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ORIGINAL PAPER

Investigating the presence of the environmental Kuznets curve (EKC) hypothesis in Kenya: an autoregressive distributed lag (ARDL) approach

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Abstract This study investigates the environmental Kuznets curve (EKC) hypothesis in Kenya using the time period of 1980–2012. To achieve the objective of this study, the ARDL approach was utilized. To prevent any estimation errors and unreliability in the model, the Narayan and Narayan (Energy Policy 38:661–666, 2010) approach was used to control the multicollinearity problems in the regression. The outcome of this research revealed that fossil fuel energy consumption, GDP, urbanization, and trade openness increase air pollution mutually in the long run and short run. However, renewable energy consumption mitigates air pollution in the long run and the short run. Moreover, financial development also reduces air pollution, but only in the long run. Based on the results, the EKC hypothesis does exist in Kenya. From the findings of this research, few policy recommendations were provided to help Kenya for reducing its air pollution levels.

Keywords Kenya · EKC hypothesis · ARDL approach

1 Introduction

Kenya witnessed a substantial boost in its economic activities which resulted from the increase in the country's urbanization, industrial output, trade, and infrastructure, especially during the period of 2000–2013. As a consequence of this boost, Kenya managed to

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achieve a positive gross domestic product (GDP) growth as well as change its position from a low-income country to a lower-middle-income country (World Bank 2015a). Thus, in 2014, Kenya was able to achieve a 5.4 % of GDP growth. Its GDP growth is expected to further increase to 6–7 % in 2015 and 2017 (World Bank 2015a). These developments helped Kenya's economy to increase by over 25 %, which makes it the ninth largest African economy with a GDP of 55.2 billion US dollars. However, these remarkable improvements in Kenya need energy to materialize. Therefore, electricity consumption increased more than double in the last three decades from 1.662 billion kilowatt-hours in 1980 to 6.627 billion kilowatt-hours in 2012 (Energy Information Administration 2015). Consequently, the level of CO_2 emission increased from 5.749 million metric tons in 1980 to 13.446 million metric tons in 2012. This increase in CO_2 emission, a main source of greenhouse gas emission, might be attributed to the increase in fossil fuel electricity consumption which represented 24 % of the total electricity generation in 2012. However, electricity consumption that is generated from renewable sources, especially electricity consumption generated from geothermal, solar, tides, wind, biomass, and biofuels, had also increased during the last three decades. Renewable electricity consumption plays over 75 % of the total electricity consumption, and it is increasing at a faster rate than the electricity consumption generated by fossil fuels (World Bank 2015b). Consequently, the increase in the role of renewable energy consumption can help to reduce the air pollution levels. Moreover, the government effort in promoting renewable energy and energy efficiency might help to establish the environmental Kuznets curve (EKC) relationship between air pollution and income.

The EKC hypothesis clarifies that during the initial phases of economic development, the increase in income will increase pollution until it reaches a certain point where the relationship between the two variables is negative. This phenomenon occurs when the country experiences improvements in energy efficiency, renewable energy, and environmental awareness which aid in forming an inverted U-shape relationship between income and pollution. Nonetheless, Kenya is still facing a number of challenges, such as poverty, inequality, low governance, investment, and firm productivity (World Bank 2015a). These challenges, therefore, might hinder the occurrence of the EKC hypothesis. Based on what has been stated, the researchers are motivated to investigate the presence of the EKC hypothesis in Kenya.

The EKC hypothesis is becoming an important focus among scholars who examine environmental policies. Hence, several studies were conducted to examine the EKC hypothesis. A number of these studies can be seen in Table 1. From Table 1, it is obvious that the previous papers investigated different countries, regions, and organizations by using different econometric methodologies. Moreover, diverse variables were used as indicators of pollution, such as ecological footprint (Al-mulali et al. 2015a) and sulfur dioxide (SO_2) (Day and Grafton 2003; Haisheng et al. 2005; Jayanthakumaran and Liu 2012). However, most of the studies utilized CO_2 emission as an indicator of pollution (Day and Grafton 2003; Pao and Tsai 2010; Arouri et al. 2012; Saboori et al. 2012; Chandran and Tang 2013; Shahbaz et al. 2014; Lau et al. 2014; Onafowora and Owoye 2014; Farhani et al. 2014; Kivyiro and Arminen 2014; Al-mulali et al. 2015a, b; Apergis and Ozturk 2015; Tang and Tan 2015; Shahbaz et al. 2015; and so forth). In addition, different determinants of pollution were used in the previous studies, most prominent of which is the gross domestic product (GDP) growth which has been utilized by all the previous studies.

Moreover, other indicators were also used, such as energy consumption (Pao and Tsai 2010, 2011; Jayanthakumaran et al. 2012; Arouri et al. 2012; Chandran and Tang 2013;

