Modeling Energy Consumption, CO2 Emissions and Economic Growth Nexus in Ethiopia: Evidence from ARDL Approach to Cointegration and Causality Analysis

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Abstract

Policy makers need to know the relationship among energy use, economic growth and environmental quality in order to formulate rigorous policy for economic growth and environmental sustainability. This study analyzes the nexus among energy consumption, affluence, financial development, trade openness, urbanization, population and CO_2 *emissions in Ethiopia using data from 1970–2014. The ARDL cointegration results show that cointegration exists among the variables. Energy consumption, population, trade openness and economic growth have positive impact on* CO_2 *in the long-run while economic growth squared reduces* CO_2 *emissions which confirms that the EKC hypothesis holds in Ethiopia. In the short-run urbanization and energy consumption intensify environmental degradation. Toda-Yamamoto granger causality results indicate the bi-directional causality between energy consumption and* CO_2 *emissions,* CO_2 *emissions and urbanization. Financial development, population and urbanization cause economic growth while economic growth causes* CO_2 *emissions. Causality runs from energy consumption to financial development, urbanization and population which in turn cause economic growth. From the result,* CO_2 *emissions extenuation policy in Ethiopia should focus on environmentally friendly growth, enhancing consumption of cleaner energy, incorporating the impact of population, urbanization, trade and financial development.*

Keywords: Economic growth; energy consumption; Financial development; Environmental Kuznets Curve; CO2 emissions; ARDL; Ethiopia

1. Introduction

Energy which is used as widely as capital and labour is regarded as the basic input for the production process. Continuous energy supply is compulsory for sustaining and improving the current production level and standard of living since energy consumption is so extensive among the industries. Energy consumption is, therefore, considered as a prerequisite of sustainable economic development in the process of production (Alam, Murad, Noman, & Ozturk, 2016). Energy consumption fuels economic growth, but also inevitably emits CO_2 (Zhou & Liu, 2016) which is one of the major causes of creating Green House Gas (GHG) in the atmosphere and resulting global warming and climate change. Global warming and climate change affect pattern of rainfall, worsen the agricultural productivity and reduce the productivity of labour force. Accordingly, economists and environmentalists became more aware of the environmental consequences of economic growth, which shifted the attention from simple economic growth to the ecology (environment) friendly economic growth (Alam, Murad, Noman, & Ozturk, 2016).

The relationship between energy consumption and economic growth, energy consumption and environmental pollution as well as economic growth and environmental pollution, has been the issue of intense research in the energy-economics literature (Acaravci & Ozturk, 2010a). Nevertheless, the empirical evidence remains controversial and unclear. The existing literature reveals that empirical studies differ substantially in terms of methods of data analysis and are not conclusive to present policy recommendation that can be applied across countries (Ozturk, Aslan, & Kalyoncu, 2010). Most of the existing studies focus either on the nexus of economic growth-energy consumption or economic growth-environmental pollutants where little effort has been made to test these two relations under the same model (Ozturk & Acaravci, 2010b).

Three research aspects in literature exist on the relationship between economic growth, energy consumption and environmental pollutants (Acaravci & Ozturk, 2010a; Alkhathlan & Javid, 2013; Jafari, Ismail, Othman, & Mawar, 2015; Baek & Kim, 2011). The first aspect, which is considered as one of the most significant empirical relationships tested in the economic literature, focuses on the relationships between economic growth and environmental pollutants: Farhani , Shahbaz , Sbia , and Chaibi (2014), Akpan and Abang (2015), Dinda and Coondoo (2006), Odhiambo (2011), Paresh and Narayan (2010), Kim , Lee , and Nam (2010), Kim and Baek (2011), Ghosh (2010) and others. The main aim of these studies are testing the validity of the environmental Kuznets curve (EKC) hypothesis which claims an inverted U-shaped relationship between the level of environmental degradation and income growth. This is to mean that environmental degradation increases with per capita income during the early stages of economic growth, and then declines with per capita income after arriving at a threshold (Acaravci & Ozturk, 2010a; Saidi & Hammami, 2015). The first empirical evidences on EKC hypothesis appeared in three independent seminal working papers (Dinda, 2004): Grossman and Krueger (1991), Shafik and Bandyopadhyay (1992) and Panayotou (1993). Literature reviews by Lapinskienė and Peleckis (2017), Stern (2004) and Dinda (2004) assert that previous EKC studies have failed to provide clear and inclusive findings on the inverted U-shaped relationship between the environment and economic growth. Moreover, Stern (2004) and Narayan and Narayan (2010) mentioned that most of the EKC literatures are based on weak econometric modeling.

The second aspect of literature emphases on the energy–economic growth nexus: Apergis and Tang (2013), Apergis and Payne (2010), Apergis and Payne (2009a), Apergis and Payne (2009b), Chen , Chen and Chen (2012), Herrerias , Joyeux and Girardin (2013). According to this relationship energy consumption and economic growth may be jointly determined, because economic growth is closely related to energy consumption as higher economic development requires more energy consumption. However, Ozturk and Acaravci (2010b) argued that the empirical literature on the energy consumption-growth nexus have yielded mixed and often contradictory results due to the different data set, countries' specific characteristics and different econometric methodologies used.

The third part of the literature combines the abovementioned lines of research in order to capture the linkages in economic growth, energy use and pollution in the same framework (see Apergis and Payne (2010b), Apergis and Payne (2014), Bella , Massidda and Mattana, 2014), Alkhathlan and Javid (2013), Yang and Zhao (2014), Saboori and Sulaiman (2013), Alam *et al.* (2016), Rafindadi (2016), Youssef, Hammoudeh, and Omri (2016) and others). However, these studies modeled carbon emissions as a function of income, income squared and/or income cubed in addition to other explanatory variables; thus, they suffered from problems of collinearity or multicollinearity (Alkhathlan & Javid, 2013).

