this paper refers to the use of Dynamic Ordinary Least Square (DOLS) estimator. The DOLS method allows for consistent and efficient estimators of the long-run relationship. It also deals with the endogeneity of regressors and account for integration and cointegration proprieties of data.

The third contribution is to examine the causal relationship between energy consumption and economic growth for heterogeneous panel of 21 African countries within a multivariate framework by including measures of capital, labor and prices. We assume that energy consumption could affect economic growth both as a direct input in the production process and indirectly as a complement to labor and capital inputs. Furthermore, the price level has been chosen as an additional variable because of its effects on both energy consumption and economic growth. From an econometric point of view we employ the Pooled Mean Group (PMG) approach of Pesaran, Shin and Smith (1999) to estimate a complete panel error-correction model (PECM) and to sort out the long-run versus short-run effects of the countries respective relationship between energy consumption and economic growth. The advantage of such approach is that it not only informs about the issue of unit-roots in the country panel but also allows for short-run versus long-run analyses of the relationship between energy consumption and economic growth in the same specification. Individual countries may well be on the same long-run path albeit with different short-run developments.

The fourth contribution is to consider a mix of African countries comprising both net energy producers and consumers. Most previous studies paid less attention to this aspect.

The structure of this paper is as follows. Section 2 proposes an overview of energy consumption and economic growth for developing countries. Section 3 outlines the econometric methodology. Section 4 provides details of the estimated model and the empirical results. The last section suggests some policy implications and offers some concluding remarks.

2. A brief overview of energy consumption and economic growth for developing countries

Since the seminal paper of Kraft and Kraft (1978), which supported the unidirectional causality from GNP growth to energy consumption in the USA for the period from 1947 to 1974, the causal relationship between energy consumption and economic growth has been extensively examined in the literature using different techniques and different samples of countries.[2] The empirical outcomes of these studies have been varied and sometime found to be conflicting. Four views currently exist regarding the causal relationship between energy consumption and economic growth. The first view, "*the growth hypothesis*", suggests that energy consumption plays an important role in economic growth. It implies that economic growth is dependent on energy consumption, and a decrease in energy consumption may restrain economic growth. The second view, called "*the conservative hypothesis*", argues unidirectional causality from economic growth to energy consumption. It suggests that energy conservation policies may have little or no impact on economic growth. The conservative hypothesis is supported if an increase in real GDP causes an increase in energy consumption. The third view, "*neutrality hypothesis*", argues that there is no causality between energy consumption and economic growth. In other words, both energy consumption and economic growth are neuter with respect to each other. The "*feedback hypothesis*" (fourth view) suggests that there is bidirectional causal relationship between energy consumption and economic growth reflecting the interdependence and possible complementarities associated with energy policies and economic growth.

Previous empirical studies on energy consumption and economic growth for developing countries provide mixed results (see Table 1). The main reason for the discrepancy in results in the previous research comes from the use of different econometric methods, divergence across countries, time horizon and model specifications that cannot accommodate structural breaks.

Table 1: Summary of main studies on energy consumption-growth relationship for developing countries

Authors	Period	Country	Methodology	Causality relationship
Ebohon (1996)	1960-1984 1960-1981	Nigeria, Tanzania	Granger Causality test	EC $\leftrightarrow$ GDP (Nigeria, Tanzania)
Asafu-Adjaye (2000)	1971-1995 1973-1995	The Philippines, Thailand, India, Indonesia	Cointegration and Granger Causality based on ECM	EC $\leftrightarrow$ GDP (The Philippines, Thailand) EC $\rightarrow$ GDP (India, Indonesia)
Jumbe (2004)	1970-1999	Malawi	Cointegration and Granger Causality based on ECM	EC $\leftrightarrow$ GDP NGDP $\rightarrow$ EC

[2] See for example Yu and Choi (1985), Erol and Yu (1987), Stern (1993), Oh and Lee (2004), Wolde-Rufael (2004), Lee (2005), Sari and Soytas (2007), Mahadevan and Asufu-Adjaye (2007) and Apergis and Payne (2009a, 2009b, 2010). For a recent survey on the literature on energy consumption and growth, see Ozturk (2010) and Payne (2008).

Lee (2005)	1975-2001	18 developing countries	Panel VECM	EC → GDP
Wolde-Rufael (2005)	1971-2001	19 developing countries	Toda-Yamamoto's Granger causality	GDP → EC (Algeria, Congo Democratic Rep, Egypt, Ghana, Ivory Coast) EC → GDP (Cameroon, Morocco, Nigeria) EC ↔ GDP (Gabon, Zambia) GDP ---- EC (Benin, Congo, Kenya, Senegal, South Africa, Sudan, Togo, Tunisia, Zimbabwe)
Wolde-Rufael (2006)	1971-2006	17 African countries	Toda-Yamamoto's Granger causality	GDP → ELC (Cameroon, Ghana, Nigeria, Senegal, Zambia, Zimbabwe) ELC → GDP (Egypt, Gabon, Morocco) ELC ↔ GDP (Egypt, Gabon, Morocco) GDP ---- ELC (Algeria, Congo, Kenya, South Africa, Sudan)
Ouedraogo (2010)	1968-2003	Burkina-Faso	ARDL Bounds tests	ELC ↔ GDP
Esso (2010)	1970-2007	Seven African countries (Cameroon, Ivory Coast, Congo, Ghana, Kenya, Nigeria, and South Africa)	Threshold cointegration approach	EC ↔ GDP (Ivory Coast) GDP → EC (Congo and Ghana) EC ---- GDP (Cameroon, Nigeria, Kenya, South Africa)
Al-Iriani (2006)	1960-2002	6 countries of GCC (Bahrain, Kuwait, UAE Oman, Qatar, Saudi Arabia)	Panel cointegration, GMM	GDP → EC
Mahadevan and Asafu-Adjaye (2007)	1971-2002	20 energy importers and exporters	Panel error correction model	EC ↔ GDP (developed countries) EC → GDP (in the short-run for developing countries)

Akinlo (2008)	1980-2003	11 Sub-Saharan African Countries	ARDL Bounds tests	GDP → EC (Gambia, Ghana, Sudan, Zimbabwe, Congo, Senegal) GDP ---- EC (Cameroon, Ivory Coast, Nigeria, Kenya, Togo)
Huang et al. (2008)	1960-2001	82 Low, Middle, and High income countries	Panel VAR, GMM model	GDP → EC (middle and high income countries) EC ---- GDP (low income countries)
Odhiambo (2009)	1971-2006	Tanzania	ARDL Bounds tests	EC→ GDP
Odhiambo (2010)	1971-2006	South Africa, Kenya and Congo Democratic Rep	ARDL Bounds tests	EC → GDP (South Africa, Kenya)
Apergis and Payne (2009a)	1991-2005	6 Countries (Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, Panama)	Panel cointegration, ECM	EC → GDP
Apergis and Payne (2009b)	1980-2004	Armenia, Azerbadjan, Belarus, Georgia, Kazakhstan, Kyrgyzstan, Moldova, Russia, Tajikistan, Ukraine, Uzbekistan	Panel cointegration, ECM	EC → GDP (in the long-run) EC → GDP (in the short-run)
Wolde-Rufael (2009)	1971-2004	17 African countries	Variance decomposition analysis and Toda-Yamamoto's Granger causality	Capital and labor are the most contributing factor to output growth in 15 out of 17 countries.
Ozturk, Aslan and Kalyoncu (2010)	1971-2005	51 low and middle income countries	Panel cointegration and causality test	GDP → EC (low income countries) EC ↔ GDP (middle income countries)

Notes: →, ↔, and ---- represent respectively unidirectional causality, bidirectional causality, and no causality.

Abbreviations are defined as follows: EC = energy consumption; ELC = electricity consumption; GDP = real gross domestic product; NGDP = nominal GDP; ECM = error correction model; ARDL = autoregressive distributed lagged; VAR = vector autoregressive model; GMM = generalized method of moments.

The majority of these studies on the causality between energy consumption and economic growth have mainly used the residual-based cointegration test associated with Engel and Granger (1987) and the maximum likelihood test based on Johansen (1988) and Johansen and Juselius (1990). For example, in a two country study, Ebohon (1996) shows a simultaneous causal relationship between energy and economic growth for Nigeria and Tanzania employing Granger causality test. Applying cointegration and error correction vector techniques on data for Malawi from 1970 to 1999, Jumbe (2004) found a bidirectional causality between electricity consumption and economic growth, but a unidirectional causality running from non-agricultural GDP to electricity consumption. Asafu-Adjaye (2000) examined the causal relationship between energy consumption, energy prices and economic growth for India, Indonesia, the Philippines and Thailand, using cointegration and error-correction modelling techniques. They show, in the short-run, unidirectional Granger causality is found between both series for India and Indonesia while bidirectional causality running from energy consumption to income for Thailand and the Philippines. Belloumi (2009) applied Johansen cointegration technique to assess the causal relationship between per capita energy consumption and per capita gross domestic product for Tunisia during the period 1971-2004. These results show a long-run bidirectional causal relationship between the two series and a short-run unidirectional causality from energy to gross domestic product. But the problem with most existing time series studies is that they are based on bivariate causality tests which have been shown to suffer from omitted variable problems and lead to erroneous causal inferences (see Caporale and Pittis, 1995).