Table 1 Environmental Kuznets curve literature summary

Author	Period	Country/region/organization	Methodology	Variables used in the study	EKC hypothesis
Al-mulali et al. (2015a)	1980–2008	93 countries based on income	Generalized method of moments (GMM) and panel fixed effect (FE) model	Ecological footprint, GDP, electricity consumption, trade openness, urbanization, and financial development	Yes for the high- and the upper-middle-income country
Apergis and Ozturk (2015)	1990–2011	Asian countries	GMM	CO_2 emission, GDP, population density, industrial output, political stability, government effectiveness, quality of regulations, and control of corruption	Yes
Lau et al. (2014)	1970–2008	Malaysia	Autoregressive distributed lag (ARDL) bounds testing and vector error-correction model (VECM) Granger causality	CO_2 emission, GDP, foreign direct investment (FDI), and trade openness	Yes
Chandran and Tang (2013)	1971–2008	Association of Southeast Asian Nations (ASEAN)-5	Johansen cointegration, VECM and vector autoregression (VAR) Granger causality	CO_2 emission, energy consumption from transportation, GDP, and FDI	No
Shahbaz et al. (2014)	1971–2010	Tunisia	ARDL bounds testing and vector error-correction model (VECM) Granger causality	CO_2 emission, energy consumption, and trade openness	Yes

Table 1 continued

Author	Period	Country/region/organization	Methodology	Variables used in the study	EKC hypothesis
Onafowora and Owoye (2014)	1970–2010	Brazil, China, Egypt, Japan, Mexico, Nigeria, South Korea, and South Africa	ARDL bounds testing	CO_2 emission, GDP, energy consumption, trade openness, and population density	Yes in Japan and South Korea
Jayanthakumaran and Liu (2012)	1990–2007	China	Fixed effects and random effects models	Chemical oxygen demand, sulfur dioxide (SO_2), GDP, and trade openness	Yes
Farhani et al. (2014)	1971–2008	Tunisia	ARDL bounds testing and vector error-correction model (VECM) Granger causality	CO_2 emission, GDP, energy consumption, and trade openness	Yes
Kasman and Duman (2015)	1992–2010	Europe	Pedroni cointegration, fully modified ordinary least square (FMOLS), and VECM Granger causality	CO_2 emission, GDP, energy consumption, trade openness, and urbanization	Yes
Pao and Tsai (2010)	1971–2005	Brazil, Russia, India, and China (BRIC)	Pedroni cointegration, OLS regression, and VECM Granger causality	CO_2 emission, energy consumption, and GDP	Yes
Jayanthakumaran et al. (2012)	1971–2007	China and India	ARDL bounds testing and vector error-correction model	CO_2 emission, GDP, energy consumption, and trade openness	Yes
Arouri et al. (2012)	1981–2005	Middle East and North African (MENA) countries	Cross-correlated effects (CCE) estimation procedure	CO_2 emission, energy consumption, and GDP	Yes for most of the countries

Table 1 continued

Author	Period	Country/region/organization	Methodology	Variables used in the study	EKC hypothesis
Saboori et al. (2012)	1980–2009	Malaysia	ARDL bounds testing and vector error-correction model (VECM) Granger causality	CO_2 emission and GDP	Yes
Shahbaz et al. (2013a)	1965–2008	South Africa	ARDL bounds testing and Pair-wise Granger causality	CO_2 emission, GDP, financial development, trade openness, and coal consumption	Yes
Kohler (2013)	1960–2009	South Africa	Johansen cointegration, ARDL bounds testing, and vector error-correction model (VECM) Granger causality	CO_2 emission, energy consumption, trade openness, and GDP	Yes
Shafiei and Salim (2014)	1980–2011	OECD countries	GMM, VECM Granger causality, and stochastic impacts by regression on population, affluence, and technology	CO_2 emission, renewable energy consumption, non-renewable energy consumption, population, and urbanization	Yes
Al-Mulali et al. (2015b)	1981–2011	Vietnam	ARDL bounds testing and vector error-correction model (VECM) Granger causality	CO_2 emission, labor, capital, GDP, export, imports, and renewable and non-renewable energy consumption	No
Govindaraju and Tang (2013)	1965–2009	China and India	Bayer and Hanck combine cointegration VECM and VAR Granger causality	CO_2 emission, GDP, and coal consumption	No
Baek (2015)	1980–2009	Nuclear generating countries	Pedroni and Kao cointegration, FMOLS, dynamic OLS (DOLS)	CO_2 emission, nuclear, energy consumption, GDP	No

Table 1 continued

Author	Period	Country/ region/ organization	Methodology	Variables used in the study	EKC hypothesis
Pao and Tsai (2011)	1992–2007	BRIC	Pedroni, Kao, and combined Fisher cointegration and VECM Granger causality	CO_2 emission, energy consumption, foreign direct investment, and GDP	Yes
Saboori and Sulaiman (2013)	1971–2009	ASEAN	ARDL bounds testing and vector error-correction model (VECM) Granger causality	CO_2 emission, energy consumption, and GDP	Yes in Singapore and Thailand
Kivyiro and Arminen (2014)	1971–2009	Sub-Saharan African countries	ARDL bounds testing and vector error-correction model (VECM) Granger causality	CO_2 emission, energy consumption, foreign direct investment, and GDP	Yes
Tang and Tan (2015)	1976–2009	Vietnam	Johansen cointegration, VECM Granger causality, normalized cointegrating vector, and vector error-correction model (VECM)	CO_2 emission, energy consumption, foreign direct investment, and GDP	Yes
Shahbaz et al. (2012)	1971–2009	Pakistan	ARDL bounds testing and vector error-correction model (VECM) Granger causality	CO_2 emission, energy consumption, trade openness, and GDP	Yes
Tiwari et al. (2013)		India	ARDL bounds testing, Johansen cointegration and vector error-correction model (VECM) Granger causality	CO_2 emission, GDP, energy consumption, and trade openness	Yes

