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Energy Consumption and Economic Growth in Ethiopia: Evidence from ARDL Bound Test Approach

A b s t r a c t. The present study aims to investigate the dynamic relationship between economic growth and energy consumption. Specifically, the study tries to answer the questions whether energy consumption has any significance effect on economic growth of the country and it also determined the magnitude of the effect. In doing this, the study used an ARDL bound test approach to analyze Ethiopian data from 1970 to 2017 with real GDP as a function of energy consumption, human capital., physical capital., trade openness and policy change dummy. To do so, secondary data were obtained from WDI, UNCTAD stat and NBE. Co-integration test approves the existence of long-run relationship among the variables. Moreover, the estimation result reveals that, energy consumption found statistically insignificant in affecting economic growth in the long-run. However, it was positive and statistically significant in short-run. Likewise, the dummy variable incorporated to capture the policy change found insignificant in long-run and with positive significant result in short-run. Also, we applied the Granger causality test in linear multivariate models to evaluate how important is the causal impact of energy consumption on economic growth. The results give the evidence of causality running from economic growth to energy consumption supporting "conservation hypothesis", implying that reducing energy consumption may be implemented with little or no adverse effect on economic growth. Hence, this study recommended the policy makers to improve the existing policies on energy consumption so as to enhance the level of efficiency in the energy sector i.e. energy regulation policies supporting the shift from lower-quality to higher-quality energy services.

K e y w o r d s: economic-growth, energy-consumption, ARDL, Ethiopia, causality.

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Introduction

Arguably, energy plays a vital role in economic and social development. The role of energy in economic growth has long been a controversial topic in economics literature. As a result, the ongoing debate among energy economists about the relationship between energy use and output growth led to the emergence of two opposite views. One point of view suggests that energy is the prime source of value because other factors of production such as labor and capital cannot do without energy. According to this argument, energy use is expected to be a limiting factor to economic growth. The other point of view suggests that energy is neutral to growth. This is what became to be known in the literature as the 'neutrality hypothesis'. The main reason for the neutral impact of energy on growth is that the cost of energy is very small as a proportion of GDP and, thus, it is not likely to have a significant impact on output growth. It has also been argued that the possible impact of energy use on growth will depend on the structure of the economy and the stage of economic growth of the country concerned (Ghali and El-Sakka, 2009).

Theoretical disagreement on the role of energy is matched by mixed empirical evidence. That is, whether economic growth leads to energy consumption or that energy consumption is the engine of economic growth. The direction of causality has significant policy implications. Empirically it has been tried to find the direction of causality between energy consumption and economic activities for the developing as well as for the developed countries employing the Granger or Sims techniques.

Like other developing countries Ethiopia is energy using growing economy, with energy production of 14.1 and 30.9 total million metric tons of oil equivalent in 1990 and 2016 respectively. The biomass energy use is predominant which accounts 93.9% and 90.2% for the year 1990 and 2016 respectively and the balance goes to the modern energy. This shows that there is a gradual shift from traditional to modern energy sources (WDI, 2017). Moreover, it is believed that the modern energy penetration rate has increased as of 2017 because of the commissioning of the three hydro power plants in the country. Ethiopia is non-oil producing countries and its fossil oil energy needs are met by large quantities of imports.

The preceding facts show the power sector in Ethiopia is underdeveloped and hence energy consumption is very low. As a result, Ethiopia is far from having satisfied the current energy demand of its people. Cognizant of this problem and in line with the millennium development goals, Ethiopia is trying to provide energy to its citizens by investing in major modern energy infrastructures in the country. This show that Ethiopia has recognized that accessibility to affordable energy services is a prerequisite to poverty alleviation, and necessary condition for sustainable economic growth. This policy goal implies that increased energy consumption can help achieve social development and enhance economic growth.

Thus, to meet its growing needs of energy, Ethiopia faces both energy constraints from the supply side and demand management policies (EEA, 2009). The current concerns about global warming also poses a question about how can economic growths in Ethiopia, will be reconciled with stabilization in the use of both traditional and fossil fuels. However, for any such policy making it is essential to determine the causal relationship between energy consumption and general economic activities.

It is important, therefore, to ascertain empirically whether there is a causal link between energy consumption and economic growth in Ethiopia. This is particularly true given the current debate about global warming and the need to reduce Greenhouse Gas Emissions by conserving energy consumption, since any constraints put on energy consumption to help reduce emissions will have an effect on growth and development if causality from energy to GDP exists.

Moreover, Ethiopia has huge potential of modern energy resources; however, availability of modern energy per se is not enough for the economic and social problems facing the country.

The power investment that is currently taking place in Ethiopia is part of the process of the recognition that the quality and quantity of modern power supply can play a pivotal role in the country's social and economic development. This investment process is implicitly based on the assumption that investment in modern energy and the drive towards making the modern energy sector more efficient can promote economic growth.

Although energy use is a reflection of climatic, geographic and economic factors (such as the relative prices of energy), it is closely related to the growth in the modern sectors (industry, motorized transport and urban areas). "There is a strong connection between the energy sector and a national economy. On the one hand, energy demand, supply and pricing have significant impact on socio-economic development and the overall quality of life of the population. On the other hand, the nature of economic structure and the change in that structure, the prevailing macro-economic conditions are key factors of energy demand and supply" (EEA, 2009).

The data compiled by Energy Information Administration for the periods 1980 to 2014 shows that GDP per capita have strong correlation coefficient of 0.6 with energy consumption (EEA, 2016). Although the existence of correlation between the two implies the existence of causality, on the other hand it is source of doubt, on the part of many growth theorists. The fact that economic growth tends to be very closely correlated with energy consumption, does not a priori mean that energy consumption is the cause of the growth. Indeed, most economic models assume the opposite: that economic growth is responsible for increasing energy consumption. It is also conceivable that both consumption and growth are simultaneously caused by some third factor.

With this background, (that is growing of different school of thought with regard to resource consumption in general and energy consumption in particular) there are numerous researches which have tried to figure out the casual relationship between energy use growth and economic growth.

The answers to questions pose in the hypothesis, which are recognized in many previous studies, have important implications for policy makers. As noted by Wolde-Rufael (2005), amongst others, if causality runs from energy consumption to GDP then it implies that an economy is energy dependent and hence energy is a stimulus to growth implying that a shortage of energy may negatively affect economic growth or may cause poor economic performance, leading to a fall in income and employment. In other words, energy is a limiting factor in economic growth (Stern, 2010). Whereas if causality only runs from GDP to energy consumption this implies that an economy is not energy dependent hence, as noted by Masih and Masih (1997) amongst others, energy conservation policies may be implemented with no adverse effect on growth and employment. If, on the other hand, there is no causality in either direction (referred to as the 'neutrality hypotheses), it implies that energy consumption is not correlated with GDP, so that energy conservation policies may be pursued without adversely affecting the economy.

