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ENERGY CONSUMPTION AND ECONOMIC GROWTH IN ETHIOPIA: A DYNAMIC CAUSAL LINKAGE

Sheilla Nyasha[1], Yvonne Gwenhure and Nicholas M. Odhiambo

Abstract

In this study, we have explored the causal relationship between energy consumption and economic growth in Ethiopia, during the period from 1971 to 2013. We have employed a multivariate Granger-causality framework that incorporates financial development, investment and trade openness as intermittent variables – in an effort to address the omission-of-variable bias. Based on the newly developed ARDL bounds testing approach to co-integration and the Error-Correction Model-based causality model, our results show that in Ethiopia, there is a distinct unidirectional Granger-causality from economic growth to energy consumption. These results apply, irrespective of whether the estimation is done in the short run or in the long run. We recommend that policy makers in Ethiopia should consider expanding their energy-mix options, in order to cope with the future demand arising from an increase in the real sector growth.

Keywords: Ethiopia, Energy Consumption, Economic Growth, Granger-Causality

JEL Classification Code: O40, Q43

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1. Introduction

The relationship between energy consumption and economic growth has been examined extensively in many studies. Various studies on the causal relationship have focused on different countries, different time periods, different methodologies, and different energy-consumption variables (Dergiades *et al.*, 2013; Ahmed and Azam, 2016; Erdal *et al.*, 2008; Lee and Chiu, 2011; Wolde-Rufael, 2010; Apergis and Payne, 2010).

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Although the studies on the causality between energy consumption and economic growth are numerous, the results have been largely mixed (Odhiambo, 2010; Govindaraju and Tang, 2013; Shahbaz *et al*., 2015; Hsiao-Ping, 2012). Four main hypotheses on the causal relationship between the two variables have emerged in the literature; and it is by these four hypotheses that the direction of causality between energy consumption and economic growth is established (see also Odhiambo, 2009).

The first hypothesis centres on the notion that energy consumption causes economic growth. This view is known as the energy-led growth hypothesis; and it implies that restrictions on the use of energy would adversely affect economic growth; while increases in energy consumption would contribute to economic growth (Alam *et al*., 2012; Tsani, 2010; Tang *et al*.. 2016; Chiou-Wei *et al*., 2008). The second hypothesis, known as the growth-led energy-consumption hypothesis, supports the view that economic growth causes energy consumption; and this is largely based on the pioneering work of Kraft and Kraft (1978). This hypothesis suggests that the policy of conserving energy consumption could be implemented with little or no adverse effect on economic growth (see Murray and Nan, 1996; Yang, 2000; Ghosh, 2002; and Narayan and Smyth, 2005).

The third category focuses on a bidirectional causal relationship between energy consumption and economic growth. This is also known as the feedback hypothesis. This relationship implies that energy consumption and economic growth cause each other (see Wang *et al*., 2016; Shuyun and Donghu, 2011; Yidirim and Aslan, 2012). The fourth hypothesis purports that no causality exists between energy consumption and economic growth. This is also known as the neutrality hypothesis; and it implies that policies in relation to conserving or expanding energy consumption have no effect on economic (see Tugcu *et al.,* 2012; Li and Leung, 2012).

Although research on this subject matter has been done on a number of countries in both developed and developing countries, to the best of our knowledge, very few studies have been done on Ethiopia. To date, energy consumption and economic growth nexus in Ethiopia has been discussed only in terms of impact and within a panel-study setting (see Al-mulali and Sab, 2012; Eggoh *et al*., 2011; Saidi and Hammami, 2015, among others).

Against this backdrop, this paper, therefore, seeks to examine the energy consumption-growth nexus in Ethiopia, in order to determine the direction of causality between these two variables, and to inform policy. The rest of the paper is organised as follows: Section 2 gives an overview of the trends in energy consumption and economic growth in Ethiopia. Section 3 reviews the literature; while Section 4 discusses the methodology employed to test the causal relationship. Section 5 provides the results of the study; and Section 6 presents the conclusions of the study.