Table 1 continued

Author	Period	Country/ region/ organization	Methodology	Variables used in the study	EKC hypothesis
Shahbaz et al. (2013c)	1970–2010	Turkey	ARDL bounds testing and vector error-correction model (VECM) Granger causality	CO_2 emission, GDP, energy consumption, and globalization	Yes
Atici (2009)	1980–2002	Central and Eastern Europe	Random and fixed effects model	CO_2 emission, energy consumption, GDP, square of GDP, and trade openness	Yes
Osabuohien et al. (2014)	1995–2010	Africa	Pedroni cointegration and dynamic OLS (DOLS)	CO_2 emission, GDP, square of GDP, rule of law, regulatory quality, government effectiveness, and trade openness	Yes
Haisheng et al. (2005)	1990–2002	China	Random and fixed effect model	Industrial waste water, SO_2 emission, GDP, square of GDP, trade openness, and foreign direct investment (FDI)	Yes
Cho et al. (2014)	1971–2000	OECD countries	Pedroni cointegration and FMOLS	CO_2 emission, N_2O emission, CH_4 emission, energy consumption, GDP, and square of GDP	Yes
Day and Grafton (2003)	1974–1997 for carbon monoxide (CO) emission@ 1958–1995 for CO_2 emission 1974–1997 for SO_2 emission 1974–1997 for Total suspended particulate (TSP)	Canada	Johansen cointegration, OLS model, and VAR Granger causality	CO emission, CO_2 emission, SO_2 emission, TSP, GDP, square of GDP, and cubic of GDP	No

Table 1 continued

Author	Period	Country/ region/ organization	Methodology	Variables used in the study	EKC hypothesis
Chow and Li (2014)	1992–2004	132 developed and developing countries	OLS model	CO_2 emission, GDP and square of GDP	Yes
Shahbaz et al. (2013b)	1971–2011	Malaysia	ARDL bounds testing and vector error-correction model (VECM) Granger causality	CO_2 emission, GDP, financial development, financial development square, trade openness, energy consumption, and foreign direct investment (FDI)	Yes

Shahbaz et al. 2013a, b, c; Kohler 2013; Govindaraju and Tang 2013; Zhang and Da 2013; Saboori and Sulaiman 2013; Shahbaz et al. 2014; Onafowora and Owoye 2014; Cho et al. 2014; Farhani et al. 2014; Shafiei and Salim 2014; Al-mulali et al. 2015b; Kasman and Duman 2015; Baek 2015; and so forth), trade openness (Haisheng et al. 2005; Atici 2009; Jayanthakumaran and Liu 2012; Jayanthakumaran et al. 2012; Shahbaz et al. 2012, 2013a; Kohler 2013; Shahbaz et al. 2013a; Tiwari et al. 2013; Lau et al. 2014; Shahbaz et al. 2014; Osabuohien et al. 2014; Onafowora and Owoye 2014; Farhani et al. 2014; Al-mulali et al. 2015a, b, c; Farhani and Ozturk 2015; Al-Mulali and Ozturk 2015; Kasman and Duman 2015; Liu and Hao 2015), urbanization (Shafiei and Salim 2014; Al-mulali et al. 2015a; Al-Mulali and Ozturk 2015; Kasman and Duman 2015; Zhang et al. 2014), population density (Shafiei and Salim 2014; Onafowora and Owoye 2014; Apergis and Ozturk 2015), and financial development indicators (Haisheng et al. 2005; Pao and Tsai 2011; Shahbaz et al. 2013a, b; Ozturk and Acaravci 2013; Chandran and Tang 2013; Lau et al. 2014; Kivyiro and Arminen 2014; Farhani and Ozturk 2015; Tang and Tan 2015; Al-mulali et al. 2015b; Ohlan 2015). Most of the previous studies reached the conclusion that the above-mentioned economic indicators have significant long-run, short-run, and causal effects on air pollution. Moreover, the EKC hypothesis was confirmed in most of the previous studies, especially in emerging and developed countries.

Even with this well-established literature, to the best knowledge of the researchers of this study, there are few studies that examined the EKC hypothesis in Kenya regardless of its improvement in economic growth and development. Furthermore, most of the scholars who investigated the EKC hypothesis used GDP and the square of GDP together in a single equation, which may generate multicollinearity problems. Therefore, this study will utilize Narayan and Narayan's (2010) method that can solve this shortcoming.

2 Methodology and data

The standard EKC equation suggests that the environmental degradation depends on GDP and square of GDP. However, with the presence of multicollinearity, it is well known that the estimates precision can be affected as multicollinearity usually causes large standard errors and wide confidence intervals. Hence, the researchers used the correlation coefficient to test the presence of multicollinearity between GDP and square of GDP. Using the Pearson product-moment correlation and Spearman rank-order methods, the outcome of the analysis indicates that correlation coefficient is greater than 0.900, which is an indication of severe collinearity between the series (see Kendall and Gibbons 1990).

This issue can be diverted through the use of Narayan and Narayan's (2010) approach which examines whether environmental quality improves overtime as the economy grows. Narayan and Narayan's (2010) method compares the short- and long-run elasticities. According to Narayan and Narayan (2010), if the coefficient of GDP in the short run is bigger than the coefficient of GDP in the long run, it can be concluded that, over time, more income will lead to less carbon dioxide emission.