The non-existence of such research work in the country, at least to the knowledge of the research worker, shows there is a gap to be filled, so that energy policy lesson can be drawn. And the inconclusive empirical results which make it difficult to draw a conclusion about Ethiopia and the important role energy plays in economic development in country, the purpose of this paper is therefore, to fill this gap by attempting to undertake the energy economic growth nexus employing multivariate model consisting of GDP, physical capital., human capital & energy consumption growth.

Moreover, previous studies are that most of them are used Johansen co-integration method of vector autoregressive method as their method of analysis. Even though the Johansen's co-integration technique is one of the widely used methods of time series analysis, its outcome could not be reliable for small sample size; that is observations less than 80 years for the time series data (Narayan, 2005; Udoh et al., 2012). Relatively, the Autoregressive distributed lag (ARDL) method has some advantage over the Johansen's method

(Pesaran et al., 1999). These advantages are it can be applied irrespective of whether the regressors are I(1) and I(0). It can also provide valid and statistically significant result or avoids the problem of biasness in small sample sizes (Pesaran et al., 1999; Narayan, 2005; Chaudhry et al., 2006; Udoh et al., 2012). This ARDL procedure can provide unbiased and valid estimates of the long run model even when some of the regressors are endogenous (Harris et al., 2003, Pesaran et al., 1999; Ang, 2007). Furthermore, in using this Approach, a dummy variable can be included in the co-integration test process, which is not permitted in Johansen's method (Rahimi et al., 2011). Hence in this paper, ARDL model is adopted so as to provide valid empirical evidence on the main target of this study which is assessing the nexus between energy consumption and economic growth in Ethiopia.

The overall objective of this paper is to empirically investigate the nexus between energy consumption and economic growth in Ethiopia. More specifically: to empirically examine the effect of energy consumption on the aggregate economic growth of Ethiopia in both short run and long run and to investigate the possible causal relationship between economic growth and energy consumption in Ethiopia, the ARDL bound test approach and Granger's causality test were used.

The reminder of the paper organized as follows. Section 2 includes review literature, section 3 presents methodology applied in the study, Section 4 reports the findings and discussion of our analysis and conclusion follows in section 5.

1. Review of Related Literature

1.1. Theoretical Literature

The laws of thermodynamics and the conservation of matter describe the immutable constraints within which the economic system must operate. The mass-balance principle means that, in order to obtain a given material output, greater or equal quantities of matter must be used as inputs with the residual a pollutant or waste product. Therefore, there are minimal material input requirements for any production process producing material outputs. The second law of thermodynamics (the efficiency law) implies that a minimum quantity of energy is required to carry out the transformation or movement of matter or, more generally, perform physical work. Carrying out transformations in finite time requires more energy than these minima. All production involves work. Therefore, all economic activities must require energy, and there must be limits to the substitution of other factors of production for energy so that energy is always an essential factor of production.

Primary factors of production are defined as inputs that exist at the beginning of the period under consideration and are not directly used up in production (though they can be degraded or accumulated from period to period), while intermediate inputs are those created during the production period under consideration and are used up entirely in production. Mainstream economists usually think of capital., labor and land as the primary factors of production, and goods (such as fuels and materials) as intermediate inputs. The prices paid for the various intermediate inputs are seen as eventually being payments to the owners of the primary inputs for the services provided directly or embodied in the produced intermediate inputs. This approach has led to a focus in mainstream growth theory on the primary inputs, and in particular, capital and labor. The classical factor of land, including all-natural resource inputs, gradually diminished in importance in economic theory as its value share of GDP fell steadily and is usually subsumed as a subcategory of capital.

Growth Models with Resources and no Technical Change

Adding non-renewable natural resources that are essential in production to the basic mainstream growth models means that capital also needs to be accumulated to compensate for resource depletion. When there is more than one input – both capital and natural resources – there are many alternative paths that economic growth can take, determined by both the nature of technology and institutional arrangements. Solow showed that sustainability is achievable in a model with a non-renewable natural resource with no extraction costs and non-depreciating capital when the elasticity of substitution between the two inputs is unity, and when certain other technical conditions are met. Sustainability, and even indefinite growth in consumption, can occur when the utility of individuals is given equal weight without regard to when they happen to live. However, under competition the same model economy results in exhaustion of the resource and consumption and social welfare eventually fall to zero. With any constant discount rate, the efficient growth path also leads to eventual depletion of the natural resource and the collapse of the economy. The Hartwick rule shows that if sustainability is technically feasible, a constant level of consumption can be achieved by reinvesting the resource rents in other forms of capital., which in turn can substitute for resources.

A common interpretation of this body of work is that substitution and technical change can effectively decouple economic growth from the use of energy and other resources. Depleted resources can be replaced by more abundant substitutes, or by 'equivalent' forms of human-made capital (people, machines, factories, etc.).

Growth Models with Resources and Technical Change

In addition to substitution of capital for resources, technological change might permit growth or at least constant consumption in the face of a finite resource base. When the elasticity of substitution between capital and resources is unity, exogenous technical progress will allow consumption to grow over time if the rate of technological change divided by the discount rate is greater than the output elasticity of resources. Technological change might enable sustainability even with an elasticity of substitution of less than one. Once again, technical feasibility does not guarantee sustainability. Depending on preferences for current versus future consumption, technological change might instead result in faster depletion of the resource. Therefore, mainstream economic growth theory assumes that resource consumption is a consequence, not a cause, of growth.

Synthesis: Unified Models of Energy and Growth

The mainstream growth models ignore energy in the economic growth, by contrast, the ecological economics literature posits a central role for energy in driving growth but argues that limits to substitutability and/or technological change might limit or reverse growth in the future. But none of the models and theories reviewed so far really provides a satisfactory explanation of the long-run history of the economy. Until the industrial revolution, output per capita was generally low and economic growth was not sustained. Ecological economists point to the invention of methods to use fossil fuels as the cause of the industrial revolution. But the mainstream growth models that ignore energy resources can at least partly explain economic growth over the last half a century.

There are currently two principal mainstream theories that explain the growth regimes of both the preindustrial and modern economies and the cause of the industrial revolution, which formed the transition between them. These are endogenous technical change approach, and the second approach is represented by two sectors – Malthusian Sector and Solow Sector.

To integrate the different approaches, Stern (2011) proposed to modify Solow's growth model. In the model Stern added an energy input that has low substitutability with capital and labor, while allowing the elasticity of substitution between capital and labor to remain at unity. In this model, depending on the availability of energy and the nature of technological change, energy can be either a constraint on growth or an enabler of growth. Omitting time indexes for simplicity, the model consists of two equations:

$$Y = [(1-\gamma)\,(A_L{}^{\beta}B^{\beta}\,K^{1-\beta} + \gamma(A_E E)\Phi\,)]\Phi \quad (1)$$

$$\Delta K = s(Y - P_E E) - \delta K \quad (2)$$

Equation (1) embeds a Cobb–Douglas production function of capital (K) and labor (L) in a constant elasticity of substitution (CES) function of value added and energy (E) that produces gross output Y.

$$\phi = (\delta - 1)/\,\delta;$$

Where δ is the elasticity of substitution between energy and the value-added aggregate; P_E the price of energy; and γ is a parameter reflecting the relative importance of energy and value added. A_L and A_E are the augmentation indexes of labor and energy, which can be interpreted as reflecting both changes in technology that augment the effective supply of the factor in question and changes in the quality of the respective factors.