Currently, development endeavors have increasingly focused on environmentally friendly growth rather than simple growth. In this respect, energy consumption and environmental degradation have gained a large amount of attention worldwide. Energy consumption plays the dual role of providing the foundation for economic activity and human well-being as well as acting as the driving force for environmental degradation. Energy is indispensable for economic activity because all production and consumption activities directly depends on energy consumption. Fossil fuels have become the main source of energy since the Industrial Revolution. The rapid use of fossil fuels for economic growth has led to a significant increase in the global emissions of several potentially harmful gases. These gases not only cause deterioration of the environment but also adversely affect human life. The ever-increasing amount of carbon dioxide (CO2) which is considered to be one of the world's greatest environmental threats is responsible for more than 60% of the greenhouse effect (Ozturk & Acaravci, 2010c).

Although a number of studies have examined the relationship between CO_2 emissions, economic growth and energy consumption in developing countries, the majority of these studies have mainly concentrated on the relevance of the Environmental Kuznets Curve (EKC). Very few studies have gone the full distance to examine the nexus between CO2 emissions, economic growth and energy consumption. Even where such studies have been done, the focus has not mainly been on Sub-Sahara African countries.

Studies on the causal relationship between carbon emissions, economic growth and energy consumption in sub-Saharan countries are very scant and the existing ones are not conclusive. In addition, the majority of the previous studies suffer from four major weaknesses; namely, 1) the use of a bivariate causality test, which may lead to the omission-of-variable bias; 2) the use of cross-sectional data, which does not satisfactorily address the country-specific effects; 3) the use of the maximum likelihood test based on Johansen (1988) and Johansen and Juselius (1990), which has been proven to be inappropriate when the sample size is too small (see Nerayan and Smyth, 2005); and 4) they employ unit root tests which fail to consider structural breaks.

It is against this backdrop that the current study attempts to examine the causal relationship and cointegration between CO2 emissions, energy consumption and economic growth, using the newly TY developed and ARDL-Bounds testing approach. By incorporating energy consumption, population, urbanization, financial development and trade openness as control variables in a tri-variate setting between CO2 emissions, energy consumption and economic growth, this study develops a simple multivariate causality model between CO2 emissions, energy consumption and economic growth.

The main objective of this paper is to analyze the significant determinants of CO_2 in Ethiopia using ARDL bounds test approach to cointegration and causal relationship among variables under consideration using Toda-Yamamoto Granger causality technique. The rest of the paper is structured as follows. Section 2 presents model specification and data; Section 3 introduces estimation method; Section 4 deals with empirical results and discussions, and the last section presents conclusion and policy implications.

2. Model Specification and Data

Unlike the recent EKC models, the earliest ones were formulated as simple quadratic functions of the levels of income. But, resources are used in an economic activity and, by the laws of thermodynamics; consumption of resources unavoidably leads to the production of waste (Stern, 2004). Due to this fact, Stern (2004) asserted that regressions output that yields zero or negative levels of pollution indicators are incorrect except in the rare case and a logarithmic dependent variable should be used to enforce this restriction. Moreover, transforming variables into their natural logarithm considerably reduces or removes any heteroscedasticity problem (Hundie, 2014). Therefore, all the variables in the model of this study are in logarithmic form.

Following Farhani, Chaibi, and Rault (2014), Shahbaz *et al.* (2013), Baek and Kim (2011), Ohlan (2015), Omri (2016), Rafindadi (2016), and Zambrano-Monserrate, Carvajal-Lara, and Urgiles-Sanchez (2016), this article employs an augmented standard EKC regression to analyze the long-run relationship and directon of causality among carbondioxide emmissions, energy consumption and economic growth with the intention of avoiding the omitted variable bias and collinearity problems. Abid (2017) and Omri (2016) argued that in addition to energy consumption and economc activity, environmental quality may be also affected by trade openness and financial development. Whether the degree of trade opnenness improves or degrades envionmental quality depends on the level of economic development of a nation according to Baek and Kim (2011)[1] and Baek and Kim (2009). Bo (2011) asserts that free trade may improve environment quality through technical effect or it may, exacerbate environmental pollution with the expansion of economic scale. For instance, Feridun (2006) found that trade instensity has deterimental effect on environmental quality of Nigeria contrary to the finding of Zambrano-Monserrate, Carvaja, and Urgiles-Sanchez (2016) for Singapore and Shahbaz *et al*. (2013) for Indonesia.

Te fnancial development plays an important role to explain the CO2 emissions throug helping companies to implement advanced technologies that are more efficient and environment-friendly resulting in reducing CO2 emissions. Besides, the fnancial development can attract foreign capital that improves the economic activity, which in turn influences the improvement of the environment through the implementation of projects that use this fnancing (Zambrano-Monserrate, Carvajal-Lara, & Urgiles-Sanchez, 2016). In line with this, Shahbaz *et al*. (2013) contended that financial development decreases CO_2 emissions in Indonesia. Additionally, Katircioğlu and Taşpinar (2017) propose that financial development might moderate the effects of economic activity and energy consumption on CO2 emissions.

Population growth is the core factor in explaining CO2 emission dynamics (Alam, Murad, Noman, & Ozturk, 2016; Ohlan, 2015; Lin , Omoju , Nwakeze, Okonkwo, & Megbowon, 2016; Sohag, Mamun, Uddin, & Ahmed, 2017) which should be included in CO2 emissions function if the consistent and robust result is required. African countries like Ethiopia are currently in the process of rapid urbanisation. Empirical evidences (see Lin *et al*., 2016) show that urbanization degrades CO_2 emission through the distance people travel and the mode of transportation. Accordingly, it is important to introduce urbanisation into the model in order to determine its impacts on CO_2 emission. Also, African countries depend largely on fossil fuel consumption, which incresases CO_2 emission. But the severity of the impact of energy consumption on the environment depends on the energy consumption structure (ES) of a country which denotes the share of clean or fossil energy in total energy consumption (Lin , Omoju , Nwakeze, Okonkwo, & Megbowon, 2016). Considering that Ethiopia is developing with substantial fossilfuel consumption, the variable ES which is the share of fossil fuel consumption (petroleum,coal and

[1] Baek and Kim (2011) support the *pollution haven hypothesis* for developing countries which implies that trade liberalization deteriorates environmental quality.

gas) in total energy consumption is included in the model. The square of GDP per capita is included to model the theoretical basis of the EKC.