This study applied the Pesaran et al. (2001) autoregressive distributed lag (ARDL) approach to test the presence of cointegration within the variables and also to estimate the long-run and short-run coefficients of the variables. Unlike the conventional Johansen system cointegration approach which uses set of equations to analyze long-run connection, ARDL adopts one equation. The application of ARDL and Granger causality can aid in avoiding problems associated with estimating short time series data. There is no requirement for pretesting variables in the case of ARDL as the method can be utilized irrespective of the order of integration of the variables as long as they are able to achieve stationarity at first difference or below. This will, consequently, reduce the need to analyze the stationarity of the series. Besides, the short- and long-run estimates can be computed simultaneously. Consequently, we can circumvent the inability to examine the long-run coefficients, which is an attribute of Engle–Granger method. Bounds testing procedure, which is based on the F-test, is the first stage of the ARDL cointegration method. To infer cointegration, the F-statistics are compared with the tabulated critical values. Due to the fact that the F-test utilized in bound test has non-standard distribution, two bounds of critical values for large sample size (500–1000 observations) were computed by Pesaran and Pesaran (1997), while two bounds of critical values for small sample size (as low as 30) were created by Narayan (2005). The lower bound assumes that all variables are $I(0)$, and the upper bound assumes that they are all $I(1)$. There is evidence for cointegration, if the calculated F-statistic is more than the upper critical value. The test is inconclusive if the F-statistic falls within the two bounds of critical values. There is no cointegration, if the F-statistic is smaller than the lower critical value.

The relevant long-run equations in this study can be expressed as:

$$\begin{aligned}\ln \mathrm{CO}_t = {} & \delta_0 \ln Y_t + \delta_1 \ln \mathrm{RE}_t + \delta_2 \ln \mathrm{FD}_t + \delta_3 \ln \mathrm{TR}_t + \delta_4 \ln \mathrm{UR}_t + \delta_5 + \delta_6 T + \delta_7 D_1 \\ & + \delta_8 D_2 + \upsilon_t \end{aligned} \tag{1}$$

$$\begin{aligned}\ln \mathrm{CO}_t = {} & \xi_0 \ln Y_t + \xi_1 \ln \mathrm{FO}_t + \xi_2 \ln \mathrm{FD}_t + \xi_3 \ln \mathrm{TR}_t + \xi_4 \ln \mathrm{UR}_t + \zeta_5 + \zeta_6 T + \zeta_7 D_1 \\ & + \zeta_8 D_2 + \upsilon_t \end{aligned} \tag{2}$$

CO_t is CO_2 emission per capita (tonnes of oil equivalent of carbon dioxide emissions by population), Y_t is real gross domestic product (GDP) per capita (constant 2005 US$), RE_t is electricity generated from renewable sources (such as hydropower and solar) in kilowatt-hours per capita, FO_t is electricity generated from fossil fuel sources (such as coal, oil, and natural gas) in kilowatt-hours per capita, FD is a measure of financial development and is represented by domestic credit to private sector by banks (constant 2005 US\$) divided by GDP (constant 2005 US\$). TR is a measure of trade openness [imports of goods and services (constant 2005 US\$) plus exports of goods and services (constant 2005 US\$) divided by GDP (constant 2005 US\$)], and UR_t is urban population ratio (urban population divided by the total population). In the model involving no break, $\delta_7 = \delta_8 = 0$ $\zeta_7 = \zeta_8 = 0$.

This study's dataset takes the period of 1980–2012. The data for CO_2 emission as well as electricity generated from renewable energy and fossil fuels were retrieved from the Energy Information Administration database (http://www.eia.gov). D_1 and D_2 are the dummies that represent the structural break periods. The data for real GDP, financial development, trade openness, and urban population ratio were retrieved from world development indicators of the World Bank. A descriptive analysis of the series is conducted in Table 2, which shows that electricity generated from renewable sources is greater than electricity generated from fossil fuels in Kenya. However, the variation (standard deviation) in electricity generated from fossil fuels is greater than electricity generated from renewable sources. The Jarque–Bera statistics suggest that the real GDP per capita and renewable electricity per capita do not follow the normal distribution. Hence, it is essential to transform the data to remove the non-normality in subsequent analysis. This step can be achieved through the use of natural logarithm.

To use the ARDL methodology, the error-correction models below were estimated:

$$\begin{aligned}\Delta \ln \mathrm{CO}_t = & \sum_{i=1}^{k} \chi_0 \Delta \ln \mathrm{CO}_{t-i} + \sum_{i=1}^{k} \chi_1 \Delta \ln Y_{t-i} + \sum_{i=1}^{k} \chi_2 \Delta \ln \mathrm{RE}_{t-i} + \sum_{i=0}^{k} \chi_3 \Delta \ln \mathrm{FD}_{t-i} \\ & + \sum_{i=0}^{k} \chi_4 \Delta \ln \mathrm{TR}_{t-i} + \sum_{i=0}^{k} \chi_5 \Delta \ln \mathrm{UR}_{t-i} + \lambda_0 \ln \mathrm{CO}_{t-1} + \lambda_1 \ln Y_{t-1} + \lambda_2 \ln \mathrm{RE}_{t-1} \\ & + \lambda_3 \ln \mathrm{FD}_{t-1} + \lambda_4 \ln \mathrm{TR}_{t-1} + \lambda_5 \ln \mathrm{UR}_{t-1} + \alpha_0 + \alpha_1 T + \alpha_2 D_1 + \alpha_3 D_2 + \upsilon_t \end{aligned} \tag{3}$$