Following advances in times series analysis in the last decade, recent investigations of the energy consumption and economic growth relationship have carried out the Granger causality test of Toda and Yamamoto (1995) to examine the relationship between energy consumption and economic growth. For instance, in a 19 country study of Africa, Wolde-Rufael (2005) applied this approach to analyse the causal relationship between energy consumption and economic growth. The results show that there is evidence for a long-run relationship for only 8 of the 19 countries and a short-run causality for 12 countries. Similarly, in a multivariate causality test, Akinlo (2008) found conflicting results for 11 African countries. Wolde-Rufael (2006) found evidence of a unidirectional causality running from economic growth to energy consumption in 5 African countries, whereas bidirectional causality was found for 2 countries and no evidence for causal relationship in 7 African countries. Odhiambo (2009) found that there is a unidirectional causal relationship running from energy consumption to economic growth for Tanzania. Wolde-Rufael (2009) reassessed the relationship between energy consumption and economic growth using 17 countries in Africa. He has taken into account labor and capital as additional variables. The results of their multivariate modified Granger causality analysis tend to reject the neutrality hypothesis for energy-income relationship in African countries. In contrast, results of variance decomposition analyses show that in 11 out of the 17 countries, energy was not even the second most important factor to output growth; capital and labor are the most important factors in output growth in 15 out of the 17 countries. Odhiambo (2010) re-examined the causal relationship between energy consumption and economic growth in three sub-Saharan African countries. He added the prices as an additional variable because of its effects on both energy consumption and economic growth. Indeed, an increase in prices is expected to lead to a decrease in energy demand, thereby leading a decrease in energy consumption. On the other hand, an increase in prices leads to a decrease in energy demand, thereby leading to a contraction in aggregate output. He discovered that the causality between energy consumption and economic growth varies significantly across the three-countries. The results indicated that for South Africa and Kenya there is a unidirectional causal relationship from energy consumption to economic growth while for Congo (DRC) it is economic growth that drives energy consumption. Similarly, Ouedraogo (2010) found that there is evidence of a positive feedback causal relationship between electricity use and real GDP for Burkina Faso.

One problem with the previous results for time series is that they don't accommodate structural breaks. It is now convenient in time-series analysis to check whether models chosen for describing data are subject to structural breaks. The need to take account structural breaks in energy consumption series comes from the possibility of external factors causing violent exogenous shocks. In this regard, Lee and Chang (2005) employed the unit root and cointegration tests allowing for structural breaks to assess the stability between energy consumption and GDP for Taiwan during 1954-2003. Their study shows unanimously in the long-run that energy acts as an engine of economic growth, and that energy conservation may harm economic growth. Esso (2010) investigated the long-run and the causality relationship between energy consumption and economic growth for seven sub-Saharan African countries during the period 1970-2007. Using Gregory and Hansen (1996a, 1997b) testing approach to threshold cointegration, he found that energy consumption is cointegrated with economic growth in Cameroon, Ivory Coast, Ghana, Nigeria and South Africa. Furthermore, causality tests suggest bidirectional causality between energy consumption and real GDP in Ivory Coast and unidirectional causality running from real GDP to energy use in Congo and Ghana.

Unfortunately, most of these studies relied upon limited time series data, usually 30 to 35 observations, which reduces the power and size properties of conventional unit root and cointegration tests. Furthermore, they did not take into account the endogeneity of regressors in panel methods.[3] Recent studies emerged to confront these problems using a dynamic panel data approach, Dynamic Ordinary Least Square (DOLS) and Fully Modified OLS (FMOLS) estimators. For example, Lee (2005) employed panel cointegration and panel error correction models to investigate the causal relationship between energy consumption and GDP in 18 developing countries during the period 1975 to 2001. He found a unidirectional causality in both the short and long-run between energy consumption and GDP. Applying the same approach for 6 countries of the Gulf Cooperation Council (GCC), Al-Iriani (2006), found a unidirectional causality running from GDP to energy consumption. Mahadevan and Asafu-Adjaye (2007) re-examined energy consumption and GDP growth relationship in a panel error correction model, using data on 20 net energy importers and exporters and taking into account prices. As mentioned above, this is because prices responses have been argued to have a crucial role in affecting income and energy consumption directly. They show that among the energy exporters, there is bidirectional causality between economic growth and energy consumption in the developed countries in both the short and long-run, while in the developing countries, energy consumption stimulates growth only in the short-run.

Apergis and Payne (2009b) examined the relationship between energy consumption and economic growth for 11 countries of the Commonwealth of Independent States (CIS) over the period 1991-2005 employing heterogeneous panel cointegration test and error correction model. They found the presence of unidirectional causality from energy consumption to economic growth in the short-run while bidirectional causality between energy consumption and economic growth in the long-run. Similarly, Apergis and Payne (2009a) discovered for

[3] However, panel methods have the disadvantages to impose some coefficients to be the same for all countries, an assumption that we will test in our econometric investigation.

six Central American countries over 1980-2004 the presence of both short-run and long-run causality from energy consumption to economic growth. Apergis and Payne (2010) used panel causality and cointegration tests of nine South American countries over 1980-2005. They found both a short-run and long-run causality from energy consumption to economic growth. Ozturk et al. (2010) analysed the causal relationship between energy consumption and economic growth for 51 countries from 1971 to 2005. These countries are divided into three groups: low income, lower middle income and upper middle income countries. They found long-run causality running from GDP to energy consumption for low income countries and bidirectional causality for middle income countries. Employing a dynamic panel for 82 countries of varying income levels for the period 1972-2002, Huang et al. (2008) provided support for the neutrality hypothesis for the low income group while in the middle income group economic growth leads energy consumption positively. In the high income group countries, the author found that the overall effect of economic on energy consumption is negative. In other words, increasing economic growth decreases energy consumption in these countries. Finally, Kebede et al. (2010) used a panel cointegration technique for 20 sub-Saharan African countries from 1980 to 2004 to estimate energy demand, which is composed of traditional (wood fuel) and commercial energy (electricity and petroleum). They showed that wood fuel accounts for 70% of energy consumption, followed by petroleum, with most industrial activities utilizing some form of wood fuel. Furthermore, the results indicated that there are regional differences in energy consumption and GDP growth rate.

To sum up, although the literature on the relationship between energy consumption and economic growth in Africa is quite vast, it provides mixed results and fails to reach a consensus as to the direction of causality. Besides, to our best knowledge, none of the existing studies has considered the problem of structural breaks in a panel framework combined with the possible cross-country dependence, which instead we do in the following analysis.

3. Methodological issues

Our examination of the relationship between economic growth, energy consumption, prices, labor and capital is conducted in three steps. First, we test for the order of integration of the variables. Second, we employ panel cointegration tests to examine whether a long-run relationship exists among the variables and we compare the situation that assumes the existence of no breaks with that accounting for the possibility of multiple heterogeneous and endogenous structural breaks. Then, we estimate long-run coefficients using appropriate methodology (Dynamic OLS, DOLS). And third, we use the Pooled Mean Group (PMG) approach of Pesaran, Shin and Smith (1999) to sort out the long-run versus short-run effects of the different countries respective relationship between energy consumption and economic growth, and we also evaluate the direction of causality among variables.

3.1 Panel unit root tests

Before proceeding to cointegration techniques, we need to determine the order of integration of each variable. One way to do so is to implement the panel unit root test of Im, Pesaran and Shin (2003, hereinafter IPS). This test is less restrictive and more powerful compared to the tests developed by Levin and Lin (1993), Levin et al. (2002) and Breitung (2000),[4] which don't allow for heterogeneity in the autoregressive coefficient. The test proposed by IPS solves Levin and Lin's serial correlation problem by assuming heterogeneity between units in

[4] For a useful survey on panel unit root tests, see Banerjee (1999).

a dynamic panel framework. The basic equation for the panel unit root test for IPS is as follows:

$$\Delta y_{it} = \alpha_i + \rho_i y_{i,\,t-1} + \sum_{j=1}^{p} \phi_{ij} \Delta y_{i,t-j} + \varepsilon_{i,\,t}\ ; \quad i = 1,\ 2,...,\ N; \quad t = 1,\ 2,...,\ T, \tag{1}$$

where y_{it} stands for each variable under consideration in our model, α_i is the individual fixed effect and p is selected to make the residuals uncorrelated over time. The null hypothesis is that $\rho_i = 0$ for all i versus the alternative hypothesis is that $\rho_i < 0$ for some $i = 1,..., N_1$ and $\rho_i = 0$ for $i = N_1 + 1,..., N$.