Equation (2) is the equation of motion for capital that assumes like Solow that the proportion of gross output that is saved is fixed at s and that capital depreciates at a constant rate δ. As $\delta \rightarrow 1$and $\gamma \rightarrow 0$ we have the Solow model as a special case, where in the steady state, K and Y grows at the rate of labor augmentation. Additionally, depending on the scarcity of energy, the model displays either Solow-style or energy constrained behaviour.

1.2. Empirical Literature Review

Over the past few years, the relationship between energy consumption and economic growth has been extensively researched. Yet, there seems to be no consensus regarding the direction of causality between energy consumption and economic growth.

In a study of over more than hundred countries, Chontanawat et al. (2008) find that the causal relationship between energy consumption and economic growth is more pronounced in developed than in developing countries. Causality running from energy consumption to economic growth. Ethiopia was included in the study and the result shows there is Granger causality running from economic growth to energy consumption.

Stern (1993) examined the causal relationship between energy use and GDP in the USA. He employed a multivariate vector autoregressive (VAR) analysis and used a weighting index of energy quality, where content of energy use shifts from lower quality energy such as coal to high quality energy such as electricity, rather than using a measure of total energy use. Also, found that total energy use does not Granger cause GDP.

Masih and Masih (1996) used cointegration analysis to study this relationship in a group of six Asian countries and found cointegration between energy use and GDP in India, Pakistan, and Indonesia. No cointegration is found in the case of Malaysia, Singapore and the Philippines. The flow of causality is found to be running from energy to GDP in India and from GDP to energy in Pakistan and Indonesia.

Nondo and Mulugeta (2009) applied panel data techniques to investigate the long-run relationship between energy consumption and GDP for a panel of 19 African countries (COMESA) based on annual data for the period 1980–2005. They have estimated the long-run relationship and test for causality using panel-based error correction models. The results indicate that long-run and short-run causality is unidirectional., running from energy consumption to GDP. The paper did not elaborate county specific result, it simply indicated the result in its aggregate form, and the study did not include Ethiopia.

Using a bivariate analysis Ebohon (1996), examines the causal directions between energy consumption and economic growth for Nigeria and Tanzania. The results show a simultaneous causal relationship between energy and economic growth for both countries. In a bivariate relationship between energy consumption and economic growth in African countries, Wolde-Rufael (2005) also found conflicting evidence with the neutrality hypothesis supported in a substantial number of countries, with little support for the hypothesis that energy consumption causes economic growth.

Bi-directional causality was detected for two countries, Gabon and Zambia. For the remaining nine countries where there was no causality in any direction between economic growth and energy consumption, energy consumption seems neither to promote nor to retard economic growth.

The most striking result of the empirical evidence is that the introduction of both gross capital formation and labor has altered the direction of causality in thirteen countries that were previously investigated by Wolde-Rufael (2005). In seven of the countries where Wolde-Rufael (2005) found no evidence of causality in any direction between energy consumption and economic growth, he now found evidence of Granger causality for seven of these countries, Benin, Senegal., South Africa, Sudan, Togo, Tunisia and Zimbabwe. In Benin and South Africa causality runs now from energy consumption to economic growth; in Senegal., Sudan and Tunisia causality runs now from economic growth to energy consumption, and in Togo and Zimbabwe we find now that energy and economic growth were mutually causal.

Causality was also reversed in another six counties: Algeria, Cameroon, Gambia, Ghana, Morocco and Nigeria. In Algeria causality was reversed from economic growth to energy consumption, to the opposite causality running from energy consumption to economic growth contrary to the no causality found by Chontanawat et al. (2008).

Amirat and Bouri (2010) undertook analyses of the causal relationship between the per capita energy consumption and the per capita GDP in Algeria by using annual data from 1980 to 2007. They include capital and labor as additional variables to the energy growth nexus. They used Granger causality test and the variance decomposition analysis. The results give the evidence of causality running from energy consumption to economic growth.

Similarly, using a multivariate causality test, Akinlo (2008) found also conflicting results for eleven African countries. The result shows that energy consumption is co-integrated with economic growth in seven of the countries. In addition, in few of the countries, the result suggests that energy consumption has a significant long run impact on economic growth.

Olatunji Adeniran (undated) tested for causal relationship between energy consumption and GDP in Nigeria using systematic econometric techniques. The study found that there is a unidirectional causality that runs from GDP to electricity consumption.

Jumbe (2004) examined cointegration and causality between electricity consumption (kWh) and, respectively, overall GDP (GDP), agricultural GDP (AGDP) and non-agricultural GDP (NGDP) using Malawi data for 1970–1999 periods. The results show that kWh is, respectively, cointegrated with GDP and NGDP, but not with AGDP. The granger causality results show a bi-directional causality between kWh and GDP, but a unidirectional causality running from NGDP to kWh.

Yohannes (2010) has conducted causal relationship between economic growth and energy consumption in Ethiopia and he found energy consumption Granger cause economic growth.

2. Methodology of the Study

Autoregressive Distributive Lag (ARDL) Approach to Co-integration

So as to capture the nexus between energy consumption and economic growth, time series secondary data was employed. Data for all variables was taken from only two sources so as to keep its consistency and avoid possible biases due to difference in measurement techniques. The data sources for this study were World Bank (WB) and UNCTAD. The study considers annual data of Ethiopia for the years from 1970 to 2017.

Most of the time series studies in this area previously conducted are used the Engle-Granger approach following Engle and Granger (1987) and the Johansen's co-integration technique following Johansen (1988) and Johansen and Juselius (1990). But its outcome could not be reliable for small sample size (Narayan, 2005; Udoh et al., 2012). Relatively, the Autoregressive distributed lag method of co-integration (ARDL) has more advantage over the Johansen's method (Pesaran et al., 1999). Johansen's co-integration technique requires that all the variables in the system have equal order of integration, that is the application of the Johansen technique will fail when the underlying regressors have different order of integration, especially when some of the variables are $I(0)$ (Pesaran et al., 2001). That means the trace and maximum eigen value tests may lead to erroneous co-integrating relations with other variables in the model when $I(0)$ variables are present in the system (Harris, 1999).

Fortunately, to overcome this problem a new Autoregressive Distributed Lag (ARDL) model is developed by Pasaran, Shin and Smith (2001) which have more advantages than the Johansen co-integration approach. First, the ARDL approach can be applied irrespective of whether the regressors are I(1) and I(0) or have a mix of these integration orders. The only exception is that none of the variables in the model is integrated of order 2 or higher. Second, while the Johansen co-integration techniques require large data samples for validity, the ARDL procedure provides statistically significant result in small samples (Pesaran et al., 1999; Narayan, 2005; Udoh et al., 2012). That means, it avoids the problem of biasness that arise from small sample size (Chaudhry et al., 2006). Third, the ARDL procedure provides unbiased and valid estimates of the long run model even when some of the regressors are endogenous (Harris et al., 2003; Pesaran et al., 1999; Ang, 2007).