Therefore, the long-run relationship between energy consumption (ES), carbondioxide emmissions (CO_2), GDP (Y), square of GDP (Y^2), financial development (F), populaltion (P) and urbanization (UR) can be specified as below:

$$\ln C_t = \alpha + \beta_1 \ln Y_t + \beta_2 \ln Y^2 + \beta_3 \ln ES_t + \beta_4 \ln T_t + \beta_5 \ln F_t + \beta_6 \ln P_t + \beta_6 UR + \varepsilon_t \text{.......................(1)}$$

The annual time series data from 1970 to 2014 on CO2 emissions measured in kt, energy consumption measured as proportion of fossil fuel (petroleum, coal and gas) in total energy consumption, population size, urbanization measured as percentage of the population living in urban centers, trade openness measured as ratio of export and import to real GDP, financial development index developed from financial development indicators (broad money to GDP and total reserve to GDP) using principal component analysis and real GDP. The data are obtained from the World Development Indicators (2016) online database and Ethiopian Economics Association (EEA) database.

3. Estimation Methods

Even though the Toda-Yamamoto (TY) and ARDL bounds test procedures are applicable irrespective of the order of integration of the series under consideration, unit root test still serves two important issues. It helps us to identify the maximum order of integration for the series which is used to augment VAR (p). Moreover, the unit root test helps to identify the series with I(2) and above in which the ARDL procedure is inappropriate. To this end, three conventional unit root tests viz. Phillips and Perron (1988) (PP), Kwiatkowski, Phillips, Schmidt, and Shin (1992) (KPSS) and augmented Dickey Fuller (1979) (ADF) were employed. Katircioglu, Feridun and Kilinc (2014) and Jafari, Othman and Nor (2012) argued that PP and ADF unit root tests have a low power of rejecting the null. It is suggested that KPSS unit root test eliminates a possible low power against stationary unit root that occurs in the ADF and PP (Katircioglu , Feridun , & Kilinc , 2014; Jafari , Othman, & Nor, 2012; Behera & Dash, 2017). Therefore, in order to obtain more robust results this study relied on the KPSS unit root test.

Baum (2001), however, argues that a well–known weakness of the conventional unit root tests with I (1) as a null hypothesis is its potential confusion of structural breaks in the series as evidence of non-stationarity because they may fail to reject the unit root hypothesis if the series have a structural break. Shahbaz, Hye, Tiwari, and Leitão (2013) also contend that these tests provide biased and spurious results due to not having information about structural break points occurred in the series.

To address this problem, Clemente, Montanes and Reyes (1998) proposed tests that would take into account for two structural breaks within the observed history of a time series, either additive outliers (the AO model) or innovational outliers (the IO model). The double–break additive outlier AO model as employed in Baum *et al*. (1999) involves the estimation of:

$$y_t = \mu + \delta_1 DU_{1t} + \delta_2 DU_{2t} + \tilde{y}_t \text{..(2)}$$

Where $DU_{mt} = 1$ for $t > T_{bm}$ and 0 otherwise, for m = 1, 2. T_{b1} and T_{b2} are the breakpoints. As stated in Baum, Barkoulas and Caglayan (1999), the residuals from this regression, $\tilde{y}_t$, are then the dependent variable in the equation to be estimated. They are regressed on their lagged values, a number of lagged differences and a set of dummy variables needed to make the distribution of the test statistic tractable:

$$\tilde{y}_t = \sum_{i=1}^{k} \omega_{1i} DT_{b1,t-i} + \sum_{i=1}^{k} \omega_{2i} DT_{b2,t-i} + \alpha \tilde{y}_{t-i} + \sum_{i=1}^{k} \theta_i \Delta \tilde{y}_{t-i} + e_t \text{..................................(3)}$$

Where $DT_{bm,t} = 1$ for $t = T_{bm} + 1$ and 0 otherwise, for m = 1, 2. The value of minimal t–ratio obtained from regression of Equation (3) is compared with critical values provided by Perron and Vogelsang (1992), as they do not follow the standard "Dickey–Fuller" distribution (Baum , Barkoulas, & Caglayan, 1999).

The comparable model for the innovational outlier (gradual change) model expresses the shocks to the series (the effects of δ_1, δ_2 below) as having the same effect on y_t as any other shocks, so that the dynamic effects of DT_b have the same ARMA representation as do other shocks to the model. This formulation, when transformed, generates the finite AR model to the model, leading to the formulation:

$$y_t = \mu + \delta_1 DU_{1t} + \delta_2 DU_{2t} + \varphi_1 DT_{b1,t} + \varphi_2 DT_{b2,t} + \alpha y_{t-i} + \sum_{i=1}^{k} \theta \Delta y_{t-i} + e_t \text{...........(4)}$$

Where again an estimate of $\alpha = 1$ will tell us that the series has a unit root with structural break(s).

Therefore, for the sake of robustness, the conventional unit root testing techniques (ADF, PP and KPSS) and unit root tests that consider structural breaks (Clemente, Montanes and Reyes (1998), CMR hereafter and Zivot and Andrews (1992), ZA hereafter) were employed to test for the stationarity of the variables under consideration.