The IPS statistic is based on averaging individual Augmented Dickey-Fuller (ADF) statistics and can be written as follows:

$$\overline{t} = \frac{1}{N} \sum_{i=1}^{N} t_{iT}, \tag{2}$$

where t_{iT} is the ADF *t-statistic* for country *i* based on the country-specific ADF regression, as in Eq (1). The $\bar{t}$ statistic has been shown to be normally distributed under H_0 and the critical values for given values of N and T are provided in Im et al. (2003).

IPS's tests have the drawback of assuming that the cross-sections are independent; the same assumption is made in all first-generation panel unit root tests. However, it has been pointed out in the literature that cross-section dependence can arise due to unobserved common factors, externalities, regional and macroeconomic linkages, and unaccounted residual interdependence.[5] Recently, some new panel unit root tests have emerged that address the question of the dependence and correlation given the prevalence of macroeconomic dynamics and linkages. These tests are called the second-generation panel unit root tests. A well-known second-generation test that is considered in this paper is Pesaran's (2007) Cross-Sectionally Augmented IPS (CIPS) test. To formulate a panel unit root test with cross-sectional dependence, Pesaran (2007) considers the following Cross-Sectionally Augmented Dickey-Fuller (CADF) regression, estimating the OLS method for the i^{th} cross-section in the panel:

$$\Delta y_{it} = \alpha_i + \rho_i y_{i,t-1} + c_i \overline{y}_{t-1} + \sum_{j=0}^{k} d_{ij} \Delta \overline{y}_{t-j} + \sum_{j=1}^{k} \delta_{ij} \Delta y_{i,t-j} + \varepsilon_{it}, \tag{3}$$

where $\overline{y}_{t-1} = \left(\frac{1}{N}\right) \sum_{i=1}^{N} y_{i,t-1}$ and $t_i\left(N,T\right)$ is the *t*-statistic of the estimate of ρ_i in the above equation used for computing the individual ADF statistics. More importantly, Pesaran proposed the following test CIPS statistic that is based on the average of individual CADF statistics as follows:

$$CIPS = \left(\frac{1}{N}\right) \sum_{i=1}^{N} t_i\left(N,T\right). \tag{4}$$

The critical values for CIPS for various deterministic terms are tabulated by Pesaran (2007).

3.2 Panel cointegration tests without structural breaks

Once the order of integration has been defined, we apply Pedroni's cointegration test methodology. Indeed, like the IPS test, the heterogeneous panel cointegration test advanced by Pedroni (1999, 2004) allows for cross-section interdependence with different individual

[5] Note that in our empirical investigation we will to test for the presence of such cross-sectional dependence in the data using the simple test of Pesaran (2004).

effects. The empirical model of Pedroni's cointegration test is based on the following equation:

$$Y_{it} = \eta_i + \delta_i t + \beta_{1i} E_{it} + \beta_{2i} P_{it} + \beta_{3i} L_{it} + \beta_{4i} K_{it} + \varepsilon_{it}, \qquad (5)$$

where $i = 1,...,N$ for each country in the panel and $t = 1,...,T$ refers to the time period; Y, E, P, L and K are the natural logarithms of real GDP, energy consumption, consumption price index, labor force and capital respectively. η_i and δ_i are country and time fixed effects, respectively. ε_{it} denotes the estimated residuals which represent deviations from the long-run relationship. The structure of estimated residuals is the following:

$$\hat{\varepsilon}_{it} = \hat{\rho}_i \hat{\varepsilon}_{it-1} + \hat{u}_{it}. \qquad (6)$$

Pedroni has proposed seven different statistics to test panel data cointegration. Out of these seven statistics, four are based on pooling, what is referred to as the "Within" dimension and the last three are based on the "Between" dimension. Both kinds of tests focus on the null hypothesis of no cointegration. However the distinction comes from the specification of the alternative hypothesis. For the tests based on "Within", the alternative hypothesis is $\rho_i = \rho < 1$ for all *i*, while concerning the last three test statistics which are based on the "Between" dimension, the alternative hypothesis is $\rho_i < 1$, for all *i*. The finite sample distribution for the seven statistics has been tabulated by Pedroni via Monte Carlo simulations. The calculated statistic tests must be smaller than the tabulated critical value to reject the null hypothesis of absence of cointegration.

A limitation of the tests proposed by Pedroni (1999) is that it based on the hypothesis of common factor restriction and that it does not take possible cross-country dependence into account. This hypothesis suggests that the long-run parameters for the variables in their levels are equal to the short-run parameters for the variables in their first differences. A failure to satisfy the restriction can cause a significant loss of power for residual-based cointegration tests. In this paper, in addition to applying the Pedroni (1999) tests, we also use the panel cointegration tests proposed by Westerlund (2007) to examine the relationship between real GDP, energy consumption and auxiliary variables in African countries. The Westerlund (2007) tests avoid the problem of common factor restriction and are designed to test the null hypothesis of no cointegration by inferring whether the error-correction term in a conditional error-correction model is equal to zero. Therefore, a rejection of the null hypothesis of no error-correction can be viewed as a rejection of the null hypothesis of no cointegration. The error-correction tests assume the following data-generating process:

$$\Delta Y_{it} = \delta_i^{'} d_t + \alpha_i \left(Y_{it-1} - \beta_i^{'} X_{it-1} \right) + \sum_{j=1}^{p_i} \alpha_{ij} \Delta Y_{it-j} + \sum_{j=0}^{p_i} \gamma_{ij} \Delta X_{it-j} + \varepsilon_{it}, \qquad (7)$$

where d_t contains the deterministic components, Y_{it} denotes the natural logarithms of the real GDP and X_{it} denotes a set of exogenous variables, including energy consumption. Equation (7) can be rewritten as:

$$\Delta Y_{it} = \delta_i^{'} d_t + \alpha_i Y_{it-1} + \lambda_i^{'} X_{it-1} + \sum_{j=1}^{p_i} \alpha_{ij} \Delta Y_{it-j} + \sum_{j=0}^{p_i} \gamma_{ij} \Delta X_{it-j} + \varepsilon_{it}, \qquad (8)$$

where $\lambda_i = -\alpha_i \beta_i^{'}$. The parameter α_i determines the speed at which the system $Y_{it-1} - \beta_i^{'} X_{it-1}$ corrects back to the equilibrium after a sudden shock. If $\alpha_i < 0$, then the model is error-correcting, implying that Y_{it} and X_{it} are cointegrated. If $\alpha_i = 0$, then there is no error correction and, thus no cointegration. The null hypothesis for all countries of the panel is:

$H_0 : \alpha_i = 0$ for all $i = 1,...,N$ versus $H_1 : \alpha_i \neq 0$ for $i = 1,...,N_1$ and $\alpha_i = 0$ for $i = N_1 + 1,...,N$. The alternative hypothesis allows α_i differing across the cross-sectional units.

Westerlund (2007) proposed four different statistics to test panel cointegration, based on least squares estimates of α_i and its $t-$ratio. While two of the four tests are panel tests with the alternative hypothesis that the whole panel is cointegrated ($H_1 : \alpha_i = \alpha < 0$ for all i), the other two tests are group-mean tests which test against the alternative hypothesis that for at least one cross-section unit there is evidence of cointegration ($H_1 : \alpha_i < 0$ for at least one i). The panel statistics denoted P_τ and P_α test the null hypothesis of no cointegration against the simultaneous alternative that the panel is cointegrated, whereas the group mean statistics G_τ and G_α test the null hypothesis of no cointegration against the alternative that at least one element in the panel is cointegrated. The test proposed by Westerlund (2007) does not only allow for various forms of heterogeneity, but also provides *p-values* which are robust against cross-sectional dependencies via bootstrapping.

3.3. Panel cointegration tests with structural breaks

A limitation of the previous cointegration tests is that they cannot accommodate structural breaks. However, using a time series approach such structural breaks have been recently found by Esso (2010) in energy consumption and economic growth relationship for seven African countries. Consequently, to deal with this issue we use the panel cointegration test proposed by Westerlund (2006) that allows for multiple structural breaks to examine the relationship between real GDP, energy consumption and auxiliary variables in African countries.