Moreover, the ARDL procedure employs only a single reduced form equation, while the other co-integration procedures estimate the long-run relationships within a context of system equations. Further, in using the ARDL approach, a dummy variable can be included in the co-integration test process, which is not permitted in Johansen's method (Rahimi et al., 2011). Therefore, in order to achieve the targeted objectives of the study, the model of economic growth equation is estimated using ARDL model of econometric technique.

The above advantages of the ARDL technique over other standard co-integration techniques justify the application of ARDL approach in the present study to investigate the link between economic growth and energy consumption.

The Empirical Model in ARDL Framework

According to Pesaran and Pesaran (1997), the ARDL approach requires the following two steps. In the first step, the existence of any long-term relationship among the variables of interest is determined using an F-test. The second step of the analysis is to estimate the coefficients of the long-run relationship and determine their values, followed by the estimation of the short-run elasticity of the variables with the error correction representation of the ARDL model. By applying the ECM version of ARDL, the speed of adjustment to equilibrium will be determined. According to Pesaran and Pesaran (1997), the ARDL model is represented by the following equation:

After checking for the order of integration of all variables in the model, the Autoregressive Distributed Lag (ARDL) model involves two steps for estimating the long-run relationship (Pesaran et al., 2001). In the first step the existence of long-run relationship among all variables in an equation should be examined and then in the second step the long-run and short-run coefficients of the variables can be estimated in the model. One can run the second step only if we find along run co-integration relationship among the variables in the first step.

In order to examine the long-run relationship and dynamic interaction between economic growth and energy consumption, this study employs an ARDL model. In general., there are three steps in estimating the model. The first step is to estimate the long-run relationship among the variables. This is done by testing the significance of the lagged levels of the variables in the error correction form of the underlying ARDL model. Our ARDL model can be written as follows:

$$\begin{aligned}\Delta LNRGDP_t = \alpha_0 &+ \beta_1 LNRGDP_{t-1} + \beta_2 LNENERGY_{t-1} + \beta_3 LNTO_{t-1} \\ &+ \beta_4 LNPC_{t-1} + \beta_5 LNHC_{t-1} + \sum_{i=1}^{p} \delta_1 \Delta LNRGDP_{t-i} \\ &+ \sum_{i=1}^{p} \delta_2 \Delta LNENERGY_{t-i} + \sum_{i=1}^{p} \delta_3 \Delta LNTO_{t-i} \\ &+ \sum_{i=1}^{p} \delta_4 \Delta LNPC_{t-i} + \sum_{i=1}^{p} \delta_5 \Delta LNHC_{t-i} + \gamma D\_energy + \varepsilon_t\end{aligned}$$

where, LNRGDP is log of real GDP, LNENERGY is log of energy consumption, LNTO is log of trade openness, LNPC is log of physical capital., $LNHC$ is log of human capital. The selection of the optimum lagged orders of the ARDL models is based on Akaike Information criteria (AIC). In order to test

co-integration among the variables, the Wald F-statistics for testing the joint hypotheses has to be compared with the critical values as tabulated by Pesaran et al. (2001).
The joint hypotheses to be tested are:

$$H_0: \beta_1 = \beta_2 = \beta_3 = \beta_4 = \beta_5 = \beta_6 = \beta_7 = 0$$

$$H_1: \beta_i \neq 0 \, , i = 1{,}2 \dots .7$$

If the F-statistics is higher than the upper bound critical value, the null hypothesis (H_0) is rejected, indicating that there is a long run relationship between the lagged level variables in the model. In contrast, if the F-statistic falls below the lower bound, then the H_0 cannot be rejected and no long run relationship exists. However, if the F-statistics falls in between the upper bound and lower bound critical values, the inference is inconclusive. At this condition, the order of integration of each variable should be determined before any inference can be made.

In the second step, once the co-integration is established, the conditional *ARDL (p,q,r,s,t,)* long-run model of the economic growth and energy consumption can be estimated as below:

$$LNRGDP_t = \alpha_0 + \sum_{i=1}^{p} \beta_1 LNRGDP_{t-1} + \sum_{i=0}^{q} \beta_2 LNENERGY_{t-1} + \sum_{i=0}^{r} \beta_3 LNTO_{t-1} + \sum_{i=0}^{s} \beta_4 LNPC_{t-1} + \sum_{i=0}^{t} \beta_5 LNHC_{t-1} + D + \varepsilon_t$$

In the final step, we obtain the short-run dynamic parameters by estimating an error correction model *(ECM)* associated with the long-run estimates. This is specified as follows:

$$\Delta LNRGDP_t = \alpha_0 + \sum_{j=0}^{n} \beta_1 \Delta LNRGDP_{t-i} + \sum_{j=0}^{n} \beta_2 \Delta LNENERGY_{t-i} + \sum_{j=0}^{n} \beta_3 \Delta LNTO_{t-i} + \sum_{j=0}^{n} \beta_4 \Delta LNPC_{t-i} + \sum_{j=0}^{n} \beta_5 \Delta LNHC_{t-i} + \gamma D + \delta ECTt - 1 + \varepsilon_t$$

where, δ_1, δ_2, δ_3, δ_4, δ_5, δ_6 , δ_7 are the short-run dynamic coefficients of the model's convergence to equilibrium, and δ is the speed of adjustment.

The theoretical foundation of the study is based on the augmented Solow model and endogenous growth model for economic growth equation which aims to show the impact of energy consumption on economic growth of Ethiopia. It is constructed based on the theoretical framework of the augmented Solow Model and endogenous growth model with a modification that extends the basic production function framework to permit human capital as an additional input in to the production function following Romer (1996) and energy following Stern and Cleveland (2004). As implied by Solow's formulation, economic growth is a function of capital accumulation, an expansion of labor force and exogenous factor, technological progress which makes physical capital and labor more productive.