In order to test the long-run cointegration among energy consumption, CO_2 emission and economic growth in Ethiopia, this study used Autoregressive Distributed Lag (ARDL) bounds test approach of Pesaran *et al.* (2001) due to its various advantages when compared to other cointegration techniques.[2] An ARDL representation of Equation (1) which involves an error-correction modeling format is given as follows:

$$\Delta C_t = \alpha_1 + \sum_{i=1}^{p} \beta_{1i} \Delta C_{t-i} + \sum_{i=0}^{q_1} \eta_{1i} \Delta Y_{t-i} + \sum_{i=0}^{q_2} \gamma_{1i} \Delta \left(Y_{t-i}\right)^2 + \sum_{i=0}^{q_3} \theta_{1i} \Delta E_{t-i} + \sum_{i=0}^{q_4} \pi_{1i} \Delta T_{t-i} + \sum_{i=0}^{q_5} \phi_{1i} \Delta F_{t-i} + \sum_{i=0}^{q_6} \omega_{1i} \Delta P_{t-i}$$
$$+ \delta_1 \ln C_{t-1} + \delta_2 \ln Y_{t-1} + \delta_3 \ln \left(Y_{t-i}\right)^2_{t-1} + \delta_4 \ln E_{t-1} + \delta_5 \ln T_{t-1} + \delta_6 \ln F_{t-1} + \delta_7 \ln P_{t-1} + \varepsilon_{1t} \text{................................(5)}$$

The parameters δ_i , where i= 1, 2, 3, 4, 5, 6,7, are the corresponding long-run multipliers, while the parameters $\beta_i, \eta_i, \gamma_i, \theta_i, \pi_i, \phi_i, \omega_i$ are the short-run dynamic coefficients of the underlying ARDL model.

The first step in the ARDL bounds testing approach to cointegration is to investigate the existence of long-run relationship among all variables in the equation. To this end, an appropriate lag length selection based on Schwartz Bayesian Criterion (SBC)[3] is conducted and Equation (5) is estimated using the OLS method. The bounds testing procedure is based on the joint F-statistic or Wald statistic that tested the null hypothesis of no cointegration, $H_0 : \delta_i = 0$ against the alternative of $H_1 : \delta_i \neq 0, i = 1,2,3,4,5,6,7$. This study applies the critical values of Narayan (2005) for the bounds F-test rather than Pesaran *et al.* (2001) since it is based on small samples ranging from 30 to 80 observations. Two sets of critical values that are reported in Narayan (2005) provide critical value bounds for all classifications of the regressors into purely I(1), purely I(0) or mutually cointegrated. If the calculated F-statistic lies above the upper level of the band, the null hypothesis is rejected, indicating cointegration. If the calculated F-statistic is

[2] See Hundie (2014), Ghosh (2010), Sarboori and Sulaiman (2013) and Farhani *et al.* (2014) for more details.

[3] Pesaran and Shin (1995) argue that the Schwartz-Bayesian Criteria (SBC) is preferable to other model specification criteria because it often has more parsimonious specifications.

below the upper critical value, we cannot reject the null hypothesis of no cointegration. Finally, if it lies between the bounds, a conclusive inference cannot be made without knowing the order of integration of the underlying regressors.

The second step is to estimate the following long-run and short-run models that are represented in Equations (6) and (7) if there is evidence of long-run relationships (cointegration) between these variables.

$$\ln C_t = \alpha_2 + \sum_{i=1}^{p}\beta_{2i}\ln C_{t-i} + \sum_{i=0}^{q_1}\eta_{1i}\ln Y_{t-i} + \sum_{i=0}^{q_2}\gamma_{1i}\ln\left(Y_{t-i}\right)^2 + \sum_{i=0}^{q_3}\theta_{1i}\ln Es_{t-i} + \sum_{i=0}^{q_4}\pi_{1i}\ln T_{t-i}$$
$$+ \sum_{i=0}^{q_5}\phi_{1i}\ln F_{t-i} + \sum_{i=0}^{q_6}\omega_{1i}\ln P_{t-i} + \sum_{i=0}^{q_7}\upsilon_{1i}UR_{t-i} + \varepsilon_{2t} \quad (6)$$

$$\Delta C_t = \alpha_3 + \sum_{i=1}^{p}\beta_{3i}\Delta C_{t-i} + \sum_{i=0}^{q_1}\eta_{3i}\Delta Y_{t-i} + \sum_{i=0}^{q_2}\gamma_{3i}\Delta\left(Y_{t-i}\right)^2 + \sum_{i=0}^{q_3}\theta_{3i}\Delta E_{t-i} + \sum_{i=0}^{q_4}\pi_{3i}\Delta T_{t-i}$$
$$+ \sum_{i=0}^{q_5}\phi_{3i}\Delta F_{t-i} + \sum_{i=0}^{q_6}\omega_{1i}\Delta P_{t-i} + \sum_{i=0}^{q_7}\upsilon_{1i}\Delta UR_{t-i} + \psi ECT_{t-1} + \varepsilon_{3t} \quad (7)$$

where ψ is the coefficient of error-correction term (ECT). ECT, defined as:

$$ECT_t = C_t - \alpha_2 - \sum_{i=1}^{p}\beta_{2i}C_{t-i} - \sum_{i=0}^{q_1}\eta_{1i}Y_{t-i} - \sum_{i=0}^{q_2}\gamma_{1i}\left(Y_{t-i}\right)^2 - \sum_{i=0}^{q_3}\theta_{1i}E_{t-i} - \sum_{i=0}^{q_4}\pi_{1i}T_{t-i}$$
$$- \sum_{i=0}^{q_5}\phi_{1i}F_{t-i} - \sum_{i=0}^{q_6}\omega_{1i}P_{t-i} - \sum_{i=0}^{q_7}\upsilon_{1i}UR_{t-i} \quad (8)$$

ECT shows how quickly variables converge to equilibrium and it should have a statistically significant coefficient with a negative sign. (Acaravci & Ozturk, 2010a)

The ARDL bounds cointegration approach proves the existence or absence of a long-term relationship between the variables included in the model (Alkhathlan & Javid, 2013), but it does not indicate the direction of causality (Acaravci & Ozturk, 2010a). Thus, this article uses Granger non-causality procedure introduced by Toda and Yamamoto (1995) (hereafter TY) to examine the causal relationship between carbon dioxide emissions, energy consumption, output, trade openness, financial development and population growth in Ethiopia. The TY approach is preferred because it has many statistical advantages over other methods of testing Granger non-causality.