Consider the following long-run model:

$$Y_{it} = \lambda_{ij} + \beta_{1i} E_{it} + \beta_{2i} P_{it} + \beta_{3i} L_{it} + \beta_{4i} K_{it} + \varepsilon_{it}, \qquad (9)$$

$$\varepsilon_{it} = r_{it} + \mu_{it}, \qquad (10)$$

$$r_{it} = r_{it-1} + \phi_i \mu_{it}. \qquad (11)$$

The index $j = 1,...,M_i + 1$ denotes structural breaks. One can allow for at most M_i breaks or $M_i + 1$ regimes that are located at dates $T_{i1},...,T_{iM_i}$, where $T_{i0} = 1$ and $T_{iM_{i+1}} = T$. α_i is the error-correction parameter measuring the speed of adjustment towards the long-run equilibrium. The location of the breaks are specified as a fixed fraction $\lambda_{ij} \in (0,1)$ of T such that $T_{ij} = \left[\lambda_{ij} T \right]$ and $\lambda_{i,j-1} < \lambda_{ij}$ for $j = 1,...,M_i$. To ensure that the break date estimator works properly we set the minimum length of each sample segment equal to 0.10T and follow the advise of Bai and Perron (2003) and use the Schwartz Bayesian Criterion. The maximum number of allowable breaks is set equal to five.

The null hypothesis of cointegration for all countries of the panel is:

$H_0 : \phi_i = 0$ for all $i = 1,...,N$, *versus* $H_1 : \phi_i \neq 0$ for all $i = 1,...,N_1$ and $\phi_i = 0$ for $i = N_1 + 1,...,N$.

The alternative hypothesis allows ϕ_i to differ across the cross-sectional units.

Note that appropriate critical values accommodating possible cross-country dependence are obtained via bootstrap simulations.

3.4. Long-run and short-run parameter estimates of the panel error-correction model

Although Pedroni (1999) and Westerlund (2007)'s methodologies allow us to test the presence of cointegration among a set of economic variables, they don't provide coefficient estimates neither for the long-run nor for the short run parameters of a panel error-correction model (PECM). In a panel framework, in presence of cointegration, several estimators can be used: OLS, Fully Modified OLS (FMOLS), Dynamic OLS (DOLS), and Pooled Mean Group (PMG). Chen, McCoskey and Kao (1999) analysed the proprieties of the OLS estimator[6] and suggest that alternatives, such as the FMOLS or the DOLS estimators may be more promising in cointegrated panel regressions. However, Kao and Chiang (2000) showed that both the OLS and FMOLS exhibit small sample bias and that the DOLS estimator appears to outperform both estimators.[7] In this paper, we consider two estimators to get the parameter estimates of the PVAR describing the linkage between energy consumption and economic growth in African countries: DOLS for the long-run parameters and PMG for the short and long-run parameters.

3.4.1. The Dynamic OLS (DOLS) estimator

In order to obtain an unbiased estimator of the long-run parameters and to achieve the endogeneity correction, DOLS estimator uses parametric adjustment to the errors by including the past and the future values of the differenced I(1) regressors. The Dynamic OLS estimator is obtained from the following equation:

$$Y_{it} = \alpha_i + X_{it}^{'}\beta + \sum_{j=-q_1}^{j=q_2} c_{ij}\Delta X_{i,t+j} + v_{it}, \quad (12)$$

where $X = [E, P, L, K]$, c_{ij} is the coefficient of a lead or lag of first differenced explanatory variables. The estimated coefficient of DOLS is given by:

$$\hat{\beta}_{DOLS} = \sum_{i=1}^{N}\left(\sum_{t=1}^{T} z_{it} z_{it}'\right)^{-1}\left(\sum_{t=1}^{T} z_{it}\hat{y}_{it}^{+}\right), \quad (13)$$

where $z_{it} = \left[X_{it} - \overline{X}_i, \Delta X_{i,t-q}, ..., \Delta X_{i,t+q}\right]$ is vector of regressors, and $\hat{y}_{it}^{+}$ ($\hat{y}_{it}^{+} = Y_{it} - \overline{Y}_i$) is the transformed variable of the real GDP.

3.4.2. The Pooled Mean Group (PMG) estimator and the test for causality

Our final step consists in implementing an alternative methodology, the PMG approach of Pesaran et al. (1999), to estimate the short and long-run parameters of the panel error-correction model (PECM), and then to test for causality between economic growth, energy consumption, consumption price index, labor and capital. The PMG is an intermediate estimator because it involves both pooling and averaging. One advantage of the PMG over the DOLS model is that it can allow the short-run dynamic specification to differ from country to country while the long-run coefficients are constrained to be the same, a restrictive assumption that we will test in our econometric investigation.[8] Given that the variables are

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[6] Following proprieties are examining by Chen et al. (1999): the finite sample proprieties of the OLS estimator, the *t-statistic*, the bias-corrected OLS estimator, and the bias-corrected *t-statistic*.

[7] See Kao and Chiang (2000) for more discussions on the advantages of these estimators.

[8] As pointed out by a referee this strong assumption of the PMG approach that consists in restricting the (long-run) coefficients to be the same in different countries deserves special empirical attention since it may be not supported by data. Besides, if it remained untested, one could truly wonder if some of our empirical results that differ from previous studies were not simply due to the fact that those studies (unlike the current one) did not

cointegrated, the PMG estimator is used in order to perform Granger-causality tests. First, the long-run model specified in Eq. (5) is estimated in order to obtain the residuals. Next, defining the lagged residuals from Eq. (5) as the error correction term, the following dynamic error correction model is estimated:

$$\Delta Y_{it} = \beta_{1j} + \sum_{k=1}^{p} \beta_{11ik} \Delta Y_{it-k} + \sum_{k=1}^{p} \beta_{12ik} \Delta E_{it-k} + \sum_{k=1}^{p} \beta_{13ik} \Delta P_{it-k} + \sum_{k=1}^{p} \beta_{14ik} \Delta L_{it-k} + \sum_{k=1}^{p} \beta_{15ik} \Delta K_{it-k} + \lambda_{1i} \varepsilon_{it-1} + v_{1it}, \quad (14a)$$

$$\Delta E_{it} = \beta_{2j} + \sum_{k=1}^{p} \beta_{21ik} \Delta Y_{it-k} + \sum_{k=1}^{p} \beta_{22ik} \Delta E_{it-k} + \sum_{k=1}^{p} \beta_{23ik} \Delta P_{it-k} + \sum_{k=1}^{p} \beta_{24ik} \Delta L_{it-k} + \sum_{k=1}^{p} \beta_{25ik} \Delta K_{it-k} + \lambda_{2i} \varepsilon_{it-1} + v_{2it}, \quad (14b)$$

$$\Delta P_{it} = \beta_{3j} + \sum_{k=1}^{p} \beta_{31ik} \Delta Y_{it-k} + \sum_{k=1}^{p} \beta_{32ik} \Delta E_{it-k} + \sum_{k=1}^{p} \beta_{33ik} \Delta P_{it-k} + \sum_{k=1}^{p} \beta_{34ik} \Delta L_{it-k} + \sum_{k=1}^{p} \beta_{35ik} \Delta K_{it-k} + \lambda_{3i} \varepsilon_{it-1} + v_{3it}, \quad (14c)$$

$$\Delta L_{it} = \beta_{4j} + \sum_{k=1}^{p} \beta_{41ik} \Delta Y_{it-k} + \sum_{k=1}^{p} \beta_{42ik} \Delta E_{it-k} + \sum_{k=1}^{p} \beta_{43ik} \Delta P_{it-k} + \sum_{k=1}^{p} \beta_{44ik} \Delta L_{it-k} + \sum_{k=1}^{p} \beta_{45ik} \Delta K_{it-k} + \lambda_{4i} \varepsilon_{it-1} + v_{4it}, \quad (14d)$$

$$\Delta K_{it} = \beta_{5j} + \sum_{k=1}^{p} \beta_{51ik} \Delta Y_{it-k} + \sum_{k=1}^{p} \beta_{52ik} \Delta E_{it-k} + \sum_{k=1}^{p} \beta_{53ik} \Delta P_{it-k} + \sum_{k=1}^{p} \beta_{54ik} \Delta L_{it-k} + \sum_{k=1}^{p} \beta_{55ik} \Delta K_{it-k} + \lambda_{5i} \varepsilon_{it-1} + v_{5it}. \quad (14e)$$

where Δ is the first-difference operator; p is the optimal lag length determined by the Schwarz Bayesian Criterion.[9] The specification in Eq. (14) allows us to test for both short-run and long-run causality. For example, in the real GDP equation (Eq. 14a), short-run causality from energy consumption, consumption price index, labor force and capital to real GDP are tested, respectively, based on $H_0 : \beta_{12ik} = 0 \ \forall ik$, $H_0 : \beta_{13ik} = 0 \ \forall ik$, $H_0 : \beta_{14ik} = 0 \ \forall ik$ and $H_0 : \beta_{15ik} = 0 \ \forall ik$. In the energy usage Eq. (14b), short-run causality from real GDP, consumption price index, labor force and capital to energy usage are tested, respectively, based on $H_0 : \beta_{21ik} = 0 \ \forall ik$, $H_0 : \beta_{23ik} = 0 \ \forall ik$, $H_0 : \beta_{24ik} = 0 \ \forall ik$ and $H_0 : \beta_{25ik} = 0 \ \forall ik$. In the consumer price index Eq. (14c), short-run causality from real GDP, energy consumption,

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force them in their econometric work to all behave the same way in the long-run. If so, then it is not clear how much if any weight we should put on these new panel estimation results - they may just be an artefact of the modelling and estimation approach that is used here, and therefore may not provide any useful information. To deal with this crucial issue we will test for this assumption in Section 4 using a Fisher statistic. Note already that it will be verified by data for the 10 net exporting and 11 net importing groups of countries taken separately, but not for all 21 countries considered together.