The presence of co-integration alone does not indicate the direction of causality. Hence, we need to test whether the relationship between the variables is unidirectional or bidirectional. Since the underlying series (LNRGDP and LNENERGY) are integrated of the same order, the ordinary Granger causality test can be applied to perform causality tests. The test proceeds in estimating the following two equations.

$$LNRGDP_t = \alpha_0 + \sum_{j=0}^{K} \alpha_1 \Delta LNRGDP_{t-i} + \sum_{j=0}^{K} \alpha_2 \Delta LNENERGY_{t-i} + \varepsilon_{1t}$$

$$LNENERGY_t = \beta_0 + \sum_{j=0}^{K} \beta_1 \Delta LNENERGY_{t-i} + \sum_{j=0}^{K} \beta_2 \Delta LNRGDP_{t-i} + \varepsilon_{2t}$$

The null hypothesis is that:

H_0: $\beta_{11} = \beta_{12} = ... = \beta_{1j} = 0$

Implying LENERGY does not Granger Cause LRGDP

H_1: $\beta_{11} \neq \beta_{12} \neq .... \neq \beta_{1j} \neq 0$

Implying LNENERGY does Granger Cause LNRGDP
The null hypothesis can be stated as:

H_0: $\alpha_{11} = \alpha_{12} = ... = \alpha_{1j} = 0$

Implying LRGDP does not Granger Cause LNENERGY

H_1: $\alpha_{11} \neq \alpha_{12} \neq .... \neq \alpha_{1j} \neq 0$

Implying LNRGDP does Granger Cause LNENERGY

The decision is that there is causality from energy consumption (LNENERGY) to economic growth (LNRGDP) if the null hypothesis H_0: $\beta_{11} = \beta_{12} = ... = \beta_{1j} = 0$ can be rejected at least at 10% level of significance. Similarly, there is causality from economic growth to energy consumption if the null hypothesis H_0: $\alpha_{11} = \alpha_{12} = ... = \alpha_{1j} = 0$ can be rejected at least at 5% level of significance.

Description of the Macroeconomic Variables

The descriptions of the dependent and the explanatory variables that are included in the study model are explained as follows:

Real gross domestic product (RGDP): It is the total market value of all final domestically produced products at constant price. It is a dependent variable of the model. Here RGDP has been transformed into log so as to keep the linearity of the variable vis-á-vis the other variables.

Energy consumption (EC): Energy consumption is proxied by (**GDP per unit of energy use)** which measured by the PPP GDP per kilogram of oil equivalent of energy use.

Physical capital (PC): Capital stock is defined as the value of the existing supply of physical goods that are used in the production process at a given point of time and includes buildings, machinery, equipment and inventory. There are points of view that capital stock is generally believed to be of critical importance, not only as a component of final aggregate demand, but also in terms of the impact of capital stock on the economy's growth and employment opportunities (Ghali, 1999). Hence, we expect that gross capital formation should have a positive coefficient in explaining economic growth.

Human capital (HC): In this study human capital is proxied by secondary school enrolments (% gross). Romer (1996) and Gungor (1997) notes that human capital which describes the knowledge and skills embodied in individuals are an important source of economic growth. Human capital accumulation that is the ability of individuals to solve problems and to think critically is believed to promote higher growth by improving labor force which will be more productive. Therefore, human capital variable is expected to have positive impact on the production and economic growth of the country.

Trade Openness (TO): trade openness is the sum of export and import divided by two divided by GDP and expected to affect economic growth positively. Romer, (1993) claimed that the countries have higher possibility to implement leading technologies from other countries if countries are more open to trade. In addition, Chang et.al (2005) emphasized trade openness promotes the efficient comparative advantage which allows the dissemination of knowledge and technological progress and encourages competition in the international market.

Policy dummy (D): Changes in political and economic policies (the dummy variable D in the model) can influence the performance of the economy through investment on human capital and infrastructure, improvement in political and legal institutions and so on (Easterly, 1993).

3. Results and Discussion

3.1. Empirical Results for Unit Root Testing

It is vital and must to test the nature of stationarity of the variables before running ARDL model, a model used to determine the existence of long run relationship among the variables. Doing so avoids the possibility of running a spurious regression, which makes the result to be unreliable and inconsistent. The null hypothesis of no stationarity cannot be rejected for all variables in level. However, every variable become stationary with trend once they are first differenced. This indicates that none of the above variables are integrated of order two I(2), which is a precondition to use ARDL model (see Appendix 1)

As a result, Autoregressive Distributed Lag approach to Co-integration is the right technique to apply in this scenario. Therefore, ARDL or bound testing approach to co-integration is the preferred and appropriate method of regression in this case.

3.2. Bounds Test for Long Run Relationship

In the ARDL approach to Co-integration, the first step is to test the presence of co-integration or long run relationship among the variables. This test for the long run relationship is done using the F-statistic. Given the annual nature of the data; it is recommended that the optimal lag length for the ARDL model is maximum two lags. Moreover, AIC is used to determine the optimal lag because of small sample size at hand.

The F statistic will then be compared with the lower and upper bounds of Kripfganz and Schneider (2018) critical values, based on the rational mentioned in chapter three. The calculated F-statistics is 5.416 and this value is higher than the upper bound critical values at 5% level of significance. The results indicate that there is strong evidence of long-run relationship or co-integration between log of RGDP and the remaining variables. This represents a co-integrated RGDP equation in Ethiopia. Thus, the null hypothesis of no co-integration between log of RGDP and its fundamentals is rejected (see Appendix 2).

A. Dynamic Long-run ARDL Estimates

Based on the confirmation obtained from the unit root test about the absence of a variable which is I(2) and given the F statistic result which indicated the existence of long run cointegration among the variables, it is now possible to proceed to the estimation of the long run coefficients of the model. The following table presents the results found after running the appropriate ARDL model to find out the long run coefficients.

Table 1. Estimated Long Run Coefficients using the ARDL Approach (Dependent variable is LNRGDP; 44 observations used for estimation from 1974 to 2017)

Regressors	Coefficient	ST. Error	T-Ratio
LNENERGY	3.84	9.27	0.41
LNTO	0.544*	0.287	1.90
LNHC	0.099	0.101	0.98
LNPC	0.455***	0.138	3.3
D	–0.274	0.176	–1.56
Constant	–5.299	15.675	–0.34

Note: The signs ***, ** and * indicate the significance of the coefficients at 1%, 5% and 10% level of significance respectively; ARDL (4, 1, 1, 0, 4, 4) selected based on Akaike Information Criterion (AIC).

The real GDP equation or growth model is specified in a log-linear form; hence, the coefficient of the dependent variable can be interpreted as elasticity with respect to economic growth. As we observe from the long-run ARDL regression result, log of energy consumption has an insignificant impact on log of real GDP. Additionally, human capital found to be statistically insignificant in the long-run. The result is inconsistent with the outcome found by Driffield and Jones (2013), and Fayissa and Nsiah (2008) where human capital is found to positively and significantly affecting output. Moreover, the dummy for policy change found statistically insignificant to affect economic growth (i.e. other things remain constant, policy change from Derg regime to post Derg regime of the country doesn’t significantly affect the performance of the economy in the long-run).

Apart from these, both trade openness and physical capital found to be positively and statistically significant to affect economic growth in Ethiopia (see Appendix 3).

B. Short-run Error Correction Model

The short run model results are different from the long run. For instance, energy consumption is significantly and positively affecting output which is dissimilar to the long run result. Also, even though trade openness has statistically significant in both long run and short run estimate, it has negative sign in short run, however. The result also suggests that, openness can be pain for an economy and invoke a call for protectionism. This may arise in line with poor quality of institutions and weak exporting capacity of the country or large share of import content of the countries international trade participation.