The basic idea is to artificially augment the correct VAR order, k, with d_{max} extra lags, where d_{max} is the maximum likely order of integration of the series in the system as follows. The TY representation of Equation (1) is given as follows:

$$\ln C_t = \beta_{10} + \sum_{i=1}^{p}\theta_{1i}\ln C_{t-i} + \sum_{i=p+1}^{p+d_{\max}}\Omega_{1i}\ln C_{t-i} + \sum_{i=1}^{p}\delta_{1i}\ln E_{t-i} + \sum_{i=p+1}^{p+d_{\max}}\phi_{1i}\ln E_{t-i} + \sum_{i=1}^{p}\gamma_{1i}\ln T_{t-i}$$
$$+ \sum_{i=p+1}^{p+d_{\max}}\psi_{1i}\ln T_{t-i} + \sum_{i=1}^{p}\mu_{1i}\ln F_{t-i} + \sum_{i=p+1}^{p+d_{\max}}\eta_{1i}\ln F_{t-i} + \sum_{i=1}^{p}\vartheta_{1i}\ln P_{t-i} + \sum_{i=p+1}^{p+d_{\max}}\omega_{1i}\ln P_{t-i}$$
$$+ \sum_{i=1}^{p}\varphi_{1i}\ln Y_{t-i} + \sum_{i=p+1}^{p+d_{\max}}\mu_{1i}\ln Y_{t-i} + \sum_{i=1}^{p}\upsilon_{1i}\ln UR_{t-i} + \sum_{i=p+1}^{p+d_{\max}}\nu_{1i}\ln UR_{t-i} + \varepsilon_{1t} \quad (9)$$

$$\ln E_t = \beta_{20} + \sum_{i=1}^{p}\theta_{2i}\ln C_{t-i} + \sum_{i=p+1}^{p+d_{\max}}\Omega_{2i}\ln C_{t-i} + \sum_{i=1}^{p}\delta_{2i}\ln E_{t-i} + \sum_{i=p+1}^{p+d_{\max}}\phi_{2i}\ln E_{t-i} + \sum_{i=1}^{p}\gamma_{2i}\ln T_{t-i}$$
$$+ \sum_{i=p+1}^{p+d_{\max}}\psi_{2i}\ln T_{t-i} + \sum_{i=1}^{p}\mu_{2i}\ln F_{t-i} + \sum_{i=p+1}^{p+d_{\max}}\eta_{2i}\ln F_{t-i} + \sum_{i=1}^{p}\vartheta_{2i}\ln P_{t-i} + \sum_{i=p+1}^{p+d_{\max}}\omega_{2i}\ln P_{t-i}$$
$$+ \sum_{i=1}^{p}\varphi_{2i}\ln Y_{t-i} + \sum_{i=p+1}^{p+d_{\max}}\mu_{2i}\ln Y_{t-i} + \sum_{i=1}^{p}\upsilon_{1i}\ln UR_{t-i} + \sum_{i=p+1}^{p+d_{\max}}\nu_{1i}\ln UR_{t-i} + \varepsilon_{2t} \quad \text{..............................(10)}$$

$$\ln Y_t = \beta_{30} + \sum_{i=1}^{p}\theta_{3i}\ln C_{t-i} + \sum_{i=p+1}^{p+d_{\max}}\Omega_{3i}\ln C_{t-i} + \sum_{i=1}^{p}\delta_{3i}\ln E_{t-i} + \sum_{i=p+1}^{p+d_{\max}}\phi_{3i}\ln E_{t-i} + \sum_{i=1}^{p}\gamma_{3i}\ln T_{t-i}$$
$$+ \sum_{i=p+1}^{p+d_{\max}}\psi_{3i}\ln T_{t-i} + \sum_{i=1}^{p}\mu_{3i}\ln F_{t-i} + \sum_{i=p+1}^{p+d_{\max}}\eta_{3i}\ln F_{t-i} + \sum_{i=1}^{p}\vartheta_{3i}\ln P_{t-i} + \sum_{i=p+1}^{p+d_{\max}}\omega_{3i}\ln P_{t-i}$$
$$+ \sum_{i=1}^{p}\varphi_{3i}\ln Y_{t-i} + \sum_{i=p+1}^{p+d_{\max}}\mu_{3i}\ln Y_{t-i} + \sum_{i=1}^{p}\upsilon_{1i}\ln UR_{t-i} + \sum_{i=p+1}^{p+d_{\max}}\nu_{1i}\ln UR_{t-i} + \varepsilon_{3t} \quad \text{..........................(11)}$$

We can write TY representation for the remaining variables in a similar fashion. The order *p* of the process is estimated by some consistent lag selection criteria. In the present study we have used SIC (preferably) and AIC and d_{max} is obtained from unit root test. Then, Granger causality is tested using the modified Wald (MWald) test which is theoretically very simple, as it involves estimation of an augmented VAR model in a straightforward way. For instance, from Equation (9) energy consumption (ES_t) Granger causes CO_2 emissions (C_t) if at least one of the $\delta_{1p}'s \neq 0$.

4. Empirical Results and Discussions

Unit Root Test

Unit root test helps to identify the maximum order of integration for the series which is used to augment VAR (p). Moreover, it is used to identify the series that surpassed the order of integration I (1) under which the application of the ARDL approach is inappropriate. To this end, three conventional unit root tests viz. Phillips and Perron (1988) (PP), Kwiatkowski, Phillips, Schmidt, and Shin (1992) (KPSS) and augmented Dickey Fuller (1979) (ADF) were employed. Katircioglu, Feridun and Kilinc (2014), Jafari, Othman and Nor (2012) and Farhani and Ozturk (2015) argued that PP and ADF unit root tests have a low power of rejecting the null hypothesis. It is suggested that the KPSS unit root test outshines the ADF and the PP in removing a possible low power against stationary unit root that occurs in them (Katircioglu , Feridun , & Kilinc , 2014; Jafari , Othman, & Nor, 2012; Behera & Dash, 2017). Therefore, this study relied on the KPSS unit root test where contradictory results arise from these conventional unit root tests. The results shown in Table 1 below indicates that most of the variables, in case of ADF, and all variables in case of PP and KPSS are non-stationary at level, but become stationary at their first difference at 5% significance level or less. This firmly proves that the conventional cointegration and granger causality testing techniques cannot be applied in this study.