2. Trends in Energy Consumption and Economic Growth in Ethiopia: An Overview

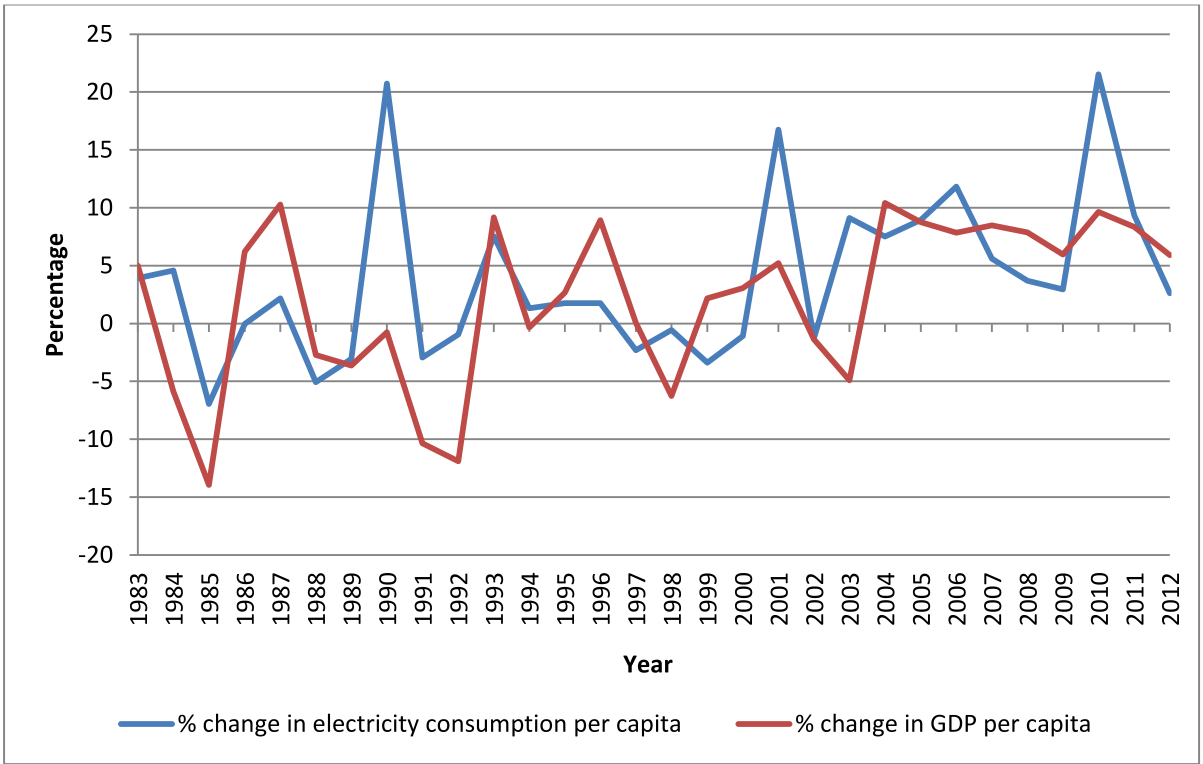
Ethiopia has various energy sources, including hydro-electric, geothermal, natural gas, coal, biomass, solar and wind energy. In 1992, Ethiopia's total energy production was 21.70 million tonnes of oil equivalent (Mtoe); and the country's electricity consumption was 1.12 terawatt hours (TWh). These statistics increased to 29.50 Mtoe and 1.84 TWh in 2002, respectively (International Energy Statistics, 2015). By then, the country's real GDP had increased from USD$5.76 billion in 1992 to USD$9.80 billion in 2002. Ten years later, Ethiopia's energy production had increased by about 45% to 43.04 Mtoe in 2012; whilst its GDP had more than doubled to USD$24.66 billion at 2005 prices (International Energy Statistics, 2015).

Ethiopia's energy consumption has predominantly been based on traditional energy sources, such as fuel wood, charcoal and dung cakes (Japan International Co-operation Agency – JICA, 2010). More than 90% of the country's total final energy consumption is accounted for by the use of traditional biomass fuels (Ministry of Water and Energy, 2011). However, the total energy consumption per capita in Ethiopia is reported to be 0.40 tons of oil equivalent (toe), which is far below the average sub-Saharan energy consumption of about 0.80 toe. This makes Ethiopia's energy consumption one of the lowest in the world (Gebreegziabher *et al.,* 2010). Currently, the per capita consumption of electricity in Ethiopia remains relatively low at about 200 kWh per year, due to the heavy reliance on traditional biomass energy sources, such as wood fuels, crop residues, and animal dung (Guta *et al*., 2015).

The country's energy policy has emphasised the need to transform from traditional to modern energy sources, in order to support the developmental requirements of the country. In addition, the use of traditional energy sources has caused the continued destruction of forestry resources for firewood, which has resulted in environmental problems, loss of productivity and an ecological imbalance (JICA, 2010). Ethiopia's energy policy, therefore, prioritises hydropower-resource development; and it also encourages an energy mix, where renewable energy, such as those of solar, wind and geothermal origin, are to be developed (Gebreegziabher *et al.*, 2010).

From the economic growth front, real GDP per capita growth fell sharply from 4.6% in 1983 to -13.9% in 1985. Between 1989 and 1990, although still in the negative region, GDP per capita growth improved from -3.6% to -0.74% (World Bank, 2016). From 2002, the GDP per capita growth rate remained in the positive region until 2012 (World Bank, 2016). Figure 1 illustrates the trends in economic growth, as measured by GDP per capita and energy consumption, proxied by electricity consumption, in Ethiopia from 1983 to 2012.

Figure 1: The Trends in Economic Growth and Energy Consumption in Ethiopia (1983-2012)



Source: World Bank (2016)

3. Literature Review

Following the pioneering works of Kraft and Kraft (1978), a wide range of studies have examined the energy consumption and economic growth causal relationship. This research spans from country-specific case studies to multi-country studies. The results have, however, been mixed. Some of the studies found that the causality runs from energy consumption to economic growth; others found that it runs from economic growth to energy consumption; while the rest either found a bidirectional relationship, or no causality at all, between the two variables.