Table 2. Error Correction Representation for the Selected ARDL Model (Dependent variable is dLNRGDP; 44 observations used for estimation from 1974 to 2017)

Regressors	Coefficient	ST. Error	T-Ratio
dLNRGDP	0.3527*	0.194	1.82
dLNENERGY	6.035**	2.486	2.43
dLNTO	–0.00971*	0.0506	–1.92
dLNPC	–0.0321	0.0593	–0.54
dD	0.206***	0.0708	2.92
ECM (–1)	–0.2779**	0.12564	-2.21
	R-squared = 0.8575		
	R-adjusted = 0.7448		

Note: The signs ***, ** and * indicate the significance of the coefficients at 1%, 5% and 10% level of significance respectively.

More interestingly, the dummy of policy change found positive and statistically significant. That means the policy transition during 1991 (departure from the previous socialist system) had significant effect on economic growth of Ethiopia in the short run.

The speed of adjustment of any disequilibrium towards long-run equilibrium or the equilibrium error correction coefficient (ECM), estimated (–0.2779) is highly significant and has the correct sign. It implies a high speed of adjustment to equilibrium after a shock. Approximately 27.79 % of the disequilibrium from the previous year's shock converges back to the long-run equilibrium in the current year and such significant error correction term is another proof for the existence of a stable a long-run equilibrium relationship among the variables.

Regarding the short run model's goodness of fit, the regression result imply that real gross domestic product is moderately explained by the explanatory variables incorporated in the model. The adjusted R-squared reveals that 74.48% of the short-run variation in real gross domestic product is explained by the explanatory variable (see Appendix 2).

Diagnostic Testing and Model Stability

In this study Akaike information criterion is used to determine the optimal lag length of each variable automatically because it is a better choice for small sample size data. Moreover, according to Pesaran and Shin (1999), for the annual data a maximum of two lag length is recommended to choose the optimal lag for each variable. Therefore, in this paper a maximum lag length of 2 was chosen for the conditional ARDL model. Finally, in this model, AIC selects the optimal lag length of each variable (LNRGDP, LNENERGY, LNTO, LNHC, LNPC, D), respectively and it is ARDL(4, 1, 1, 0, 4, 4). This automatically determination of the lag length is to get the valid result and inferences (see Appendix 4)

To check the reliability and verifiability of the estimated long-run and short-run models, diagnostic tests are undertaken. These tests include serial correlation (Breusch and Godfrey LM test), Functional form (Ramsey's RESET test), Normality (Jarque-Bera test), Hetroscedasticity (Breusch-Pagan-Godfrey test) and also CUMSUM recursive residuals and CUMSUM square recursive residuals tests are applied to check the overall stability of the long-run and short-run coefficients which are recommended by Pesaran et al. (2001).

The results indicate that both the LM version and the F version of the statistics are unable to reject the null hypothesis specified for each test. Hence, there is no serial correlation problem and the Ramsey functional form test confirms that the model is specified well. Likewise, the errors are normally distributed and the model doesn't suffer from heteroskedasticity problem (see Appendix 6).

A. The null hypothesis of no serial correlation (Bruesch-Godfrey LM test) is failed to reject for the reason that that the p-value associated with test statistic is greater than the standard significant level (0.234> 0.05). Since the lagged dependent variable appear as a regressor in the model, LM test avoid the use of the traditional Durbin Watson test statistic.

B. For Ramsey's RESET test, which tests whether the model suffers from omitted variable bias or not we failed to reject the null hypothesis of this test which says that the model is correctly specified, because the p-value is larger than the conventional significance value (0.716> 0.05).

C. Similarly, we could not reject the null hypothesis for the Jarque-Bera normality test which says that the residuals are normally distributed, for the reason that the p-value associated is larger than the standard significance level (0.627>0.05). Therefore, the error term is normally distributed.

D. The last diagnostic test is hetroscedasticity test and as we can understand from the result, the null hypothesis of no heteroscedasticity is failed to be rejected at 5% significant level due to its p-value associated is greater than the standard significance level (0.301> 0.05).

Pesaran and Shin (1997) further suggested that structural stability or presence of structural break of the long run and short run relationships for the sample period can be better examined by cumulative sum (CUMSUM) and the cumulative sum of squares (CUMSUMSQ) of the recursive residual test. The test is based the first set of n observations and is updated recursively which will then be plotted against the break points to assess the given parameter consistency. In this study the plot of CUMSUM and CUMSUMSQ starts from 1994/95, implying that the test is based on the recursive residuals from observations before 1994/95. The test chooses the first n observation by itself.

For the stability test the graph plots both the cumulative sum and the 5% critical lines. And, if the cumulative sum remains inside between the two critical lines or bounds back after it is out of the boundary lines, the null hypothesis of correct specification of the model cannot be rejected. But, if the CUSUM goes outside (never returns back) between the two critical bounds there exists series parameter instability problem.

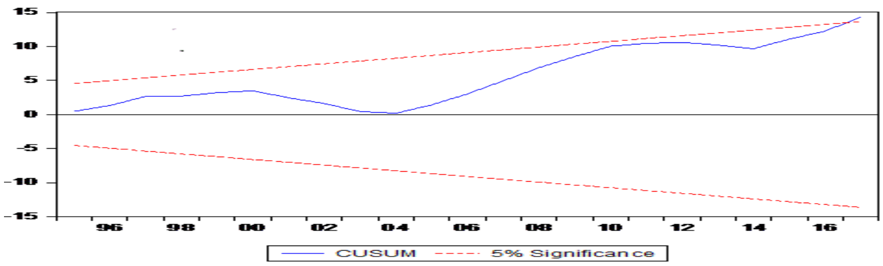

Figure 1. Cumulative Sum of Recursive Residuals

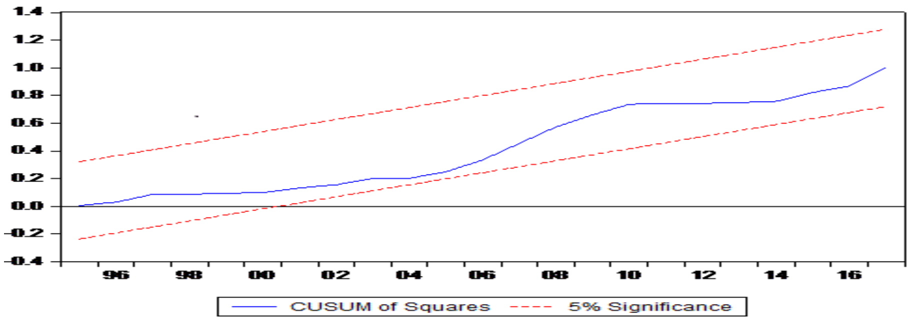

Figure 2. Cumulative Sum of Square of Recursive Residuals (ARDL(4, 1, 1, 0, 4, 4) result).

As the two plots above clearly reveal the plots of CUMSUM and CUMSUMSQ stay within the lines, and, therefore, this confirms the equation is correctly specified and the model is stable. Furthermore, the result shows that there is no structural instability in the model during the sample period. From this, the model appears to be robust in estimating short run and long run relationship between real gross domestic product and the included regressor.