Table 1

Results of Conventional Unit Root Tests

		ADF: t-Statistic	PP: Adj. t-Stat.	KPSS: LM-Stat.
Levels				
Intercept only	lnC	-4.088403**	-1.553601	0.506271(5)**
	lnES	-1.350324	-1.145716	0.689806(5)**
	lnT	-1.724615	-1.782051	0.599053(5)**
	lnF	-1.377113	-1.377113	0.501733 (5)**
	lnY	4.158995	5.364499	0.812004(5)***
	lnY^2	4.745510	6.643138	0.804810(5)***
	lnP	-4.579469**	-1.971074	0.180746(5)***
	lnUR	0.521673	-0.202579	0.862220(5)***
Intercept and trend	lnC	-4.477194**	-2.333245	0.183850(4)**
	lnES	-3.146223	-2.826115	0.188741(4)**
	lnT	-2.032029	-2.273933	0.599053(5)**
	lnF	-1.077342	-1.077342	0.156875(5)***
	lnY	0.847281	0.272262	0.218929(5)***
	lnY^2	1.234922	0.616090	0.218657(5)***
	lnP	-4.321182**	-1.989558	0.116834(5)***
	lnUR	-2.132119	-1.691429	0.147678(5)**
First Differences				
Intercept only	lnC	-4.850183***	-3.972950***	0.076415(3)
	lnES	-6.857512***	-7.396352***	0.216862(12)
	lnT	-6.241112***	-6.267085***	0.100138(6)
	lnF	-5.652532***	-5.660883***	0.160865(2)
	lnY	-10.15517***	-9.335105***	0.760101(3)
	lnY^2	-12.60877	-8.808092***	0.815341(3)
	lnP	-4.305795***	-2.049215	0.068504(3)
	lnUR	-1.637434	-2.926925	0.157059(5)
Intercept and trend	lnC	-5.058499***	-3.439057	0.055504(4)
	lnES	-6.874491***	-8.560948	0.190530(15)
	lnT	-6.193555***	-6.207440	0.095380(4)
	lnF	-5.665636***	-5.646782***	0.097060(3)
	lnY	-12.60877***	-12.60877	0.141915(13)
	lnY^2	-3.654045***	-12.38597**	0.139209(10)
	lnP	-2.234572	-2.016299	0.062434(3)
	lnUR	-1.532285	-2.842904	0.154517(5)

Note: *, ** and *** show rejection of the null hypothesis at 10, 5 and 1 per cent level of significance respectively. Figure in () for KPSS is bandwidth based on Bartlett kernel.

Table 2

Unit Root Tests with Structural Breaks

CMR Unit-Root Test with Double Mean Shifts							ZA Unit Root test allowing for a single break in intercept and/or trend	
At Levels	**Innovative Outliers**			**Additive Outliers**			**t-statistic**	**Break Date**
	t-statistic	**TB1**	**TB2**	**t-statistic**	**TB1**	**TB2**		
lnC	-6.905(2)**	2002	2009	-1.815(8)	2002	2009	-6.136(2)***	2003
lnES	-4.702(0)	1984	1999	-4.822(1)	1990	2002	-4.090(0)	2001
lnT	-7.161(0)	1987	1990	-3.540(7)	1985	1993	-4.316(0)	1992
lnF	-6.679(10)	-	2009	-3.688(0)	1984	2008	-3.924(0)	2005
lnY	2.111(10)	1994	2002	-3.059(0)	1991	2005	-2.916(1)	1991
lnY^2	2.305(0)	1992	2002	-2.983(0)	1991	2005	-2.476(1)	1991
lnP	-4.579(8)	1973	1977	-6.630(1)**	1984	2000	-5.273(2)**	1992
lnUR	-5.692(2)**	1993	2002	-8.286(10)**	1984	1997	-3.975(1)	1990
At First Difference								
lnC	-5.681(5)**	1991	2006	0.235(6)	1990	2007	-3.441(0)	1979
lnES	-7.873(3)**	1983	1991	-7.650(1)**	1982	1990	-6.946(0)***	1994
lnT	-9.265(0)**	1990	1994	-4.331(2)	1989	1994	-8.704(0)***	1992
lnF	-12.766(2)**	2003	2009	-1.393(7)	2003	2008	-7.547(0)***	2001
lnY	-8.338(1)**	1992	2001	-8.165(1)**	1991	2003	-13.657(0)***	1983
lnY^2	-14.256(0)**	1992	2001	-8.168(1)**	1991	2003	-13.574(0)***	1983
lnP	-6.741(11)**	-	1985	-5.348(10)	1981	1987	-4.948 (2)***	1984
lnUR	-253.986(11)**	1983	1994	-1.273(8)	1986	1996	-8.915(1)***	1995

*Note: *, ** and *** show rejection of the null hypothesis at 10, 5 and 1 per cent level of significance respectively.*

Results of unit root test that consider structural breaks are given in Table 2 above[4]. CMR unit root test result confirms that lnC, lnP and lnUR are stationary at level, I (0), as well as at their first difference, I (1). But lnES, lnT,lnF, lnY and lnY^2 become stationary after first differences, i.e. they are I(1). This implies that lnC, lnP and lnUR are both I(0) and I(1) while the remaining variables are I(1). This result corroborates with the evidences obtained by the conventional unit root tests given in Table 1. Moreover, the ZA unit root test result reveals that all the variables are integrated of order one, I (1), except lnC.

Cointegration Tests

Selection of appropriate lag length is a crucial step in estimating the ARDL model. To do so, this study employed the SBC criteria as Pesaran and Shin (1995) recommended that this criterion results in more parsimonious specifications. The results of the cointegration test based on the ARDL bounds test approach are presented in Table 3.

Table 3

ARDL Bounds Test Result

[4] Most of the beak dates determined by the tests coincide with the political and economic events of Ethiopia.