Wolde-Rufael (2004) used Toda and Yamamoto's Granger-causality test for China from 1952 to 1999; and they found that energy consumption Granger-causes economic growth. Bowden and Payne (2009) used the same approach in a study of the United States of America (USA) between 1949 and 2006; and they also confirmed the energy-led growth hypothesis. In a multi-country setting, the Granger-causality test was also used by Yu and Choi (1985) in 5 countries; and the study found that the energy-led growth thesis was validated in the Philippines. Pao and Tsai (2010) used Granger-causality tests and found that energy consumption Granger-causes economic growth for the BRIC (Brazil, Russia, India and China) countries from 1965 to 2009; whilst Wolde-Rufael (2009) found the same for Algeria, Benin and South Africa in a panel study of 17 African countries.

Apergis and Payne (2010) used panel co-integration and error-correction modelling to examine the causal relationship between nuclear energy consumption and economic growth for a panel of sixteen countries for the period between 1980 and 2005. The results of the panel-vector error-correction model showed that there is a unidirectional causal flow from nuclear energy consumption to economic growth in the long run. Co-integration and vector error-correction modelling were used to confirm the energy consumption-led growth hypothesis in Shiu and Lam (2004), for China; Akinlo (2009) for Nigeria; and Ciarreta and Zarraga (2008) for a panel of 12 European Countries.

Odhiambo (2009) used the autoregressive distributed lag (ARDL) bounds-testing procedure for Tanzania, and confirmed the energy-led growth hypothesis. Al-mulali and Sab (2012) used panel co-integration for sub-Saharan African countries; and they confirmed the energy-led growth hypothesis. Iyke (2015) examined the dynamic causal linkage between electricity consumption and economic growth in Nigeria within a trivariate VECM, for the period 1971-2011. The results show that there is a distinct causal flow from electricity consumption to economic growth both in the short run and in the long run.

Fang and Chang (2016) also examined the causal relationship between energy consumption and economic development in the Asian Pacific countries for the period between 1970 and 2011. Using the bootstrap-panel Granger-causality test, the results showed that in India, Korea, Pakistan and Taiwan, energy consumption Granger-causes GDP.

Other studies have, however, validated the growth-led energy consumption hypothesis that postulates that economic growth drives energy consumption. Kraft and Kraft (1978) used a Granger-causality approach and found a unidirectional causal relationship running from GNP to energy consumption for the USA for the period from 1947 to 1974. The same approach was used by Cheng and Lai (1997) for Taiwan for the period from 1954 to 1993; and they found that economic growth Granger-causes energy consumption.

Hsiao's version of the Granger-causality approach was also employed for Japan by Cheng (1998) for the period from 1952 to 1995. The results also confirmed a unidirectional causal flow from economic growth to energy consumption. Zhang and Chen (2009) also found the same results when using the Granger-causality methodology for China for the period from 1960 to 2007. Stern and Enflo (2013) found a causal flow from output to energy consumption in Sweden – after also employing the Granger-causality test from 1850 to 2000.

Aqeel and Butt (2001) employed co-integration techniques, together with Hsiao's version of the Granger-causality method, for Pakistan from 1955 to 1996; and they confirmed the growth-led energy consumption hypothesis. Yu and Choi (1985) examined the causal relationship between energy consumption and economic growth in 5 countries, using the Granger-causality test, from 1950 to 1976; and they found the growth-led energy consumption hypothesis to hold in Korea. Erol and Yu (1987) found the same relationship in Italy and Germany; whilst Lee (2006) also concluded the same for France, Italy and Japan.

In Asia, Chiou-Wei *et al*. (2008) found a causal relationship from economic growth to energy consumption in the Philippines and Singapore, using the Granger-causality test in a multi-country setting. Ang (2008) used the Johansen co-integration and VEC modelling technique on Malaysia from 1971 to 1999; and they confirmed the growth-led energy consumption hypothesis.

Ouedraogo (2013) also confirmed the growth-led energy consumption hypothesis for 15 countries in the Economic Community of Western African States (ECOWAS) in the short run, using panel co-integration methods, based on the data from 1980 to 2008. Al-Iriani (2006) used the same methodology for the Gulf Co-operation countries from 1971 to 2002; and also confirmed the growth-led energy consumption hypothesis. Ozturk *et al*. (2010) used panel co-integration from 1971 to 2005 for 51 countries classified as low and middle-income countries, and found a long-run Granger-causality running from GDP to energy consumption for low-income countries.

Mehrara (2007) used panel co-integration and causality tests for 11 oil-exporting countries, namely: Iran, Kuwait, UAE, Saudi Arabia, Bahrain, Oman, Algeria, Mexico, Nigeria, Ecuador and Venezuela from 1971 to 2002; and confirmed the growth-led energy consumption hypothesis.