Granger Causality Test Results

Granger causality test provides important information of the causal direction between the variables and knowing the direction of causality between the variables. In this study, Granger causality Wald test after VAR model was employed to look at the causal linkages between economic growth and energy consumption in Ethiopia.

C. Pairwise Granger Causality Test

This section is concerned with tests of Granger causality between GDP and energy. The estimated F-statistics of the causality test are reported in the Tables below. From the result we fail to accept the null hypothesis that LNGDP does not Granger causes LNENERGY, but we fail to reject the null hypothesis that LNENERGY does not Granger cause LNGDP. Therefore, it appears that Granger causality runs one-way from GDP to ENERGY and not the other way (See Appendix 5).

From the above pairwise granger causality we fail to reject the null hypothesis for LNENERGY does not granger cause LNGDP because the p-value is 0.93326 which much higher than 0.05. However, in the second case we can reject the Ho and accept the alternative which states LNRGDP can granger cause LNENERGY.

D. Vector Error Correction Granger Causality (Wald Test)

After undertaking pair wise granger causality test, Error Correction Model is also used and the result are shown in below.

Table 3. Granger causality test results for LNRGDP equation

Dependent Variable: LNRGDP (log of real GDP)		
Excluded	Chi 2	P-value
LNENERGY	0.02524	0.874
LNTO	2.8082	0.094*
LNHC	0.5262	0.468
LNPC	8.2672	0.004***
D	3.7145	0.054*
All	53.656	0.000***

In Table 3 where GDP is dependent variable the null hypothesis energy consumption does not Granger cause economic growth and the alterative hypothesis is energy consumption Granger cause economic growth. From the Table 3 it shown that the p-value is 0.874 and based on the ‘p-value’ we tend to accept H_O. That is, energy does not Granger cause economic growth.

Table 4. Granger causality test results for LNENERGY equation

Dependent Variable: LNENERGY (log of energy consumption)		
Excluded	Chi 2	p-value
LNRGDP	8.344	0.004***
LNTO	5.5232	0.019**
LNHC	1.1691	0.28
LNPC	4.413	0.036**
D	16.982	0.000***
All	38.881	0.000***

Note: The signs ***, ** and * indicate the significance of the coefficients at 1%, 5% and 10% level of significance respectively.

In the Table 4 where energy is dependent variable and with hypothesis GDP does not Granger cause energy consumption and the alternative hypothesis that GDP does Granger cause energy consumption. The 'p-value' is 0.004 and accordingly we have to reject the null hypothesis and hence we tend to accept the alterative hypothesis. Therefore, the evidence of multi-variate analysis is in line with the growth-led energy consumption hypothesis where causality running from economic growth to energy consumption.

The above two results that is the pair wise Granger causality (which is bivariate analysis) and the vector error correction model Granger causality test (which is multivariate analysis including physical & human capital., trade openness and policy dummy) are consistent with each other. Both evidences are in line with the growth-led energy consumption hypothesis where causality running from economic growth to energy consumption, implying that economic development seems to take precedence over energy consumption and that economic growth caused greater demand for energy. The economy of Ethiopia is heavily dominated by the agricultural sector. However, the energy use of the sector is insignificant. And the results show that shortage of energy may not adversely affect GDP growth or cause a fall in the GDP in the short run. This is because the agricultural sector does not depend on energy.

The above result of Granger causality running from economic growth to energy consumption in Ethiopia goes in line with the finding of Chontanawat et al. (2008) who found economic growth Granger cause energy consumption using bivariate analysis for Ethiopia.

GDP is generally less in the developing world than the developed world (or alternatively causality from energy to GDP generally increases at higher stages of development). Hence the results support the view that energy is generally neutral with respect to its effect on economic growth in the developing world, implying that the effect of energy conservation policies to help combat global warning would have a greater detrimental effect on the overall growth of OECD/developed countries than that of the non-OECD/developing countries".

And it also supports the finding of Wolde-Rufael (2005) for five countries (Algeria, Democratic Republic of Congo, Egypt, Ghana and Ivory Coast) who found economic growth Granger cause energy consumption using bivariate analysis. And similarly, it goes in line with what found by Wolde-Rufael (2009) for Sudan and Zimbabwe which Granger causality test shows that economic growth Granger cause energy consumption using multi-variate analysis consisting GDP, capital., energy and labor. However, it contradicts with the results for Cameroon, Gambia, Ghana, Morocco and Nigeria. And the result goes in line with the result of Akinlo (2008) who found for Sudan and Zimbabwe Granger causality running from economic growth to energy consumption. The result is also consistent with Masih and Masih (1996) for Pakistan and Indonesia, Olatunji Adeniran(undated) for Nigeria, Jumbe (2004) for Malawi.

This finding is contrary with the result of Yohannes (2010) in Ethiopia and Amirat and Bouri (2010) who undertook analyses of the causal relationship between the per capita energy consumption and the per capita GDP in Algeria adding capital and labor to the economic growth and energy consumption nexus and found Granger causality running from energy consumption to economic growth which reverse the result of Chontanawat et al. (2008) for Algeria. It is also inconsistent with Nondo et.al (2009) for 19 CEMESA member countries.

The implication of the uni-directional causality running from economic development to energy consumption result is that, the result may statistically suggest that energy conservation measures may be taken without jeopardizing economic development. In practice however, to suggest measures that can lead to the reduction of energy consumption to the end-user in order to halt any conservation problem arising out energy consumption may not be a viable option for Ethiopia particularly given the magnitude of the energy problems and the fact that the current energy infrastructure of the country is still inadequate to support the quest for rapid economic growth that is required to eradicate poverty and to raise the living standards of the people. Reducing energy consumption while the overwhelmingly majority of the population is still denied access to the use of modern form of energy may not be a viable option. Ethiopia has not yet reached the energy ladder that may warrant such a suggestion but it can still substantially improve the detrimental consequences of energy consumption (example the loss of natural resource for energy and the subsequent loss of soil fertility and erosion) without reducing its use. By making its energy sector more efficient and by making it available to a larger part of the population (especially electricity) energy used per unit of output can be raised.

Conclusions and Policy Implications

This study aimed to examine the dynamic relationship between economic growth and energy consumption in Ethiopia. In order to achieve objectives, data from different relevant source were collected over the years 1970–2017 and the parameters of the model were estimated using ARDL system of data estimation technique. The estimation result reveals that, energy consumption found statistically insignificant in affecting economic growth in the long-run. However, it was positive and statistically significant in short-run. Similarly, the dummy variable incorporated to capture the policy change effect found insignificant in long-run and with positive significant result in short-run.

Regarding the causality, the evidence is in line with the growth-led energy consumption hypothesis where causality running from economic growth to energy consumption, implying that reducing energy consumption may be implemented with little or no adverse effect on economic growth. In practice however any conservation measures taken to reduce energy consumption may not be a viable option for Ethiopia particularly given the magnitude of its energy problems and the fact that the current energy infrastructure of the country is still inadequate to support its quest for rapid economic growth and for eradicating poverty.