[9] A maximum number of six lags were considered and the optimal number of lags in the VAR system was determined via the Schwarz Bayesian Criterion. In order to avoid some endogeneity problem, the lags of the explanatory variables (other than the lagged of the dependent variable) start at *k=1* rather than *k=0*. For instance, the current growth in energy consumption would affect the current growth in real GDP.

labor force and capital to CPI are tested, respectively, based on $H_0:\beta_{31ik}=0\ \forall ik$, $H_0:\beta_{32ik}=0\ \forall ik$, $H_0:\beta_{34ik}=0\ \forall ik$ and $H_0:\beta_{35ik}=0\ \forall ik$. In the labor force Eq. (14d), short-run causality from real GDP, energy consumption, consumption price index, and capital to labor force are tested, respectively, based on $H_0:\beta_{41ik}=0\ \forall ik$, $H_0:\beta_{42ik}=0\ \forall ik$, $H_0:\beta_{43ik}=0\ \forall ik$ and $H_0:\beta_{45ik}=0\ \forall ik$. Finally, in the capital Eq. (14e), short-run causality from real GDP, energy consumption, consumption price index and labor force to capital are tested, respectively, based on $H_0:\beta_{51ik}=0\ \forall ik$, $H_0:\beta_{52ik}=0\ \forall ik$, $H_0:\beta_{53ik}=0\ \forall ik$ and $H_0:\beta_{54ik}=0\ \forall ik$. More generally, with respect to Eqs. (14a)-(14e), short-run causality is determined by the statistical significance of the partial *F*-statistic associated with the corresponding right hand side variables. The presence (or absence) of long-run causality can be established by examining the significance using a *t-statistic* on the coefficient λ, of the error correction term, ε_{it-1} in Eqs. (14a)-(14e).

4. Data and empirical results

4.1. Data

Annual data covering the period from 1970 to 2006 were obtained from the World Development Indicators (WDI, 2008) CD-ROM for 21 African countries.[10] The length of the period and the countries selected are dictated by the data availability on energy consumption. The sample includes 10 net exporting and 11 net importing countries. The multivariate framework includes real Gross Domestic Product (Y) in constant 2000, US dollar (in million), energy consumption (E), represented by energy use in kg of oil equivalent per capita, consumer price index (P) of year base 2000 as a proxy for energy prices,[11] total labor force (L) and real gross fixed capital formation (K) as a proxy of capital (in million).[12] Table 2 presents descriptive statistics for the sample and the different country groups (net energy exporters and net energy importers) during the period from 1970 to 2006. The descriptive statistics show a great variability across country and motivate the interest to have more homogenous sub-groups. The comparison of descriptive statistics between country groups reveals interesting results. The real GDP of net energy exporter's countries is 4 times higher than the level in the net energy importer countries. Likewise, the level of energy usage and the capital are two and four times higher respectively in net energy exporters than in net importers countries. On the other hand, considering CPI and labor force, a little difference is observed between both country groups. Overall, net energy exporters have relatively higher real GDP, energy consumption, capital and labor and lower CPI than net energy importers.

[10] The selected countries are: *Net exporting* (Algeria, Cameroon, Congo Republic, Ivory Coast, Egypt, Gabon, Libya, Nigeria, South Africa, and Sudan) - *Net importing* (Benin, Ethiopia, Ghana, Kenya, Morocco, Senegal, Tanzania, Togo, Tunisia, Zambia and Zimbabwe).

[11] We use prices in our multivariate framework because price responses have been argued to have a crucial role in affecting income and energy consumption. Although data on energy prices would be ideal to use, this data is not available for all 21 African countries over 1970-2006. Following Mahadevan and Asafu-Adjaye (2007), we use consumer price index instead as energy prices, because it sufficiently reflected in this index.

[12] The use of real gross fixed capital as a proxy of capital follow the works by Sari and Soytas (2007), and Apergis and Payne (2009a, 2010) in that under the perpetual inventory method with a constant depreciation rate, the variance in capital is closely related to the change in investment.

Table 2: Descriptive statistics of variables over 1970-2006

	Variables	Mean	Std. Dev.	Minimum	Maximum
All countries (21)					
	Y	18238.535	26190.069	1031.249	108736.597
	E	737.812	667.621	279.829	2500.100
	P	53.834	10.653	32.829	71.541
	L	7.640	7.917	0.385	33.228
	K	4430.820	5879.620	197.022	18391.040
Energy exporters (10)					
	Y	30257.472	33984.976	2501.625	108736.597
	E	1039.770	866.665	401.117	2500.100
	P	52.766	11.751	32.830	71.542
	L	8.791	9.935	0.385	33.228
	K	7537.140	7225.740	846.697	18391.040
Energy importers (11)					
	Y	7312.280	7522.034	1031.249	27527.187
	E	463.308	203.407	279.829	873.448
	P	54.805	10.026	36.556	65.990
	L	6.593	5.830	1.387	20.990
	K	1606.900	1930.910	197.022	6746.800

Notes: real GDP (Y), labor (L) and capital (K) in million.

Before proceeding to econometric estimation on panel, we test whether data on the sample have the appropriate properties. We test for individual heterogeneity (i.e. variation of the intercept across countries) and cross-country homogeneity (i.e. the coefficients of the regressors are the same for all countries under consideration) using standard Fisher tests. The test statistic ($F_{(20, 752)}$=2.38) for individual fixed effects equality reject the null hypothesis at the 1% significance level. Moreover, the test for coefficients equality across countries does not reject the null hypothesis, respectively, at the 10% significance level for the 10 net exporting and 11 net importing groups of countries taken separately, and at the 1% level of significance for the whole sample. Overall, the results of the specification tests indicate that there is individual heterogeneity and cross country homogeneity on the coefficients of the regressors. Hence, we can use a panel data analysis to evaluate the relationship between real GDP, energy consumption and auxiliary variables in African countries.

4.2. Results of unit roots and cointegration tests

Panel data integration tests of ‘‘first generation’’ (as IPS, 2003) assume cross-sectional independence among panel units (except for common time effects), whereas panel data unit root tests of the ‘‘second generation’’ (as Pesaran, 2007), allows for more general forms of cross sectional dependency (not only limited to common time effects). To test for the presence of such cross-sectional dependence in our data, we have implemented the simple test of Pesaran (2004) and have computed the CD (Cross-section Dependence) statistic. This test is based on the average of pair-wise correlation coefficients of the OLS residuals obtained from standard augmented Dickey-Fuller regressions for each individual. Its null hypothesis is cross-sectional independence and is asymptotically distributed as a two-tailed standard normal distribution. Results available on request indicate that the null hypothesis is always rejected regardless of the number of lags included in the augmented DF auxiliary regression (up to five lags) at the 5% level of significance. This indicates that our sample of African countries are, crosssectionally correlated, which can indeed reflect here the presence of similar regulations in various fields (such as economy, finance, trade, customs, tourism, legislation and administration), and increasing financial integration.

The results of the IPS (2003) and Pesaran's (2007) panel unit root tests with and without trend are both presented in Tables 3 and 4. For all five variables, the null hypothesis of the unit roots cannot be rejected in level. These results strongly indicate that the variables in level are non-stationary and stationary in first-differences (at the 1% significance level). Similar results are obtained for the two groups of countries of our sample: net energy exporters and net energy importers countries.[13] Therefore, we conclude that whether cross-sectional dependence is taken (or not) into account all our series are non-stationary and integrated of order one.