Odhiambo (2014) used the ARDL bounds-testing procedure for Ghana, Cote d'Ivoire, Brazil and Uruguay from 1972 to 2006, and found the growth-led energy consumption hypothesis to hold in the case of Ghana and Cote d'Ivoire only. In 2010 Odhiambo also used the same approach for the Democratic Republic of Congo, Kenya and South Africa for the period from 1972 to 2006, and found the relationship to hold for the Democratic Republic of Congo. Kayikci and Bildirici (2015) also validated the growth-led energy consumption hypothesis in a study on economic growth and electricity consumption in the Arab states of the Gulf, the Middle East and North African countries from 1972 to 2011. They used the ARDL bounds-testing approach, and found that the direction of the Granger-causality tests differs for each country, depending on the level of their natural resources endowment. Causality was found to flow from GDP to electricity consumption for those countries, that do not have enough natural resources, implying that a policy of conserving electricity consumption could be implemented – with little or no effect on economic growth.

A number of studies have also found the relationship between energy consumption and economic growth to exhibit a bidirectional causal relationship. Odhiambo (2009b), for example, created a trivariate causality framework for South Africa, and found distinct bidirectional causality between electricity consumption and economic growth. Ozturk *et al*. (2010), in a panel co-integration framework found bidirectional causality between energy consumption and economic growth for middle-income countries. Al-mulali and Sab (2012) found a bidirectional causal relationship between GDP and energy consumption in sub-Saharan Africa in the long run, based on error-correction modelling.

Francis *et al*. (2007) used BVAR models and co-integration techniques to investigate the energy consumption and economic growth nexus in Haiti, Jamaica and Trinidad and Tobago for the period 1971 to 2002. The study found that in the short run, the feedback hypothesis holds true for all three countries; whereas in the long run, it only holds true for Trinidad and Tobago. Tang (2008) used error-correction modelling and ARDL tests for Malaysia, and found the feedback hypothesis to hold true between electricity consumption and economic growth.

Solarin and Shabaz (2013) used ARDL bounds-testing and VECM causality test and confirmed the feedback hypothesis for Angola, between 1971 and 2009. Shahbaz *et al*. (2015), in the case of Pakistan, examined the relationship between renewable energy consumption and economic growth. Using the ARDL model and rolling-window approach, the study confirmed that there is a feedback effect between economic growth and renewable energy consumption.

Naser (2015) examined the causal linkages between oil consumption and economic growth in four emerging economies – Russia, China, South Korea and India – from 1965 to 2010. The study showed that bidirectional causality exists between oil consumption and economic growth in Russia, China and South Korea. Wang *et al*. (2016) also investigated the relationship between economic growth, energy consumption, and carbon dioxide emissions in China, from 1990 to 2012. The study employed Granger-causality tests and found a bidirectional causal relationship between economic growth and energy consumption.

However, some of the research on the energy consumption and economic growth thesis are consistent with the neutrality view. Altinay and Karagol (2004), for example, used the Hsiao's version of Granger-causality test for Turkey, from 1950 to 2000 and validated this hypothesis. In 2007, another study for Turkey by Jobert and Karanfil (2007) also validated the neutrality hypothesis, for the period from 1960 to 2003. Yu and Wang (1984) used the Sims and Granger-causality technique for the USA, from 1947 to 1979; and they found no causal relationship between energy consumption and economic growth.

Using the Granger-causality model, together with the ARDL approach, and Toda and Yamamoto test for New Zealand from 1960 to 1999, Fatai *et al*. (2002) also found the same relationship between economic growth and energy consumption. Wolde-Rufael (2005) found no causal relationship in a multi-country study, using Toda and Yamamoto's Granger-causality test for Benin, Congo, Kenya, Senegal, South Africa, Sudan, Togo, Tunisia and Zimbabwe. Huang *et al*. (2008) employed a panel VAR modelling approach; and they also found no causal relationship in the case of low-income countries.

Hsiao-Ping (2012) validated the neutrality hypothesis for 24 countries from a panel of 49 countries, when investigating oil consumption and output from 1970 to 2010, using the panel-causality analysis. Wolde-Rufael (2014) also confirmed evidence of neutrality between electricity consumption and economic growth in 8 out of 15 transition economies, namely: Albania, Macedonia, Moldova, Poland, Romania, Serbia, the Slovak Republic and Slovenia. The study employed the bootstrap-panel Granger-causality method for the period 1975 to 2010.

4. Methodology

Although it is now well-appreciated that causality results from a bivariate model might suffer from the omitted variable bias (see, for example, Loizides and Vamvoukas, 2005; Pradhan, 2011; and Odhiambo, 2011), a number of existing studies on energy-growth causality are still based on a bivariate framework. To distinctly differentiate itself from the majority of the related studies, this study employs a multivariate Granger-causality model – which is based on an autoregressive distributed lag (ARDL) bounds-testing approach, as developed by Pesaran and Shin (1999); and as later enhanced by Pesaran *et al*. (2001) – to examine the dynamic causal linkage between energy consumption and economic growth in Ethiopia.

In this study, the annual growth rate of real GDP is used as a proxy for economic growth (y). This proxy has been used extensively in literature (see, among others, Shan and Jianhong, 2006; Majid, 2008). Energy consumption, on the other hand, is proxied by energy use, as measured by the kilograms of oil equivalent per capita (E). Three additional variables – namely: financial development, investment and trade openness – have been incorporated, as intermittent variables – to form a multivariate Granger-causality model. The choice of these variables as intermittent variables is underpinned by both the theoretical and empirical literature.