$$\begin{aligned}\Delta \ln \mathrm{CO}_t = & \sum_{i=1}^{k} \kappa_0 \Delta \ln \mathrm{CO}_{t-i} + \sum_{i=1}^{k} \kappa_1 \Delta \ln Y_{t-i} + \sum_{i=1}^{k} \kappa_2 \Delta \ln \mathrm{FO}_{t-i} + \sum_{i=0}^{k} \kappa_3 \Delta \ln \mathrm{FD}_{t-i} \\ & + \sum_{i=0}^{k} \kappa_4 \Delta \ln \mathrm{TR}_{t-i} + \sum_{i=0}^{k} \kappa_5 \Delta \ln \mathrm{UR}_{t-i} + \eta_0 \ln \mathrm{CO}_{t-1} + \eta_1 \ln Y_{t-1} + \eta_2 \ln \mathrm{FO}_{t-1} \\ & + \eta_3 \ln \mathrm{FD}_{t-1} + \eta_4 \ln \mathrm{TR}_{t-1} + \eta_5 \ln \mathrm{UR}_{t-1} + \phi_0 + \phi_1 T + \phi_2 D_1 + \phi_3 D_2 + \varepsilon_t \end{aligned} \tag{4}$$

The null hypothesis of no-cointegration $\lambda_0 = \lambda_1 = \lambda_2 = \lambda_3 = \lambda_4 = \lambda_5$ was tested against the alternative hypothesis of $\lambda_0 \neq \lambda_1 \neq \lambda_2 \neq \lambda_3 \neq \lambda_4 \neq \lambda_5$ in Eq. (3), and the null hypothesis of no-cointegration $\eta_0 = \eta_1 = \eta_2 = \eta_3 = \eta_4 = \eta_5$ was tested against the alternative hypothesis of $\eta_0 \neq \eta_1 \neq \eta_2 \neq \eta_3 \neq \eta_4 \neq \eta_5$ in Eq. (4). Subsequent to testing for long-run relationship between the series to find the long-run coefficients, we investigated the short-run coefficients with the aim of establishing the presence of the EKC hypothesis. Therefore, the short-run model of Eqs. (1) and (2) is specified as follows, respectively:

Table 2 Descriptive analysis

Statistics	CO_2 emission per capita	Real GDP per capita	Renewable electricity per capita	Fossil fuel electricity per capita	Financial development	Trade openness	Urban population ratio
Mean	0.285	530.776	115.660	28.572	22.882	53.697	19.047
Median	0.278	523.311	124.437	24.773	22.767	54.715	18.579
Maximum	0.352	614.306	143.290	71.495	30.420	78.578	24.370
Minimum	0.242	495.569	65.750	4.500	18.416	34.905	15.583
SD	0.026	29.773	18.626	19.372	3.424	13.565	2.812
Skewness	0.606	1.181	−0.949	0.523	0.340	0.287	0.403
Kurtosis	2.926	3.928	3.253	2.135	2.065	1.981	1.822
Jarque–Bera	2.029	8.855	5.039	2.536	1.838	1.880	2.801
Probability	0.363	0.012	0.080	0.281	0.399	0.391	0.247
Sum	9.403	17,515.620	3816.764	942.867	755.107	1772.002	628.563
Sum Sq. Dev.	0.022	28,365.904	11,101.351	12,009.382	375.190	5887.870	253.028
Observations	33	33	33	33	33	33	33

$$\Delta\ln\mathrm{CO}_t = \sum_{i=1}^{k}\varphi_0\Delta\ln\mathrm{CO}_{t-i} + \sum_{i=1}^{k}\varphi_1\Delta\ln Y_{t-i} + \sum_{i=1}^{k}\varphi_2\Delta\ln\mathrm{RE}_{t-i} + \sum_{i=0}^{k}\varphi_3\Delta\ln\mathrm{FD}_{t-i} + \sum_{i=0}^{k}\varphi_4\Delta\ln\mathrm{TR}_{t-i} + \sum_{i=0}^{k}\varphi_5\Delta\ln\mathrm{UR}_{t-i} + \varphi_6 + \varphi_7 T + \varphi_8 D_1 + \varphi_9 D_2 + \varphi_{10}\mathrm{ECT}_{T-1} + \mu_t \quad (5)$$

$$\Delta\ln\mathrm{CO}_t = \sum_{i=1}^{k}\sigma_0\Delta\ln\mathrm{CO}_{t-i} + \sum_{i=1}^{k}\sigma_1\Delta\ln Y_{t-i} + \sum_{i=1}^{k}\sigma_2\Delta\ln\mathrm{RE}_{t-i} + \sum_{i=0}^{k}\sigma_3\Delta\ln\mathrm{FD}_{t-i} + \sum_{i=0}^{k}\sigma_4\Delta\ln\mathrm{TR}_{t-i} + \sum_{i=0}^{k}\sigma_5\Delta\ln\mathrm{UR}_{t-i} + \sigma_6 + \sigma_7 T + \sigma_8 D_1 + \sigma_9 D_2 + \sigma_{10}\mathrm{ECT}_{T-1} + v_t \quad (6)$$

where φ_{10} is speed of adjustment parameter and the ECT in Eq. (5) is residuals obtained from the estimated cointegration model 1; σ_{10} is speed of adjustment parameter and the ECT in Eq. (6) is residuals obtained from the estimated cointegration model of (2). For the ECT to be valid in both cases, it must produce statistically significant negative coefficients.