	Models based on BIC	F-Stat.	Result
F_{lnC}(lnC|lnES,lnY,lnY2,lnF, lnT,lnP,lnUR)	(4, 4, 3, 4, 4, 4, 4, 4)	181.04***	Cointegration
F_{lnES}(lnES|lnC,lnY,lnY2,lnF, lnT,lnP,lnUR)	(4, 4, 3, 4, 4, 4, 4, 4)	71.90***	Cointegration
F_{lnY}(lnY|lnC,lnES,lnY2,lnF, lnT,lnP,lnUR)	(4, 4, 1, 4, 0, 4, 2, 4)	5.64***	Cointegration
F_{lnF}(lnF|lnC,lnES,lnY2,lnY, lnT,lnP,lnUR)	(4, 4, 4, 4, 3, 4, 4, 4)	45.61***	Cointegration
F_{lnT}(lnT|lnC,lnES,lnY2,lnY, lnF,lnP,lnUR)	(4, 4, 4, 4, 3, 4, 4, 4)	38.55***	Cointegration
F_{lnP}(lnP|lnC,lnES,lnY2,lnY, lnF,lnT,lnUR)	(4, 4, 4, 4, 3, 4, 4, 4)	44.56***	Cointegration
F_{lnUR}(lnUR|lnC,lnES,lnY2,lnY, lnF,lnT,lnP)	(4, 4, 4, 4, 4, 3, 4, 4)	102.75***	Cointegration

*** indicates significance at 1%

Table 3 above presents estimated ARDL models, F-statistic and optimal lag lengths selected by the SBC. Bounds F-test for cointegration reveals that there is a long-run relationship between CO_2 emissions, energy intensity (lnES), real GDP (lnY), real GDP squared (lnY^2), financial development (FINDEX), trade openness (lnT), population (lnP) and urbanization (lnUR) at 1% level of significance since the calculated F-statistic is greater than the upper bound critical value. Moreover, the null hypothesis of no long-run relationship is rejected when each variable is considered as a dependent variable.

The next step, after investigating the long run relationship between the variables, is to examine impacts of economic growth, economic growth squared, energy consumption, financial development, population, urbanization and trade openness on CO2 emissions. The results are reported in Table 4 showing that energy structure has positive and statistically significant impact on CO2 emissions. The coefficient of energy structure is the fourth largest (0.130386) among the statistically significant coefficients, indicating that a 1 per cent increase in the share of fossil fuel in the share of total energy consumption leads to about .13% increase in CO_2, keeping other factors constant. This implies that fossil fuel consumption is among the leading factor causing CO_2 in Ethiopia. This is due to the fact that majority of the rural as well as urban population in Ethiopia which account for 88% of total energy consumption depends on biomass fuels as the energy consumption as indicated in Ramakrishna (2015). Trade openness is the second largest contributor to CO_2 emissions with a coefficient of 0.195622 which implies that a 1% percent increment in trade openness leads to 0.2% increase in CO_2 emissions. This finding is in line with earlier findings by Al-Mulali, Ozturk and Solarin (2016), Baek and Kim (2011) and Nahman and Antrobus (2005) which argued that trade openness has an adverse effect on the environment for the developing countries because relatively low-income developing countries will be made dirtier with trade due to the fact that pollution intensive manufacturing relocates from developed to developing countries where environmental regulations are assumed to be less strict. Under this situation, as developed countries create demand for tighter environment protection, trade openness leads to move more rapid growth of dirty industries from developed economies to developing world, thereby deteriorating environmental quality. Financial development and urbanization have no statistically significant impact on CO_2. This result is in line with Kais and Sami (2016).

Table 4

Estimated Long Run Coefficients (dependent variable is lnC)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
lnES	0.130386	0.034582	3.770323	0.0327
lnY	0.976414	0.019382	50.377055	0.0000
lnY2	-0.044616	0.001589	-28.086026	0.0001
FINDEX	-0.031841	0.017412	-1.828656	0.1649
lnT	0.195622	0.050043	3.909071	0.0297
lnP	0.155104	0.018981	8.171453	0.0038
lnUR	-0.121495	0.062605	-1.940658	0.1476

Economic growth is the first largest contributor to CO_2 emissions in Ethiopia, with a coefficient of 0.976414 which is statistically significant at 1% level of significance. This indicates that a 1% increase in real GDP results in 0.98% increase in CO2 emissions. Contrary, a 1% rise in real GDP square reduces CO2 emissions by 0.045%. This result shows that there is evidence for the existence of EKC hypothesis in Ethiopia which corroborates with the findings of Onater-Isberk (2016), Halicioglu and Ketenci (2016) for Armenia, Estonia, Kyrgyzstan, Turkmenistan and Uzbekistan and Ben Youssef, Hammoudeh, and Omri (2016). However, it contradicts with result obtained by Lin *et al*. (2016) which argued that the EKC hypothesis does not holf for African countries while it conforms with result obtained by population has statistically significant positive impact on CO_2 in Ethiopia. This result corroborates the findings of earlier studies by Ohlan (2015) and Alam *et al.* (2016) for India. The justification is that more than 85% of the Ethiopian population which is growing at a very rapid rate, of about 3 percent annually depends on agriculuter for their livelihood. This resulted in land degradation main causes for increasing numbers of people to remain in poverty, suffer from shortage of food and deteriorating living conditions. Due to this fact the population has been clearing forests and vegetation to satisfy its increasing requirements of food and energy which results in environmental degradation, in addition to the pressure put on the environment from the growing industry.

After estimating the long-run coefficients, the next step is to find the error correction representation of (Equation 7) of the ARDL model. Table 5 provides the short-run results of ARDL approach to cointegration.The estimated coefficient of lagged error correction term, ECM(-1), is -0.103. It is statistically significant at 1% level of significance with correct sign which indicates that departure from the long-term CO_2 emissions path due to a certain shock is adjusted by 10.3% over the next year. And complete adjustment will take about 10 years. This is the alternative evidence for the existence of cointegration among the variables under consideration. In the short-run energy structure and urbanization are the only factors that are positively deriving CO_2 emissions. The EKC hypothesis is not confirmed in Ethiopia in the short-run because it is not a short-run phonomena.

Table 5

Estimated Short-Run Coefficients

Variable	Coefficient	Std. Error	t-Statistic	Prob.