The study utilises the causality model that originates from Granger's definition of causality, based on the notion that the future cannot cause the past; but the past can cause the future. Within the context of this study, using the energy consumption (E) and economic growth (y) variables, the Granger's definition can be stated as follows: If 'E causes y', then changes in E should precede changes in y. In other words, for E to Granger-cause y, two conditions must be met. Firstly, E should help predict y, i.e. in a regression of y against past values of E and y as independent variables; E should contribute significantly to the explanatory power of the regression. Secondly, y should not help to predict E. If E helps to predict y; and y helps to predict E, then it is more likely that one or more variables are in fact, causing both E and y.

The dynamic causal linkage between energy consumption and economic growth in Ethiopia is explored using the recently developed ARDL bounds-testing approach. The approach has a number of advantages over conventional estimation techniques, such as the residual-based technique and the Full-Maximum Likelihood (FML) test (see, among others, Pesaran and Shin, 1999; Duasa, 2007; Odhiambo, 2008; Majid, 2008). The first advantage is that it does not impose the restrictive assumption that all the variables need to be integrated of the same order. Thus, the ARDL approach can be utilised to test the existence of a relationship between variables that are integrated of order zero [I(0)] or order one [I(1)], or a mixture of the two.

The second advantage is that the ARDL-based co-integration method provides unbiased long-run estimates and valid t-statistics – even when some of the regressors are endogenous (Odhiambo, 2008). Thirdly, the ARDL approach is based on only a single reduced form equation; while conventional co-integration methods estimate the long-run relationship within the context of a system of equations (Pesaran and Shin, 1999). The fourth advantage is that the ARDL approach takes a sufficient number of lags to capture the data-generating process in a general-to-specific modelling framework, in order to obtain optimal lag length per variable. The fifth advantage is that the ARDL procedure possesses superior small-sample properties; hence, it is suitable even when the sample size is small. Based on these advantages, the ARDL approach is considered the most suitable method of analysis in this study. This technique has also been increasingly used in empirical research of late.

The co-integration relationship among the variables is tested, using the ARDL-based co-integration test; and a system of co-integration equations, associated with the multivariate Granger-causality models, is expressed as follows:

ECM-Based Co-integration Model

$$\Delta y_t = \alpha_0 + \sum_{i=1}^{n} \alpha_{1i}\Delta y_{t-i} + \sum_{i=0}^{n} \alpha_{2i}\Delta E_{t-i} + \sum_{i=0}^{n} \alpha_{3i}\Delta F_{t-i} + \sum_{i=0}^{n} \alpha_{4i}\Delta I_{t-i} + \sum_{i=0}^{n} \alpha_{5i}\Delta T_{t-i} + \alpha_6 y_{t-1} + \alpha_7 E_{t-1} + \alpha_8 F_{t-1} + \alpha_9 I_{t-1} + \alpha_{10} T_{t-1} + \mu_{1t} \dots\dots\dots (1)$$

$$\Delta E_t = \beta_0 + \sum_{i=0}^{n} \beta_{1i}\Delta y_{t-i} + \sum_{i=1}^{n} \beta_{2i}\Delta E_{t-i} + \sum_{i=0}^{n} \beta_{3i}\Delta F_{t-i} + \sum_{i=0}^{n} \beta_{4i}\Delta I_{t-i} + \sum_{i=0}^{n} \beta_{5i}\Delta T_{t-i} + \beta_6 y_{t-1} + \beta_7 E_{t-1} + \beta_8 F_{t-1} + \beta_9 I_{t-1} + \beta_{10} T_{t-1} + \mu_{2t} \dots\dots\dots (2)$$

$$\Delta F_t = \delta_0 + \sum_{i=0}^{n} \delta_{1i}\Delta y_{t-i} + \sum_{i=0}^{n} \delta_{2i}\Delta E_{t-i} + \sum_{i=1}^{n} \delta_{3i}\Delta F_{t-i} + \sum_{i=0}^{n} \delta_{4i}\Delta I_{t-i} + \sum_{i=0}^{n} \delta_{5i}\Delta T_{t-i} + \delta_6 y_{t-1} + \delta_7 E_{t-1} + \delta_8 F_{t-1} + \delta_9 I_{t-1} + \delta_{10} T_{t-1} + \mu_{3t} \dots\dots\dots (3)$$

$$\Delta I_t = \vartheta_0 + \sum_{i=0}^{n} \vartheta_{1i}\Delta y_{t-i} + \sum_{i=0}^{n} \vartheta_{2i}\Delta E_{t-i} + \sum_{i=0}^{n} \vartheta_{3i}\Delta F_{t-i} + \sum_{i=1}^{n} \vartheta_{4i}\Delta I_{t-i} + \sum_{i=0}^{n} \vartheta_{5i}\Delta T_{t-i} + \vartheta_6 y_{t-1} + \vartheta_7 E_{t-1} + \vartheta_8 F_{t-1} + \vartheta_9 I_{t-1} + \vartheta_{10} T_{t-1} + \mu_{4t} \dots\dots\dots (4)$$