Table 3: IPS (2003) panel unit root test results

	Variables	**Level**		**First difference**	
		Constant	Constant and trend	Constant	Constant and trend
All countries (21)					
	Y	-1.525	-2.048	-3.088***	-3.388***
	E	-1.629	-2.009	-3.234***	-3.615***
	P	-0.782	-1.327	-2.559***	-3.012***
	L	-1.593	-2.195	-3.950***	-3.637***
	K	-1.239	-2.056	-3.330***	-3.382***
Energy exporters (10)					
	Y	-1.370	-1.884	-3.046***	-3.302***
	E	-1.777	-1.987	-3.467***	-3.865***
	P	-0.928	-2.067	-2.768***	-2.831***
	L	-0.976	-1.281	-3.631***	-3.506***
	K	-1.498	-2.172	-3.513***	-3.763***
Energy importers (11)					
	Y	-1.493	-1.947	-3.224***	-3.567***
	E	-1.016	-2.244	-3.393***	-3.526***
	P	-0.419	-0.643	-2.406***	-3.127***
	L	-1.665	-2.177	-3.806***	-3.611***
	K	-1.538	-1.857	-3.201***	-3.218***

Notes: *** Rejection of null hypothesis of non-stationary at the 1 percent level of significance.

Table 4: Pesaran (2007) panel unit root test results

	Variables	**Level**		**First difference**	
		Constant	Constant and trend	Constant	Constant and trend
All countries (21)					
	Y	-1.768	-2.113	-2.968***	-3.212***
	E	-1.691	-2.335	-3.098***	-3.428***
	P	-1.157	-1.024	-2.617***	-2.946***
	L	-1.915	-2.122	-2.823***	-3.529***
	K	-1.866	-2.162	-3.092***	-3.149***
Energy exporters (10)					
	Y	-1.638	-1.757	2.850***	-3.059***

[13] Individual ADF tests show that real GDP and energy consumption are I(1) for each country at the 5% significance level.

	E	-1.776	-2.174	-3.381***	-3.695***
	P	-1.139	-0.971	-2.280**	-2.846**
	L	-2.027	-2.300	-2.882***	-3.402***
	K	-1.125	-2.256	-3.377***	-3.668***
Energy importers (11)					
	Y	-1.832	-1.973	-2.933***	-3.281***
	E	-1.536	-1.904	-3.194***	-3.391***
	P	-1.184	-1.013	-2.350**	-2.860**
	L	-1.858	-2.068	-2.441***	-3.140***
	K	-1.721	-2.140	-2.992***	-3.148***

Notes: ***, ** Rejection of the null hypothesis of non-stationary at 1 and 5 percent levels of significance.

Note that the presence of structural breaks in panel series data can induce behaviour similar to that of an integrated process, making it difficult to differentiate between a unit root and a stationary process with a regime shift. For this reason, the previous panel unit root tests may potentially suffer from a significant loss of power if structural breaks are present in the data. To deal with this issue, we have also employed as a robustness check, the panel data unit root test based on the Lagrangian multiplier (LM) principle developed by Im and Lee (2001), which is very flexible since it can be applied not only when a structural break occurs at a different time period in each time series, but also when the structural break occurs in only some of the time series. The proposed test is not only robust to the presence of structural breaks, but is also more powerful than the popular IPS test in the basic scenario where no structural breaks are involved. Furthermore, as reported by Im and Lee (2001), since the LM test loses little power by controlling for spurious structural breaks when they do not exist, this represents a reasonable strategy to control for breaks even when they are only at a suspicious level. Moreover, this panel LM test does not require the simulation of new critical values that depend on the number and location of breaks.

After allowing for a possible structural break, we report that the panel data unit root test of Im and Lee (2001), whose results are available upon request, cannot reject the unit root null in any countries for our five series of interest at the 5% level, thereby demonstrating that the non-stationarity property of our series is a robust result. These results allow us to test for panel cointegration between the five variables.

Given that real GDP, energy consumption, price index, labor and capital are I(1), we test whether a long-run relationship exists between them. Table 5 shows the results of Pedroni's (1999) tests between the five variables. We use four within-group tests (panel statistics based on estimators that pool the autoregressive coefficient across different countries for the unit root tests on the estimated residual) and three between-group tests (group statistics based on estimators that average individually estimated coefficients for each countries). Almost the statistics reject the null hypothesis of no cointegration. The same issues are obtained for the two country groups (energy importers and energy exporters).

Table 5: Pedroni (1999) panel cointegration tests

	Panel statistics				Group statistics		
	v-stat	rho-stat	pp-stat	adf-stat	rho-stat	pp-stat	adf-stat
All countries	1.330^{*}	-1.437^{*}	-2.651^{***}	-1.922^{**}	-1.543^{*}	-2.804^{***}	-2.317^{**}
Energy exporters	1.451^{*}	-1.527^{*}	-1.778^{**}	-2.558^{***}	-1.363^{*}	-2.008^{**}	-3.049^{***}
Energy importers	1.969^{**}	-1.012	-2.161^{**}	-1.282^{*}	-1.831^{**}	-1.960^{**}	-2.494^{***}

Notes: The test statistics are normalized so that the asymptotic distribution is standard normal. *, ** and *** indicate rejection of the null hypothesis of no cointegration at the 10, 5 and 1 percent levels of significance based respectively on the following critical values: 1.281, 1.644 and 2.326.

Pedroni cointegration tests have the drawbacks to require the long-run cointegrating vector for the variables in the levels to be equal to the short-run adjustment process for the variables in the differences, and to assume cross-country independence. Failure of this common factor restriction causes significant loss of power in the Pedroni procedures. In order to check the robustness of the previous results, we considered four additional cointegration tests proposed by Westerlund (2007) that allow for cross-sectional dependence. Table 6 summarizes the outcome of Westerlund's cointegration tests. Excepted for the G_α statistic test, the null hypothesis of no cointegration is rejected at the 1% significance level. When robust p-values are computed based on the bootstrapped p-values (i.e when allowance is made for cross-sectional dependence), the no cointegration null hypothesis is rejected in all cases at the 1% significance level. The results with the bootstrapped p-values (that take cross-country dependence into account) provide stronger evidence of cointegration relationship between real GDP, energy consumption, consumer price index, labor and capital in African countries.

Table 6: Westerlund (2007) panel cointegration tests

	All countries			Energy exporters			Energy importers		
	Value	P-value	Robust p-value	Value	P-value	Robust p-value	Value	P-value	Robust p-value
G_τ	-4.202	0.000	0.000	-4.799	0.000	0.000	-4.014	0.000	0.000
G_α	-11.858	0.744	0.003	-7.161	0.992	0.698	-13.747	0.366	0.003
P_τ	-17.034	0.000	0.000	-16.318	0.000	0.000	-12.743	0.000	0.000
P_α	-21.786	0.000	0.010	-18.063	0.000	0.020	-12.518	0.080	0.003

Notes: Optimal lag/lead length determined by Akaike Information Criterion with a maximum lag/lead length of 2. Width of Bartlett-kernel window set to 2. Number of bootstraps to obtain bootstrapped p-values which are robust against cross-sectional dependencies set to 400.

These results support the recent empirical assessments of Mahadevan and Asafu-Adjaye (2007), Apergis and Payne (2009a, 2010), Ozturk et al. (2010) and suggest that in African countries, there is a long-run equilibrium relationship between real GDP, energy consumption, price index, labor and capital. However, these results contrast with those of Acaravci and Ozturk (2010), who do not find evidence for long-run relationship between electricity consumption and growth from a sample of 15 transitional countries over the period 1990-2006.

Finally, the case of cointegration with structural breaks is considered (as a robustness check) with the use of the recent Lagrange multiplier (LM) test developed by Westerlund (2006) for the null hypothesis of cointegration, which shows small size distortions and reasonable power.[14] This test allows for multiple structural breaks in both the level and trend of a cointegrated panel regression, being general enough to allow for endogenous regressors, serial correlation and an unknown number of breaks, which may differ among units. The results are reported in Table 7.

Table 7 – Estimated structural breaks (Westerlund, 2006)

Energy exporters	**Number of breaks**	**Location of structural break**	
Algeria	2	1977	1997
Cameroon	2	1977	1982
Congo Republic	2	1980	2000
Egypt	2	1979	1994
Gabon	2	1974	1992
Ivory Coast	2	1975	1995
Libya	2	1989	1994
Nigeria	2	1989	2001
South Africa	2	1979	1996
Sudan	2	1975	1995
Energy importers	**Number of breaks**	**Location of structural break**	
Benin	2	1979	1995
Ethiopia	0		
Ghana	2	1975	1992
Kenya	0		
Morocco	0		
Senegal	2	1975	1984
Tanzania	2	1974	1979
Togo	2	1984	1996
Tunisia	2	1981	1997
Zambia	2	1980	2001
Zimbabwe	2	1980	1988

Note: The breaks are estimated using the Bai and Perron (2003) procedure with a maximum number of five breaks for each country. The minimum length of each break regime is set to $0.1T$.