D(lnF)	-0.003604	0.006078	-0.592988	0.5570
D(lnES)	0.081821	0.023808	3.436712	0.0015
D(lnP)	0.001369	0.026631	0.051413	0.9593
D(LNT)	0.023910	0.017434	1.371461	0.1790
D(lnUR)	2.056206	0.722202	2.847134	0.0073
D(LnY)	-0.643940	0.515147	-1.250013	0.2196
D($\ln Y^2$)	0.027408	0.021575	1.270395	0.2123
Constant	-0.025479	0.010708	-2.379439	0.0229
ECM(-1)	-0.102626	0.033519	-3.061711	0.0042

Note: Dependent variable is lnC

Granger Causality

The presence of cointegration among the variables guarantees the existence of at least a unidirectional causality (Ghosh, 2010) but it does not tell us the direction of causality. When the variables under consideration are mixture of I(0) and I (1) or above, the TY procedure is the most appropriate method to test for the granger causality (Chindo, Abdulrahim, Ahmad, Waziri, & Huong, 2014). In order to apply the TY method, the optimal lag length of VAR suggested by all lag length criteria (LR, FPE, AIC, BIC and HQ) is 2 and since the maximum order of integration is $1(d = 1)$, augmented VAR (3) model was estimated using the Seemingly Unrelated Regression (SUR) framework[5]. Table 6 presents the empirical results obtained from TY (Eq. 9-11) approach to granger causality.

Table 6

Toda-Yamamoto Granger Causality Results

Dependent variables	Sources of Causation						
	lnC	lnES	lnF	lnT	lnP	lnUR	lnY
	χ^2 (2)	χ^2 (2)	χ^2 (2)	χ^2 (2)	χ^2 (2)	χ^2 (2)	χ^2 (2)
lnC	-	21.896***	0.150	0.703	3.803	4.984*	5.666*
lnES	4.833*	-	2.324	2.782	1.858	4.665*	4.553
lnF	1.940	5.944*	-	10.173***	6.830**	0.903	1.767
lnT	1.068	2.133	3.642	-	5.075*	0.192	4.380
lnP	0.544	7.878**	3.642	2.749	-	0.032	1.883
lnUR	0.940	17.916***	18.722***	8.910**	3.880	-	10.590***
lnY	0.142	0.831	12.128***	3.672	43.215***	10.590***	-

*Notes: *, **and *** indicate significance at 10 %, 5% and 1% respectively.*

The results shown in Table 6 above can be summarized as below:

1. There is two-way causal relationship between CO_2 emissions and energy consumption (fossil fuels as share of total energy consumption). This means that energy consumption granger causes CO_2 emissions and there is feedback from CO_2 emissions as well. The presence of bidirectional

[5] This augmented VAR model was estimated using Zellner (1962) seemingly unrelated regression (SUR) model because the coefficient estimators obtained by the SUR are more efficient than those obtained by an equation-by-equation of least squares.

causal relationship between energy consumption and CO_2 emissions recommends that any fluctuations in energy consumption may change the environmental quality and any effort that may reduce CO_2 emissions will affect energy consumption.

2. Moreover, bi-directional causality exists between energy consumption and urbanization. Urban areas are where economic activities and industrializations are concentrated which granger cause energy consumption.
3. There is no direct causal relationship between energy consumption and economic growth. Energy consumption granger causes financial development, population and urbanization and they in turn cause economic growth. Moreover, economic growth granger causes CO_2 emissions. However, energy consumption affects economic growth through financial development, urbanization and population while economic growth and energy consumption are related through CO_2 emissions.
4. Population size causes financial development, economic growth and trade openness and trade openness in turn causes urbanization.

5. Conclusion and Policy Implications

The main objective of this paper is to investigate the impact of population, energy consumption, economic growth, financial development, urbanization and trade openness on environmental quality (CO_2) and causal relationship between them in Ethiopia from 1970-2014. Unit root tests were conducted using conventional (ADF, PP and KPSS) and second generation (ZA and CMR) unit root test methods. The result reveals that some variables are I(0), others are I(I) while some of them are I(1)/I(0). For this reason ARDL approach to cointegration was applied to establish the long-run relationship among the variables and to obtain the estimates for both long-run and short-run effects. Moreover, Toda-Yamamoto approach to Granger causality was employed to investigate the causal relationship between the series.

The results of the analysis show that economic growth and its square (measured by real GDP) are statistically significant positive and negative impact on CO_2 emissions respectively. This finding points the presence of the evidence for EKC hypothesis in Ethiopia which implies that economic growth negatively harms environmental quality at early stage of development and becomes panacea for environmental degradation at higher stages of economic development. Therefore, the EKC hypothesis is a worthy model for environmental and sustainable development policy in Ethiopia. Energy structure is also the key factor which positively contributes to CO2 emissions in Ethiopia due to the high share of fossil fuel in total energy consumption and low penetration of clean energy in the country. Increase in population size exacerbates CO2 emissions due to the pressure that the populated human being puts on the environment. Urbanization and financial development do not affect CO_2 in the long-run. However, energy structure and urbanization are factors that determine the short-run dynamics of CO_2 emissions in Ethiopia. CO2 emissions are found to have a positive long-run relationship with trade openness.

The TY granger causality results show that energy consumption causes financial development, urbanization and population which in turn cause CO_2 emissions. Economic growth causes CO_2 emissions and CO_2 emissions granger causes energy consumption with feedback effect.

Based on the above findings the main policy implication that can be forwarded is summarized as follows. First, economic growth leads to more carbon dioxide emissions at lower stage of development. This implies that Ethiopia should focus on formulating environmentally friendly growth strategies and policies. Second, the degree to which economic growth affects environmental quality depends on quality and efficiency of energy used. Since energy consumption contributes to economic growth through financial development, population and urbanization, the effort of designing sustainable and environmentally favorable policy should take these variables into account. Moreover, the country should shift from fossil fuel consumption to renewable and cleaner energy sources. Third, Ethiopia should give due attention to having standard trade policies and restrictions to reduce import of environmentally pollutant products and investments.

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