$$\Delta T_t = \theta_0 + \sum_{i=0}^{n} \theta_{1i}\, \Delta y_{t-i} + \sum_{i=0}^{n} \theta_{2i}\, \Delta E_{t-i} + \sum_{i=0}^{n} \theta_{3i}\, \Delta F_{t-i} + \sum_{i=0}^{n} \theta_{4i}\, \Delta I_{t-i} + \sum_{i=1}^{n} \theta_{5i}\, \Delta T_{t-i} + \theta_6 y_{t-1} + \theta_7 E_{t-1} + \theta_8 F_{t-1} + \theta_9 I_{t-1} + \theta_{10} T_{t-1} + \mu_{5t} \ldots\ldots\ldots (5)$$

Where:

y = growth rate of real gross domestic product (a proxy for economic growth)

E = energy use, as measured by kilograms of oil equivalent per capita (a proxy for energy consumption)

F = share of M2 in GDP (a proxy for financial development)

I = share of gross-fixed capital formation in GDP (a proxy for investment)

T = sum of exports and imports, as a percentage of GDP (a proxy for trade openness)

a_0, β_0, δ_0, ϑ_0 and θ_0= respective constants; $\alpha_1 - \alpha_5$, $\beta_1 - \beta_5$, $\delta_1 - \delta_5$, $\vartheta_1 - \vartheta_5$ and $\theta_1 - \theta_5$ = respective short-run coefficients; $\alpha_6 - \alpha_{10}$, $\beta_6 - \beta_{10}$, $\delta_6 - \delta_{10}$, $\vartheta_6 - \vartheta_{10}$ and $\theta_6 - \theta_{10}$ = respective long-run coefficients; Δ = difference operator; n = lag length; t = time period; and μ_{it} = white-noise error terms.

ECM-Based Granger-Causality Model

Following the work of Narayan and Smyth (2008), the ECM-based multivariate Granger-causality model adopted in this study can be expressed as follows (see also Odhiambo, 2014):

$$\Delta y_t = \alpha_0 + \sum_{i=1}^{n} \alpha_{1i} \Delta y_{t-i} + \sum_{i=1}^{n} \alpha_{2i} \Delta E_{t-i} + \sum_{i=1}^{n} \alpha_{3i} \Delta F + \sum_{i=1}^{n} \alpha_{4i} \Delta I_{t-i} + \sum_{i=1}^{n} \alpha_{5i} \Delta T_{t-i} + \alpha_6 ECM_{t-1} + \mu_{1t} \ldots\ldots\ldots (6)$$

$$\Delta E_t = \beta_0 + \sum_{i=1}^{n} \beta_{1i} \Delta y_{t-i} + \sum_{i=1}^{n} \beta_{2i} \Delta E_{t-i} + \sum_{i=1}^{n} \beta_{3i} \Delta F_{t-i} + \sum_{i=1}^{n} \beta_{4i} \Delta I_{t-i} + \sum_{i=1}^{n} \beta_{5i} \Delta T_{t-i} + \beta_6 ECM_{t-1} + \mu_{2t} \ldots\ldots\ldots (7)$$

$$\Delta F_t = \delta_0 + \sum_{i=1}^{n} \delta_{1i} \Delta y_{t-i} + \sum_{i=1}^{n} \delta_{2i} \Delta E_{t-i} + \sum_{i=1}^{n} \delta_{3i} \Delta F_{t-i} + \sum_{i=1}^{n} \delta_{4i} \Delta I_{t-i} + \sum_{i=1}^{n} \delta_{5i} \Delta T_{t-i} + \delta_6 ECM_{t-1} + \mu_{3t} \ldots\ldots\ldots (8)$$

$$\Delta I_t = \vartheta_0 + \sum_{i=1}^{n} \vartheta_{1i}\Delta y_{t-i} + \sum_{i=1}^{n} \vartheta_{2i}\Delta E_{t-i} + \sum_{i=1}^{n} \vartheta_{3i}\Delta F_{t-i} + \sum_{i=1}^{n} \vartheta_{4i}\Delta I_{t-i} + \sum_{i=1}^{n} \vartheta_{5i}\Delta T_{t-i} + \vartheta_6 ECM_{t-1} + \mu_{4t} \dots\dots\dots\dots\dots\dots (9)$$

$$\Delta INV_t = \vartheta_0 + \sum_{i=1}^{n} \vartheta_{1i}\Delta y_{t-i} + \sum_{i=1}^{n} \vartheta_{2i}\Delta E_{t-i} + \sum_{i=1}^{n} \vartheta_{3i}\Delta F_{t-i} + \sum_{i=1}^{n} \vartheta_{4i}\Delta I_{t-i} + \sum_{i=1}^{n} \vartheta_{5i}\Delta T_{t-i} + \vartheta_6 ECM_{t-1} + \mu_{5t} \dots\dots\dots\dots\dots\dots (10)$$

Where:

y = growth rate of real gross domestic product (a proxy for economic growth)

E = energy use, as measured by kilograms of oil equivalent per capita (a proxy for energy consumption)

F = share of M2 in GDP (a proxy for financial development)

I = share of gross fixed-capital formation in GDP (a proxy for investment)

T = sum of exports and imports, as a percentage of GDP (a proxy for trade openness)

ECM = Error-correction term

$a_0, \beta_0, \delta_0, \vartheta_0$ and θ_0= respective constants; $\alpha_1 - \alpha_6$, $\beta_1 - \beta_6$, $\delta_1 - \delta_6$, $\vartheta_1 - \vartheta_6$ and $\theta_1 - \theta_6$ = respective coefficients; Δ = difference operator; n = lag length; t = time period; and μ_{it} = mutually uncorrelated white-noise residuals.