Allowing for multiple possible breaks (Table 7) the Westerlund (2006) test is able to detect 20 breaks in the net exporting countries panel and 16 breaks in the net importing countries one, and up to 2 significant breaks for most countries. The asymptotic and bootstrap p-values for the null hypothesis of cointegration are respectively of 0.11 and 0.19, for the net exporting countries panel, and of 0.15 and 0.24 for the net importing countries panel, indicating non-rejection of the null at five and ten percent levels of significance, according to asymptotic p-values (cross-country independence). Similarly, the null hypothesis cannot be rejected based on the bootstrap p-values at all conventional level of significance. Hence we can still conclude for the existence of strong evidence that real GDP, energy consumption, consumer price index, labor force and capital respectively, taken in natural logarithm, are cointegrated when multiple structural and endogenous breaks are accommodated, and whether conventional or suitable generated bootstrap values take cross-sectional dependence into account are used.

Compared to the existing studies, the estimated date of our structural breaks is roughly consistent with Narayan and Popp (2009) and Lee and Chiu (2011) who found two structural

[14] We thank J. Westerlund for providing us the GAUSS codes.

breaks for respectively industrial electricity demand of the G7 and 6 developed countries. Our results are also broadly in accordance with Esso (2010) that used the Gregory and Hansen (1996a; 1996b) testing approach to threshold cointegration for 7 African countries.

As far as the net exporting countries are concerned, our study shows that the first structural breaks occurred in the 1970s or 1980s, while the second structural breaks in the 1980s, 1990s or 2000s. Roughly, our structural breaks are associated globally and with great shocks. They may reflect the energy crises triggered by the 1973 Arab oil embargo; the 1978 Iranian revolution, accompanied by escalating oil prices and a period of high inflation during the 1970s decade; the deep world-wide recession in the early 1980s; the 1987 wall Street stock market crash; the commodities crises of the 1980s due to the second oil shocks and to the start period of the economic liberalization within the context of structural adjustment in most of the sub-Saharan African countries (Esso, 2010). Indeed, Africa countries faced to a serious economic crisis in the 1980s which is culminated in pronounced disequilibria in both the domestic and external sector. Moreover, for Algeria, Cameroon, Gabon, Ivory Coast, Egypt, South Africa and Sudan, the first structural breaks appear between 1974 and 1979 before the commodity crisis around the time of the second oil price shock in 1979 and the Iran-Iraq war in 1980. In Lybia and Nigeria, the first structural breaks occurred in 1989 just after the stock market crash in the United States and just prior to the Gulf War.

Concerning the net importing countries, the results of the estimated date of structural breaks are broadly similar to those obtained in net exporting countries with exception of Ethiopia, Kenya and Morocco. The events causing structural breaks in world energy markets did not generate structural breaks in the energy consumption-economic growth relationship in these countries. Furthermore, for Benin, Ghana, Senegal and Tanzania, whose economies are predominantly agricultural-based, the first structural breaks occurred before the commodity crisis. In the other countries such as Togo, Tunisia, Zambia and Zimbabwe, the first structural appeared in the 1980s during the commodities crisis of the 1980s. Except for Tunisia, most of these countries are largely monoculture and rely on one or two commodity exports. For instance, in Zambia the copper sector represents 90% of tax exports (Cashin et al., 2003). In this regard, a perennial balance of payment deficit, brought about largely by commodity price fluctuation and adverse terms of trade led these countries to be heavily indebted.

4.3. Results of DOLS and panel causality tests

As mentioned above, we use two techniques to obtain the parameter estimates of the panel error-correction model for the relationship between real GDP, energy consumption, price index, labor and capital: DOLS for the long-run parameters and PMG for the short and long-run parameters. Table 8 shows the DOLS results. All the coefficients are positive and statistically significant at the 1% significance level and given the variables are expressed in natural logarithms, the coefficients can be interpreted as elasticity. Overall, the outcomes of this study show that there is strong long-run relationship between real GDP, energy consumption and the other control variables. The results on the global sample suggest that a 1% increase of energy consumption, consumer price index, labor and capital increases real GDP respectively by 0.369%, 0.020%, 0.363% and 0.564%. Thus, energy consumption is the second more contributing factor to real GDP, after capital in African countries. There is difference in results when country groups are considered. For instance, in net energy exporters, a 1% increase of energy consumption, consumer price index, labor and capital increases real GDP respectively by 0.570%, 0.068%, 0.592% and 0.275%. As far as net energy importers are concerned, a 1% increase of energy consumption, consumer price index, labor and capital increases real GDP respectively by 0.272%, 0.012%, 0.167% and 0.664%.

We also carefully investigate whether the (long-run) coefficients can be considered as being the same in the different countries for our three panels using a Fisher statistics. Our results indicate that with a p-value of 0.005 the null hypothesis of coefficients equality for all countries taken together is strongly rejected at any conventional level of significance. However with p-values respectively of 0.11 and 0.15 this same hypothesis is not rejected by data for the energy exporters and importers panels taken separately. Moreover, the null hypothesis of the coefficients equality between energy exporters and energy importers is rejected at 1% significance level.[15] Then, energy consumption affects in different way economic growth in energy exporting and energy importing countries.

Comparisons of the elasticity estimates in both sub-samples imply that the energy endowment has an impact on the responsiveness of real GDP to the various variables (energy usage, consumer price index, labor and capital). Probably, the need for energy input is especially relevant in energy exporting countries as they are energy-intensive users in the extraction and production of energy. Hence, energy consumption increases and this in turn can increase value added to GDP by way of output and exports.

Compared to the results of other FMOLS and DOLS estimates using panel data in developing countries, the elasticity of energy consumption in African countries is within the range of these studies.[16] For the sample as a whole, the elasticity of energy usage with respect to real GDP is slightly smaller than the 0.50% reported by Lee (2005) for a sample of 18 developing countries, and the 0.41%, 0.52% and 0.49%, respectively for low income countries, low middle income countries and upper middle income countries reported by Ozturk et al. (2010). However, the elasticity estimate associated with energy usage is larger for different country groups than the 0.24% reported by Apergis (2009b) for a panel of Commonwealth of Independent States (CIS) excluding Russia, the 0.04% reported by Narayan and Smyth (2009) for 6 Middle Eastern countries, the 0.25% for 22 OECD countries reported by Lee et al. (2008) and the 0.12% reported by Narayan and Smyth (2009) for G7 countries.

Table 8: Panel DOLS long-run estimates

	All countries	**Energy exporters**	**Energy importers**
E	0.369 (0.026)***	0.570 (0.033)***	0.272 (0.037)***
P	0.020 (0.007)***	0.068 (0.013)***	0.012 (0.005)**
L	0.363 (0.017)***	0.592 (0.022)***	0.167 (0.017)***
K	0.564 (0.016)***	0.275 (0.029)***	0.664 (0.018)***
Const.	1.893 (0.134)***	2.308 (0.154)***	2.171 (0.208)***
R2	0.813	0.819	0.812
Obs.	714	340	374

Notes: Standard errors are reported in parentheses. *** Significant at 1 percent and ** significant at 5 percent.

[15] Under the null hypothesis that coefficients of exogenous variables are equal across sub samples the Fisher statistic is: $F(J,n-2K)=\left[\left(SSR-SSR^{I}-SSR^{E}\right)/J\right]/\left[\left(SSR^{I}+SSR^{E}\right)/n-2K\right]$, where *SSR*, SSR^{I} and SSR^{E}, are the sum of squared residuals from the regression on global sample, energy importer and energy exporter's countries, respectively; *n* is the number of observations, *K* the number of exogenous variables and *J* the number of restrictions.

[16] We do not report here the results on times series papers.