3 Empirical results and discussion

The empirical analysis commenced with the testing for the unit root properties of the series. As a benchmark, the researchers first applied the traditional unit root tests, including the Said and Dickey (1984) or ADF, Phillips and Perron (1988) or PP, to examine the non-stationarity of the seven series. The results, in Tables 3 and 4, reveal that the null

Table 3 Conventional unit root tests

Variables	ADF unit root test *T*-statistic	PP unit root test *T*-statistic
ln CO_t	−2.865 (0)	−2.770 (2)
Δln CO_t	−5.626*** (2)	−7.037*** (2)
ln Y_t	−1.525 (1)	−0.775 (2)
Δln Y_t	−3.585** (1)	−3.582** (2)
ln RE_t	−2.777 (1)	−3.115 (0)
Δln RE_t	−5.529*** (0)	−5.546*** (0)
ln FO_t	−1.945 (1)	−2.169 (2)
Δln FO_t	−3.736** (1)	−5.565*** (2)
ln FD_t	−2.977 (1)	−2.624 (1)
Δln FD_t	−6.265*** (1)	−7.918*** (1)
ln TR_t	−0.346 (2)	−0.041 (0)
Δln TR_t	−4.088*** (1)	−5.351*** (0)
ln UR_t	−1.510 (2)	−1.458 (2)
Δln UR_t	−3.447* (2)	−3.838** (2)

*, **, and *** indicate significance at 10, 5, and 1 % levels, respectively. With maximum lag set at 4, the optimal lags in ADF are selected based on Akaike information criterion, whereas the Bartlett with Newey–West bandwidth is used for PP. For uniformity sake, the regressions in each test include a constant trend. Due to the finite nature of the dataset, the maximum lag length is set at 2

Table 4 LM unit root test

Variable	*T*-statistics	TB1	TB2	DU1	DT1	DU2	DT2
$\ln \mathrm{CO}_t$	−5.005 [0]	1984	2003	−0.005 (−0.100)	0.051* (1.859)	0.020 (0.381)	0.045** (2.050)
$\Delta\ln \mathrm{CO}_t$	−7.344*** [0]	2000	2006	−0.248*** (−3.691)	0.110*** (3.394)	−0.166** (−2.479)	−0.048 (−1.245)
$\ln Y_t$	−2.202 [0]	2000	–	0.008 (0.372)	0.027*** (3.132)	–	–
$\Delta\ln Y_t$	−5.858** [1]	1984	2004	0.054** (2.697)	−0.048*** (−3.992)	0.002 (0.092)	0.030*** (3.328)
$\ln \mathrm{RE}_t$	−5.017 [2]	1986	1997	−0.105 (−0.889)	−0.030 (−0.462)	0.247* (1.937)	−0.351*** (−4.275)
$\Delta\ln \mathrm{RE}_t$	−6.816*** (0)	1998	2002	−0.479*** (−3.323)	0.315*** (3.777)	0.106 (0.793)	−0.366*** (4.094)
$\ln \mathrm{FO}_t$	−4.957 [2]	1987	1996	0.312 (0.853)	−0.619** (−2.568)	−0.045 (−0.135)	0.941*** (4.136)
$\Delta\ln \mathrm{FO}_t$	−6.436*** (0)	2000	–	−1.102*** (−2.861)	0.411*** (2.581)	–	–
$\ln \mathrm{FD}_t$	−2.340 [0]	1987	–	0.121* (1.650)	−0.739*** (−4.041)	–	–
$\Delta\ln \mathrm{FD}_t$	−8.358*** [1]	1987	2000	−0.426*** (−4.460)	0.167*** (4.431)	−0.296*** (−3.893)	0.195*** (4.527)
$\ln \mathrm{TR}_t$	−3.236 [2]	1991	2000	−0.157** (−2.154)	0.234*** (3.372)	0.088 (1.402)	−0.100** (−2.565)
$\Delta\ln \mathrm{TR}_t$	−6.225*** [0]	1994	–	−0.073 (−1.190)	−0.092*** (−3.296)	–	–
$\ln \mathrm{UR}_t$	−2.089 [0]	1990	–	−0.001 (−0.119)	0.013*** (11.800)	–	–
$\Delta\ln \mathrm{UR}_t$	−8.402*** (0)	1987	1991	0.002 (1.367)	−0.002* (−1.871)	0.002** (2.060)	0.002* (1.947)

*, **, and *** denote significance at 10, 5, and 1 %, respectively. TB is the estimated break points. *, **, and *** imply 10, 5, and 1 % levels of significance. The critical values can be found in Lee and Strazicich (2003: 2004). *TB1 and TB2* are the structural break dates. The dummy variables for breaks in intercept are DU1 and DU2, while the dummy variables for trend breaks are DT1 and DT2. With maximum lag set at 2, the optimal lags are selected based on Akaike information criterion. The estimates are free of serial correlation and heteroscedasticity. The optimal lag length is reported in the brackets, while the *t*-statistics are reported in parentheses

hypothesis of non-stationarity cannot be rejected when the variables are in level. However, the null hypothesis is rejected once the series are in the first difference. The power of these tests becomes questionable in the presence of structural break(s). Consequently, the test statistics of Lee and Strazicich (2003, 2004) tests are subsequently presented. As reported in Table 3, we cannot reject the null of unit root for all the variables when examined in level form in the country. When the variables are specified in their first differences, the null of unit root can be rejected in all the variables. Two breaks are significant in most of the cases. About 22 % of the structural breaks (or 8 of the 23 structural breaks) are in the late 1980s, while 35 % of the structural breaks (or 8 of the 23 breaks) are located in the early 2000s. In all the break dates, 1987 and 2000 are the most recurring, and as a result, we utilized these dates as the structural break dates for the cointegration tests.