Data Sources

This study is based on the annual time-series data, from 1971 to 2013. The data sources for this study are the United Nations Conference on Trade and Development (UNCTAD), the National Bank of Ethiopia, and the World Bank Group. The growth rate of real GDP, the share of gross fixed capital formation in GDP, and the ratio of imports and exports to the GDP data were obtained from UNCTAD (2016); while the nominal GDP and M2 data were sourced from the National Bank of Ethiopia (2016). The energy-consumption data were collected from the World Bank Group's databank (World Bank, 2016).

5. Results

Stationarity Tests

Although the ARDL technique does not require pre-testing of the variables for the unit root, the test provides guidance on whether the technique is applicable or not; as it is only appropriate for the variables that are integrated of order one [I(1)] and/or zero [I(0)]. Hence, before co-integration test is conducted, the variables should be first tested for stationarity. For this purpose, the Dickey-Fuller generalised least squares (DF-GLS), Phillips-Perron (PP) and Perron (1997) (PPURoot) unit-root tests are used. The PPURoot is employed to cater for possible structural breaks within the dataset. The results of the stationarity tests for all the variables are presented in Table 1.

Table 1: Stationarity Tests of all Variables

Panel 1: Dickey-Fuller generalised least squares (DF-GLS)				
Variable	**Stationarity of all Variables in Levels**		**Stationarity of all Variables in First Difference**	
	Without Trend	With Trend	Without Trend	With Trend
y	-4.12***	-5.26***	-	-
E	9.25***	6.37***	-	-
F	-1.74	-0.63	-5.53***	-5.79***
I	-0.16	-2.55	-8.05***	-8.36***
T	-1.26	-1.66	-5.22***	-5.14***
Panel 2: Phillips-Perron (PP)				
Variable	**Stationarity of all Variables in Levels**		**Stationarity of all Variables in First Difference**	
	Without Trend	With Trend	Without Trend	With Trend
y	-4.11***	-5.18***	-	-
E	8.39***	6.37***	-	-
F	-1.75	-0.95	-5.59***	-5.80***
I	0.13	-2.55	-8.03***	-8.36***
T	-1.31	-1.80	-5.12***	-5.03***
Panel 3: Perron, 1997 (PPURoot)				
Variable	**Stationarity of all Variables in Levels**		**Stationarity of all Variables in First Difference**	
	Without Trend	With Trend	Without Trend	With Trend
y	-6.22***	-6.36***	-	-
E	1.04	-2.37	-5.95***	-6.65***
F	-4.61	-5.14	-6.97***	-7.34***
I	-4.44	-4.41	-8.95***	-8.87***
T	-2.74	-2.75	-7.25***	-7.13***

Note: *** denotes stationarity at 1% significance level
See the appendix for the PPURoot break dates

The results of the stationarity tests reported in Table 1, Panels 1 to 3, confirm that all the variables are either integrated of order zero, or one. This confirmation implies that the ARDL approach to co-integration can be applied.

Bounds F-Test for Co-integration

The ARDL-based co-integration test is carried out in two steps. The first step involves the determination of the order of lags on the first differenced variables in equations (1) to (5). The second step is the application of the bounds F-test to equations (1) to (5), in order to establish whether a long-run relationship between the variables under study exists or not. In each of the five equations, the null hypothesis of no co-integration is tested against the alternative hypothesis of co-integration.

The calculated F-statistic is matched with the critical values provided by Pesaran *et al*. (2001). In the event that the calculated F-statistic is above the upper bound level, the null hypothesis of no co-integration is rejected. Hence, it is concluded that the variables in question are co-integrated. On the other hand, if the calculated F-statistic is below the lower-bound level, the null hypothesis of no co-integration is accepted; and it therefore concluded that the variables in question are not co-integrated. Conversely, if the calculated F-statistic falls within the upper and the lower-bound levels, the results are inconclusive. The results of the bounds F-test for co-integration are presented in Table 2.