After establishing that economic growth is linked in the long-run with energy consumption, price index, labor and capital, we need to examine the causality between the five variables. Panels A, B and C of Table 9 report the results of the short-run and long-run Granger-causality tests for each panel data set. The optimal lag structure of two years is chosen using the Schwarz Bayesian Criterion. In panel A which includes all countries of our sample, Eq. (14a) shows that energy consumption, labor force and capital have a positive and statistically significant impact in the short-run on economic growth whereas price index has negative impact on economic growth. The sum of the lagged coefficients indicates that energy consumption (0.337) has greater impact on real GDP than labor force (0.279) and less than real gross fixed capital formation (0.413).[17] This highlights the importance of energy in the economic growth process in African countries. Moreover, the error correction term is statistically significant at 5% and denotes the speed of adjustment to long-run equilibrium. In term of Eq. (14b), it appears that economic growth and capital have positive impact on energy consumption, whereas, labor has no impact on energy consumption. On the other hand, the impact of price index is negative in the short-run. Then, there is complementarity between energy usage and capital, and substitutability between price index and energy consumption. The statistically significance at 1% of the error correction term suggests that energy consumption responds to deviations from long-run equilibrium. In regards to Eq. (14c), it is not surprising that energy consumption has positive impact on price index, and the other variables are not significant. There is also no evidence for long-run adjustment in price index, because the error correction term is statistically insignificant. With respect to Eq. (14d), both real GDP and capital have a positive and statistically significant impact on labor in the short-run, while the impact of energy is statistically insignificant. Finally, in Eq. (14e), real GDP and energy consumption have a positive and significant impact on capital, whereas price index have negative impact and labor is statistically insignificant. In terms of the long-run dynamics, based on the statistical significance of the error correction terms from Eqs. (14d)-(14e), capital and the labor force each responds to deviations from long-run equilibrium. Overall, the relationship between energy consumption and economic growth is characterized by bidirectional causality, in both the short and long-run.

As far as the short-run dynamics in energy exporters and energy importers countries is concerned, the Eq. (14a) shows that energy consumption, prices, labor and capital each have a positive and statistically significant impact on economic growth in the short-run. This suggests that energy can be a driving force to enhance economic growth in both African energy importer and energy exporter countries. With respect to Eq. (14b), real GDP and price index have significant impact in short-run on energy consumption in net energy importers and exporters, while labor has significant effect only in energy exporters and capital does not affect energy consumption in both sub-sample. Unlike to energy exporter countries, where energy consumption only has significant impact on prices, all other variables affect prices level in energy importer countries (Eq. 14c). However, in regard to Eq. (14d), the impact of real GDP, energy consumption and capital is significant in energy exporters, whereas real GDP and CPI only have significant effect in net importer countries. In terms of Eq. (14e), it appears that real GDP, energy consumption and prices have significant impact on capital in both countries group, whilst labor is only significant in energy exporter countries. Concerning the long-run relationship, the error correction terms are statistically significant (except for consumer price index), but the speed of adjustment can vary according to the country groups.

[17] These results are robust to Fisher tests. For example, the test statistics ($F_{(1,724)}$=5.01 and $F_{(1,724)}$=4.12) reject the null hypothesis for equality between sum of lagged values of energy consumption and labor, and sum of lagged values of energy consumption and capital, respectively at the 5% significance level.

Table 9: Panel causality tests[18]

Dependant variables	Sources of causality					
	Short-run					**Long-run**
	ΔY	ΔE	ΔP	ΔL	ΔK	ECT
Panel A - All countries						
(14a) ΔY	-	11.26*** [0.337]	4.56** [-0.021]	8.50*** [0.279]	11.17*** [0.413]	-0.115** (-2.667)
(14b) ΔE	4.47** [0.184]	-	5.63*** [-0.089]	1.32 [0.017]	4.21** [0.482]	-0.277*** (-3.801)
(14c) ΔP	2.49 [-0.208]	19.16*** [0.292]	-	2.06 [-0.605]	2.83 [0.221]	-0.025 (-0.963)
(14d) ΔL	5.21*** [0.475]	1.53 [0.191]	8.11*** [-0.097]	-	3.56** [0.563]	-0.053*** (-2.726)
(14e) ΔK	7.39*** [0.532]	6.03*** [0.688]	14.53*** [-0.125]	2.67 [0.091]	-	-0.328*** (-3.816)
Panel B - Energy exporters						
(14a) ΔY	-	7.13*** [0.295]	5.02*** [-0.029]	7.21*** [0.166]	15.26*** [0.612]	-0.189*** (-2.462)
(14b) ΔE	3.29** [0.137]	-	3.97** [-0.051]	3.90** [-0.962]	2.66 [0.049]	-0.174*** (-2.223)
(14c) ΔP	2.72 [-0.391]	12.21*** [0.189]	-	2.38 [-0.134]	2.30 [0.219]	-0.005 (-1.218)
(14d) ΔL	3.15** [0.230]	4.82*** [0.175]	2.87 [-0.043]	-	3.11** [0.213]	-0.066* (-1.572)
(14e) ΔK	13.74*** [1.786]	7.24*** [0.843]	9.54*** [-0.144]	3.21** [0.112]	-	-0.288*** (-2.687)
Panel C - Energy importers						
(14a) ΔY	-	10.34*** [0.394]	4.29*** [-0.035]	6.71*** [0.435]	7.81*** [0.511]	-0.073*** (-2.414)
(14b) ΔE	5.41*** [0.194]	-	6.23*** [-0.107]	1.31 [0.065]	1.67 [0.028]	-0.391*** (-3.273)
(14c) ΔP	3.16** [-0.379]	3.35** [0.164]	-	3.08** [-0.176]	4.39** [0.156]	-0.009 (-0.712)
(14d) ΔL	3.89** [0.145]	2.74 [0.103]	6.23*** [-0.048]	-	2.43 [0.121]	-0.041*** (-2.586)
(14e) ΔK	5.83*** [1.451]	4.76*** [0.744]	4.28** [-0.103]	2.16 [0.218]	-	-0.431*** (-3.183)

Notes: Partial *F-statistics* are reported with respect to short-run changes in the independent variables. ECT represents the coefficient of the error correction term. *t-statistics* are reported in parentheses. The sum of the lagged coefficients for the respective short-run changes is denotes in brackets *** Significant at 1 percent and ** significant at 5 percent.

The impact of economic growth on energy consumption is greater in energy importers than energy exporters. This outcome suggests that in energy producing countries, since they have significant endowment of energetic resources, increasing in production does not generates huge changes in energy use, because this consumption is already high. Conversely, in energy

[18] Note that the panel causality results for all countries taken together are only given here for information purpose and may not be too reliable since as indicated earlier they restrict the coefficients to be the same in all 21 countries, an assumption which is only valid for the energy exporters and importers panels taken separately.

importers, an increase in GDP could significantly affect energy consumption for two raisons: first, economic growth could increase producing activities and infrastructures building, then enhance energy needs, because this latter is an important input in the production process. Second, insofar as production increased, higher revenues are distributed to households. In search of comfort, households can improve their living through higher energy goods such as household appliances, transport or computers. Our results overall show that energy consumption and economic growth are interrelated and may very well serve as complements to each other. Hence, an increase in real GDP enhances energy consumption and this in turn can increase production in real sector. This explains the bidirectional causality obtained between energy consumption and growth.

4. Conclusion and policy implications

The aim of this study was to shed light on the relationship between energy consumption, economic growth and auxiliaries' variables for 21 African countries over the period from 1970 to 2006. We have made use of recent panel unit root tests, Pedroni (1999) and Westerlund (2006, 2007) panel cointegration and causality tests to analyse the nexus between energy consumption and economic growth. Since African countries react in different ways to energy shock, the sample is divided into two groups: net energy importers and net energy exporters. Our results reveal that there is a long-run equilibrium relationship between real GDP, energy consumption, consumer price index, labor and capital. Moreover, we find that decreasing energy consumption decreases growth and vice versa, and that increasing energy consumption increases growth, and vice versa, and that this applies for both energy exporters and importers. This result is robust to possible cross-country dependence and still holds when allowing for multiple endogenous structural breaks, which can differ among countries. Note however that a possible limitation of our analysis is related to the specific panel causality results for all 21 countries taken together for which the long-run coefficients cannot actually be considered as being the same for all countries. This may explain why some of our results for this panel differ to those of other authors.

From a policy perspective, the results mean that adopting an apparently simple solution of reducing energy use is not going to help with development. What is necessary is to alter the relationship between energy use and growth. In this regard, one solution consists in focusing on energy efficiency, that is, to produce the same output or consume the same energy services (like heat, cooling, light, appliance use etc.) provided by energy-using products in a more efficient way. Of course, this would require capital investment, but to the extent that capital is less environmentally harmful than energy consumption, this might be a choice that is necessary to make.

Furthermore, given that the estimated structural break dates are globally in accordance with great shocks i.e. mainly occurred during the energy crisis, it implies that energy crisis have a significant impact on the energy consumption-economic nexus. Thus, countries that are energy-dependent such as net importing countries should actively practice some energy policy, i.e. the oil reservation mechanism, the improvement of energy consumption efficiency and the development of substitute energy for oil, in order to reduce the negative energy crises on their economic growth.

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