The structural breaks that were concentrated in the late 1980s can be explained by the financial sector crises of that period. Starting in 1986, many financial institutions that collapsed in Kenya, which was due to non-performing loans, had an overreaching impact on the economy (Waweru and Kalani 2009). The structural breaks of the early 2000s can be explained by the drought that was witnessed in the country in that period. Declared as a national disaster by the Kenya government, the drought negatively impacted virtually all the sectors, including livestock and wildlife, biodiversity, agriculture and water resources, industry, as well as social and economic welfare (Duran 2004). Worsened by the effects of the 1997–1998 El Nino rains, which had reduced the water-holding capacity, the drought was estimated to have economic costs of 2.8 billion US dollars resulted from the loss of crops and livestock, forest fires, damage to fisheries, reduced hydropower generation, reduced industrial production, and reduced water supply.

Having determined that the variables are integrated in order (1), the cointegration test (presented in Table 5) was applied. The results obtained from the ARDL indicate that there is a long-run relationship between the variables. For comparison purposes, the researchers applied the test without structural breaks and with structural breaks. Table 5 presents the model of electricity consumption from renewable energy without structural breaks. The results show that the *F*-statistic is 5.264, which is above the upper bound critical values at

Table 5 Cointegration results

Model	Model 1	Model 2	Model 3	Model 4
F-statistics	5.264**	7.210***	6.378**	7.586***
Optimal lag length	(1, 1, 1, 1, 0, 0)	(2, 2, 0, 0, 2, 0)	(2, 0, 0, 0, 0, 0)	(2, 2, 0, 0, 2, 0)
Serial correlation	0.559 [1]	0.848 [1]	0.129 [1]	0.725 [1]
Heteroscedasticity	0.835 [1]	0.383 [1]	0.482 [1]	0.147 [1]
Normality	0.940 [2]	0.554 [2]	0.663 [2]	0.685 [2]
Functional form	0.299 [1]	0.143 [1]	0.289 [1]	0.017 [1]
Significant level	Critical values ($T = 33$)			
	Lower bounds $I(0)$		Upper bounds $I(1)$	
1 percent level	4.849		6.511	
5 percent level	3.353		4.500	
10 percent level	2.831		3.879	

** implies 5 % level of significance

*** implies 1 % level of significance. [] is the order of diagnostic tests. The critical values are obtained from Narayan (2005). Critical values for the bounds test: case IV: unrestricted intercept and restricted trend

5 % significance level (4.500). In the model involving electricity consumption from renewable energy with structural breaks, it is observed that the *F*-statistic of 7.210 is greater than the upper bounds critical values at 5 % significance level of 6.511. In the case of models involving electricity consumption from fossil fuel renewable energy with and without structural breaks, the results show that the *F*-statistics (6.378 and 7.586, respectively) are greater than the upper bounds critical values, respectively. This is evidence that there is a long-run relationship in the series, no matter which of the models is analyzed. The diagnostic tests suggest no autocorrelation in the disturbance of the error term, and also the ARCH test denotes that the errors are homoscedastic and independent of the regressors. The model passes the Jarque–Bera normality test, signifying that the errors are normally distributed.

After establishing the existence of long-run relationship between the variables, the next step is to analyze the impact of the variables on emission and also to examine the presence of the EKC. The short- and long-run results are reported in Table 6. Starting with the regression involving renewable energy without structural breaks in model 1, it is observed that GDP, trade openness, and urbanization have a positive impact on emission in the long run and short run. Renewable energy indicates a negative effect on emission in the long run and short run. Although the output of the regression involving renewable energy with structural breaks in model 2 is not too different from the results in model 1, the coefficients are noted to be more significant. For instance, the estimates of financial development are only significant in the long run, while the long-run significance of GDP, trade openness, and urbanization are greater. These can be explained by the fact that Kenya has witnessed a substantial boost in GDP growth, trade liberalization, and urbanization which increased substantially in the last three decades (World Bank 2015a, b). These variables are renowned to be energy intensive. Moreover, the previous studies (Table 1) also confirmed that the above perspective variables are the main contributors of air pollution. In addition, fossil fuel energy consumption has a significant positive effect on air pollution in both the short run and the long run. This outcome is expected as fossil fuel energy is the main source of greenhouse gases. However, the negative long-run effect of financial development on pollution implies that there is an improvement in the financial sector development. Moreover, the domestic credit provided to the private sector is used in less energy-intensive or environment-friendly projects. This outcome is consistent with the results of Shahbaz et al. (2013a, b, c) and Al-mulali et al. (2015a, b, c).

In addition, the negative effect of renewable energy on pollution in both models indicates that the improvements in the renewable energy sector reached the level where it can mitigate greenhouse gases. Moreover, it is well known that renewable energy contains zero fossil carbon atoms that form air pollution. Moreover, the break in 1987 has a negative long-run and short-run influence on emission. The break of 2000 has a positive long-run and short-run effect on emission. To investigate the presence of EKC, we compared the relation between short- and long-run coefficients of GDP. The estimates indicate that the short-run coefficient of the GDP is stronger than its long-run coefficient, which indicates that the EKC hypothesis does exist. The results are consistent with the studies of Haisheng et al. (2005), Atici (2009), Pao and Tsai (2010, 2011), Jayanthakumaran and Liu (2012), Saboori et al. (2012), Kohler (2013), Shahbaz et al. (2014), Lau et al. (2014), Farhani et al. (2014), Al-mulali et al. (2015b), Apergis and Ozturk (2015), Kasman and Duman (2015), and so forth that the EKC hypothesis does exist in the emerging countries since these countries are adopting renewable energy and energy efficiency which is growing in a faster past than the developed nations.