Table 2: Bounds F-test for Cointegration

Dependent Variable	**Function**	**F-statistic**	**Cointegration Status**
y	F(y|E, F, I, T)	5.75***	Cointegrated
E	F(E|y, F, I, T)	8.74***	Cointegrated
F	F(F|y, E, I, T)	1.99	Not cointegrated
I	F(I|y, E, F, T)	0.91	Not cointegrated
T	F(I|y, E, F, I)	1.25	Not cointegrated

Asymptotic Critical Values

Pesaran *et al*. (2001), p.300 Table CI(iii) Case III	1%		5%		10%	
	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
	3.74	5.06	2.86	4.01	2.45	3.52

Note: *** denotes statistical significance at 1% level

The co-integration results, presented in Table 2, reveal the existence of two co-integrating vectors. Although the existence of co-integration between the variables suggests that there must be Granger-causality in at least one direction, it does not show the direction of causality between the variables (see also Narayan and Smyth, 2004; Odhiambo, 2009). The short-run causality is determined by the F-statistics on the explanatory variables, based on the Wald Test or the Variable Deletion Test. However, the long-run causality is confirmed by the significance and the sign of the coefficient of the error-correction term.

Even though the error-correction term has been included in all the Granger-causality equations [equations (6) to (10)], only those equations in which the null hypothesis of no co-integration is rejected will be estimated with an error-correction term (see also Narayan and Smyth, 2004; Odhiambo, 2009, among others).

There are four expected outcomes regarding the causality between energy consumption and economic growth. The first one is a unidirectional causality flowing from energy consumption to economic growth. The second expected outcome is the unidirectional causal flow from economic growth to energy consumption; while the third one is the bidirectional causality between energy consumption and economic growth. The fourth possible outcome is no causality at all between the two variables of interest.

ECM-Based Granger-Causality Results

Following the establishment of the existence of co-integration in the specified Granger-causality model, the Granger-causality is tested using the ARDL-based technique. The lagged error-correction term is incorporated in the relevant equations (equations 6 and 7). The results of the causality test are displayed in Table 3.

Table 3: Results of Granger-Causality Tests

Dependent Variable	F-statistics [probability]					ECT_{t-1} [t-statistics]
	Δy_t	ΔE_t	ΔF_t	ΔI_t	ΔT_t	
Δy_t	-	2.141 [0.102]	2.921* [0.099]	0.004 [0.952]	4.11** [0.050]	- 1.018*** [-6.026]
ΔE_t	5.735** [0.024]	-	9.386*** [0.001]	4.696** [0.040]	4.087** [0.050]	-0.978*** [6.398]
ΔF_t	4.324** [0.046]	5.100** [0.031]	-	0.626 [0.435]	1.725 [0.198]	-
ΔI_t	0.621 [0.436]	5.624** [0.024]	2.609 [0.115]	-	7.175*** [0.003]	-
ΔT_t	4.558** [0.040]	0.338 [0.565]	1.704 [0.200]	7.036*** [0.010]	-	-

Note: *, ** and *** denote statistical significance at 10%, 5% and 1% levels respectively

The empirical results reported in Table 3 show that there is a unidirectional Granger-causality from economic growth to energy consumption in Ethiopia. These results apply, irrespective of whether the estimation is done in the short run or in the long run. The short-run results are supported by the F-statistics of Δy in the energy-consumption function that is statistically significant; while the long-run results are confirmed by the error-correction term (ECM_{t-1}) in the same function, which is both negative and statistically significant. The results are consistent with the growth-driven energy consumption thesis (see also Ouedraogo, 2013; Stern and Enflo, 2013; Odhiambo, 2014). These findings imply that in Ethiopia, it is economic growth that drives energy consumption, both in the short and in the long run.

The results further show that there is: (i) a bidirectional causality between financial development and economic growth in the short run; (ii) unidirectional Granger-causality flowing from financial development to economic growth in the long run; (iii) bidirectional causality between economic growth and trade openness in the short run; (iv) unidirectional causality from trade openness to economic growth in the long run; (v) bidirectional causality between financial development and energy consumption in the short run; (vi) unidirectional causality from financial development to energy consumption in the long run; (vii) bidirectional causality between investment and energy consumption in the short run; (viii) unidirectional causality from investment to energy consumption in the long run; (ix) bidirectional causality between investment and trade openness in the short run; (x) unidirectional causality from trade openness to energy consumption in the short run; (xi) no causality between investment and economic growth, financial development and investment, and between financial development and trade openness in the short run and in the long run.

6. Conclusion

This study has explored the causal relationship between energy consumption and economic growth – using the time-series data from Ethiopia during the period from 1971 to 2013. The study is fundamentally different from the majority of previous studies on energy-growth causality nexus in that it has used a multivariate framework – with financial development, investment and trade openness as the intermittent variables. The study has also utilised the ARDL bounds testing approach to co-integration and the ECM-based Granger-causality tests to examine this linkage. The results of this study show that in Ethiopia, there is a distinct unidirectional causal flow from economic growth to energy consumption. These results apply, irrespective of whether the estimation is done in the short run or in the long run. The study, therefore, recommends that in Ethiopia, policy makers should consider expanding their energy-mix options, in order to cope with the future demand arising from increased economic growth.

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Appendix: PPURoot Break Dates

Variable	Stationarity of all Variables in Levels		Stationarity of all Variables in First Difference	
	Without Trend	With Trend	Without Trend	With Trend
y	2002	1991	-	-
E	2007	2006	2006	2004
F	2007	2001	2002	2006
I	1997	1997	1992	1992
T	1997	1984	1992	1992