The option therefore might be for Ethiopia to enhance the level of efficiency in the energy sector. Increasing energy efficiency can cut down growth of energy demand that can mitigate conservation and health problem. As noted by IEA (2002), finding ways of expanding the quality and quantity of energy services while simultaneously addressing the environmental impacts associated with energy use represents one of the critical challenges Africa is facing. This means that energy regulation policies supporting the shift from lower-quality (typically less efficient and more polluting) to higher-quality energy services could provide impulse to economic growth rather than be detrimental to the development process (Costantini and Martini, 2010).

Since short run energy shortages may have significant impacts on the long run economic performances, the country needs to attract new capital for its energy industries. However, expanding energy production is not the one and only solution to the growth problems of the country. Promoting energy efficiency and focusing on decreasing energy intensity may also have positive impacts on economic growth rates without putting considerable pressure on the environment. Developing energy sources that are renewable and that have low or no carbon content seem to be essential for this purpose.

Irrespective of the strength of the causal relationship between energy consumption and economic growth, the energy challenge facing Ethiopia is daunting. Unfortunately, in Africa, it is not energy lack that is the basic problem but the lack of institutions, rules, financing mechanisms, and regulations needed to make markets work in support of energy for sustainable development .Until these elementary limitations that are restraining the development of an efficient and accessible energy sector are fully solved, energy supply will still persist to be a major obstacle for the economic and social development Ethiopia.

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Appendix

Appendix 1. Results of Augmented Dickey Fuller Test

Variables		At level I(0)	At 1st difference I (1)	Order of Integration
Ln Real GDP	Intercept	3.264	-4.643**	
	Trend	0.565	-5.633**	I (1)
Ln Energy cons.	Intercept	0.783	-6.427**	
	Trend	-1.534	-6.991**	I (1)
Ln Trade Openness	Intercept	-1.209	-5.448**	
	Trend	-2.001	-5.406**	I (1)
Ln Physical capital	Intercept	1.821	-6.852**	
	Trend	-0.570	-7.883**	I (1)
Ln Human capital	Intercept	-1.298	-4.026*	
	Trend	-1.188	-4.067**	I (1)

Appendix 2. Bound Test Result

```
. estat ectest

Pesaran, Shin, and Smith (2001) bounds test

H0: no level relationship                                   F =     5.416
Case 3                                                      t =    -3.009

Finite sample (5 variables, 46 observations, 4 short-run coefficients)

Kripfganz and Schneider (2018) critical values and approximate p-values

   | 10%               | 5%                | 1%                | p-value
   |   I(0)     I(1)   |   I(0)     I(1)   |   I(0)     I(1)   |   I(0)     I(1)
---+-------------------+-------------------+-------------------+------------------
 F |   2.428    3.691  |   2.911    4.327  |   4.043    5.806  |   0.002    0.015
 t |  -2.518   -3.826  |  -2.867   -4.238  |  -3.572   -5.065  |   0.037    0.299

do not reject H0 if
    both F and t are closer to zero than critical values for I(0) variables
      (if p-values > desired level for I(0) variables)
reject H0 if
    both F and t are more extreme than critical values for I(1) variables
      (if p-values < desired level for I(1) variables)
```

Appendix 3. ARDL regression result (using AIC lag selection criteria)

```
. ardl lnrgdp lnenergy lnto lnhc lnpc D, aic ec

ARDL(4,1,1,0,4,4) regression

Sample: 1974 - 2017                             Number of obs     =         44
                                                R-squared         =     0.8575
                                                Adj R-squared     =     0.7448
Log likelihood =  98.496424                     Root MSE          =     0.0349

------------------------------------------------------------------------------
    D.lnrgdp |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
ADJ          |
      lnrgdp |
         L1. |  -.2779594   .1256454    -2.21   0.037    -.5372788     -.01864
-------------+----------------------------------------------------------------
LR           |
    lnenergy |   3.843454   9.277611     0.41   0.682    -15.30459     22.9915
        lnto |   .5444754   .2870811     1.90   0.070    -.0480309    1.136982
        lnhc |   .0992804   .1013946     0.98   0.337    -.1099879    .3085486
        lnpc |   .4555515   .1382543     3.30   0.003     .1702086    .7408945
           D |  -.2748932   .1761806    -1.56   0.132    -.6385121    .0887256
-------------+----------------------------------------------------------------
SR           |
      lnrgdp |
         LD. |   .3527601   .1940001     1.82   0.082    -.0476366    .7531567
        L2D. |  -.0992182   .1940987    -0.51   0.614    -.4998183    .3013818
        L3D. |    .334598   .1949743     1.72   0.099    -.0678092    .7370053
             |
    lnenergy |
         D1. |   6.035592    2.48643     2.43   0.023     .9038526    11.16733
             |
        lnto |
         D1. |  -.0971763   .0506137    -1.92   0.067    -.2016378    .0072852
             |
        lnpc |
         D1. |  -.0321597   .0593711    -0.54   0.593    -.1546955    .0903762
         LD. |  -.0298997   .0594317    -0.50   0.619    -.1525608    .0927614
        L2D. |  -.1246635   .0604452    -2.06   0.050    -.2494161    .0000892
        L3D. |  -.0716564   .0520453    -1.38   0.181    -.1790727    .0357599
             |
           D |
         D1. |   .2069438   .0708412     2.92   0.007     .0607347    .3531528
         LD. |  -.0235592   .0707011    -0.33   0.742    -.1694792    .1223607
        L2D. |   .1624917   .0663116     2.45   0.022     .0256313    .2993522
        L3D. |   .0888911   .0534729     1.66   0.109    -.0214716    .1992538
             |
       _cons |   -5.29906   15.67556    -0.34   0.738    -37.65184    27.05371
------------------------------------------------------------------------------
```

Appendix 4. Optimal lag length for each variable (Akaike information criterion

```
. matrix list e(lags)


e(lags)[1,6]
      lnrgdp  lnenergy      lnto      lnhc      lnpc         D
r1         4         1         1         0         4         4
```

Appendix 5. Pair wise granger causality test

Pairwise Granger Causality Tests
Date: 04/06/19 Time: 22:25
Sample: 1970 2017
Lags: 2

Null Hypothesis:	Obs	F-Statistic	Prob.
LNENERGY does not Granger Cause LNRGDP	46	0.069179...	0.93326...
LNRGDP does not Granger Cause LNENERGY		7.031050...	0.00236...

Appendix 6: Diagnostic tests of the model

Test statistics	LM version	F version
Serial Correlation	CHSQ(1)= 1.2024[.234]**	F(4, 41)= .62469[.423]**
Functional Form	CHSQ(1)= .011370[.716]**	F(4, 39)= .0053317[.943]**
Normality	CHSQ(2)= 1.5745[.627]**	Not applicable
Heteroscedasticity	CHSQ(1)= 1.3321[.301]**	F(4, 38)= 1.3031[.263]**

A: Lagrange multiplier test of residual serial correlation
B: Ramsey's RESET test using the square of the fitted values
C: Based on a test of skewness and kurtosis of residuals
D: Based on the regression of squared residuals on squared fitted values