Table 6 Long-run and short-run results

Model	ELR without structural break	ELR with structural break	ELF model without structural beak	ELF model with structural beak
Long-run coefficients				
ln Y_t	0.821*** (6.021)	0.825*** (9.184)	0.845*** (7.407)	0.958*** (11.498)
ln RE_t	−0.084* (−1.632)	−0.107*** (−4.024)		
ln FO_t	–	–	0.029** (2.040)	0.035*** (4.563)
ln FD_t	0.019 (0.189)	−0.151** (−2.749)	−0.074 (−1.074)	−0.145*** (−3.176)
ln TR_t	0.201** (2.400)	0.296*** (4.261)	0.136 (1.706)	0.331*** (5.625)
ln UR_t	2.329*** (5.045)	1.036 (1.513)	2.264*** (4.212)	0.431 (0.716)
Constant	−12.967*** (−10.057)	−9.233*** (−5.202)	−12.901*** (−10.131)	−9.142*** (−6.158)
Trend	−0.043*** (−6.485)	−0.024** (−2.304)	−0.041*** (−5.715)	−0.020** (−2.282)
Dummy 1987	–	−0.051* (−1.897)	–	−0.040* (−1.761)
Dummy 2000	–	0.035 (1.738)	–	0.069*** (4.425)
Short-run coefficients				
Δln Y_t	2.271*** (5.581)	1.785*** (4.333)	1.471*** (4.400)	1.589*** (3.722)
Δln RE_t	−0.241*** (−3.566)	−0.239*** (−3.764)	–	–
Δln FO_t	–	–	0.050* (1.829)	0.098*** (3.258)
Δln FD_t	−0.107 (−1.003)	−0.335** (−2.460)	−0.129 (−1.046)	−0.411** (−2.642)
Δln TR_t	0.270*** (2.176)	0.185 (1.100)	0.237 (1.619)	0.283 (1.552)
Δln UR_t	3.126*** (3.964)	2.301 (1.379)	3.940*** (3.460)	1.220 (0.694)
Constant	−17.405*** (0.000)	−20.502*** (−3.456)	−22.453*** (−5.026)	−25.898*** (−3.710)
Trend	−0.058*** (−4.533)	−0.052* (−1.959)	−0.072*** (−4.022)	−0.056* (−1.958)
Dummy 1987	–	−0.114* (−1.985)	–	−0.113* (−1.850)
Dummy 2000	–	0.077 (1.616)	–	−0.195*** (3.352)
ECT_{t-1}	−0.342*** (6.747)	−0.221*** (−6.318)	−0.740*** (−6.017)	−0.833*** (−5.772)
Joint significance test				
*R*2	0.689	0.729	0.571	0.693
F-statistics	10.863***	7.892***	5.992***	6.807***

Considering the regression involving fossil fuel energy without structural breaks in model 3, it is observed that GDP, fossil fuel energy, and urbanization have a long-run and short-run influence on emission. Financial development has negative impact on emission in the long run and short run. Similar to the equations involving renewable energy, the break in 1987 has a negative long-run and short-run influence on emission, while the break of 2000 has a positive long-run and short-run effect on emission. The estimates indicate that the long-run coefficient is stronger than the short-run coefficient, which implies that EKC does exist. The results imply that an inverted U-shaped relationship between economic growth and CO_2 emission does not exist in the country.

4 Conclusion and policy implications

The main goal of this study is to investigate the environmental Kuznets curve (EKC) hypothesis in Kenya during the period 1980–2012. This goal was achieved by employing autoregressive distributed lag (ARDL) and utilizing the Narayan and Narayan (2010) approach to control the multicollinearity problem that might take place during the econometric analysis. Moreover, a number of structural breaks were included in the regression to avoid the estimating errors and unreliability of the model.

The most important finding of this study is that urbanization, trade openness, GDP, and fossil fuel energy consumption increase air pollution in both the short run and long run. However, renewable energy consumption reduces air pollution in both the short run and the long run. Similarly, financial development also reduces air pollution but only in the long run. Regarding the EKC hypothesis, the results confirm that this phenomenon does exist in Kenya.

From the outcome of this research, a number of policy recommendations can be provided for the investigated country. Since fossil fuels increase air pollution, Kenya should utilize cleaner-type energy sources, such as natural gas and higher-grade coal to reduce the air pollution levels. Moreover, it is essential to promote effective projects and investments that enhance and increase the role of renewable sources of energy, especially from wind and solar sources. In addition, it is important for Kenya's urban policy makers to reduce the rapid growth in urbanization, induce environmental laws and regulation, and include taxes on carbon, air, water pollution, and energy for the purpose of reducing the environmental pressure caused by the urban areas. Furthermore, trade-related actions and policies to increase environmental protection are needed because trade openness in Kenya increases air pollution. Moreover, reducing the tax levels on products that are environmentally friendly is important. In general, endorsing these recommendations might help Kenya to achieve a better and more sustainable economic development in the future.

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