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Fossil Fuel Energy Consumption, Economic Growth, Urbanization, and Carbon Dioxide Emissions in Kenya

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ABSTRACT

The increase in the level of CO_2 emissions has triggered the global temperature to rise above the pre-industrial levels. The unprecedented climate change has resulted in flooding and droughts that have displaced millions of people from their homes, plunged them into poverty, famine, and stunted economic growth, especially in countries with shoddy infrastructure. The large-scale use of fossil fuels across the globe, increase in urbanization and economic growth are likely to worsen the environmental quality. However, the proponents of the economic growth hypothesis do not admit that the consumption of fossil fuels, economic growth and urban expansion, are responsible for the increased level of CO_2 emissions in the atmosphere. The current study, therefore, examines the effects of fossil fuels consumption, economic growth, urbanization and on CO_2 emissions in Kenya from 1971–2014. The study follows a formal time series econometric estimation approach and estimates the long-run model using an autoregressive distributed lag. The study findings show that economic growth and the uptake of fossil fuels increase CO_2 emission, while urbanization reduces it. The study recommends phasing out subsidies for conventional energy supply, promoting energy efficiency and accelerating the development of clean energy technologies.

Keywords: CO_2 Emissions, Fossil Fuel Energy Consumption, Economic Growth, Cointegration, Granger Causality, Kenya.
JEL Classification: K32, P18, Q35, Q43, Q44

1. INTRODUCTION

Carbon dioxide (CO_2) emission from the combustion of fossil fuels is one of the most serious environmental threats of our time, contributing to global warming and eventual climate change (Zhang et al., 2018). The Conference of Parties (COP) 26 recognizes the adverse impact of climate change on the environment and calls for drastic measures to cap global warming to 1.5°C by reducing CO_2 emissions and other greenhouse gases (UNFCCC, 2021). COP 27 observes with concern that the severe impact of climate change falls disproportionally on African countries (Atwoli et al., 2022). Further, COP 27, mandates Parties to make immediate, and significant steady cuts in the emissions coming from conventional fuels across all relevant sectors of their economies (Stanczyk, 2022). This entails increasing the use of non-fossil fuels and low-emission energy sources, decarbonization, and taking other collaborative measures to combat climate change.

Kenya faces severe impacts of climate change in terms of floods and drought and the country requires US$ 62 billion to mitigate and adapt to the climate crisis by 2030 if economic growth is to be maintained in the right trajectory (Odhengo et al., 2021). Before COVID-19, the average annual economic growth rate was 5.6% (KIPPRA, 2020). Due to the intermittent nature of hydropower, economic growth in Kenya is associated with 32.5% of fossil fuel as an input in the production energy mix (Government of Kenya, 2018). Furthermore, the country heavily relies on imported liquid petroleum for the transportation of people and goods to and from urban and rural areas, even though fossil fuel consumption is not environmentally sustainable. The transportation sector accounts for 83.3% of the consumption of liquid fossil fuels and has the potential to increase CO_2 emissions (Government of Kenya, 2018). Besides, the total Greenhouse Gas (GHG) emissions were projected to rise by 143 MtCO2e by 2030, with the energy sector emitting the most (Government of Kenya, 2018).

The growing demand for energy to steer economic growth in developing countries raises policy concerns (Kaika and Zervas, 2013). This is because CO_2 emissions resulting from the usage of fossil fuels in the manufacturing process contribute to climate change (Omri, 2014). Coal, crude oil, natural gas, and shale oil are examples of fossil fuels whose primary supplies are derived from the finite and nonrenewable stock of resources (Bhattacharyya, 2019). Nonrenewable energy resources have two major drawbacks: they are depletable in a finite amount of time horizon and they contaminate the environment. Shafiei and Salim (2014) use Stochastic Impacts by Regression on Population, Affluence, and Technology (STIRPAT) identity which is the empirical work of York et al. (2003) to analyze the impact of non-renewable energy on emissions using a panel of 29 OECD countries from 1980 to 2011. Their study reveals that the consumption of nonrenewable energy has a significant and positive effect on CO_2 emissions. Empirical studies from both rich and developing countries back up their findings (Anwar et al., 2021; Awodumi and Adewuyi, 2020; Erdogan et al., 2020; Koengkan et al., 2020; Sahoo and Sahoo, 2022).

Economic growth is always associated with the growth of urban centres (Easterlin et al., 2011). However, the effect of urbanization as a determinant of CO_2 emissions is inconclusive in the literature. According to a study on the impact of urbanization on CO_2 emissions in Malaysia, urbanization has both positive and negative consequences. At first, urbanization reduces CO_2 emissions; but once a threshold is reached, CO_2 emissions begin to rise again (Shahbaz et al., 2016). While other studies find urbanization to have a positive effect on CO_2 emissions (Ali et al., 2019; Khoshnevis Yazdi and Dariani, 2019). Besides, a study on urbanization and carbon emissions nexus using a panel of 20 MENA countries' annual data running from 1980 to 2014 shows that urbanization does not affect the level of CO_2 emissions (Abdallh and Abugamos, 2017). Liu and Liu (2019) using a panel of 30 provinces in China, show that urbanization has a positive effect on emissions in certain provinces but has no effect in others. Further, Rahman and Vu (2020) examine the impact of urbanization on emissions using a time series approach and compare Australia and Canada. Their study shows that urbanization raises the level of carbon emissions in Canada but decreases it in Australia in the long run. We, therefore, conclude that the impact of urbanization on CO_2 emissions is mixed and inconclusive. However, understanding the sources of CO_2 emissions is critical for developing effective and appropriate energy conservation programs. This is because reducing carbon intensity, promoting energy efficiency, and improving energy conservation policies will go a long way toward reducing the demand for fossil fuels, primarily for powering transportation and industrial sectors. It also reduces demand for hydrocarbons, which is associated with import inflation, as well as investment in additional energy generation plants.

The current study contributes to the existing literature by examining the effects of fossil fuel consumption, urbanization, and economic growth on Kenya's carbon dioxide emissions level and evaluates the causality between the variables under consideration. Our study is different from the previous studies and the work of Sarkodie and Ozturk (2020), which investigates the environmental Kuznets hypothesis in Kenya using data from 1971 to 2013. We introduce fossil fuel energy as a variable in the STIRPAT model, which is omitted by earlier papers. Fossil fuel energy drives the transport and industrial sectors of Kenya's economy. The study result shows that fossil fuel consumption Granger causes economic growth and economic growth Granger causes CO_2 emissions. Further, a unidirectional causality runs from urbanization to CO_2 emissions with a positive effect. The empirical findings of this study are expected to contribute to the existing body of knowledge on Kenya as a middle-income economy, thereby guiding its long-term growth trajectory.

The remaining sections of the paper are structured as follows: Section 2 presents the literature review, Section 3 provides the empirical framework, data and methodology, Section 4 includes results and discussion, and Section 5 shows the conclusion and policy implications.

2. LITERATURE REVIEW

Energy is key to fostering human development and quality of life (Shobande, 2023). Energy and environmental economists have primarily used two theories to investigate the driving force behind global warming, with a greater emphasis on CO_2 emissions as an indicator of pollution or degradation of the environment (Shobande and Ogbeifun, 2022). IPAT (Impact= Population x Affluence x Technology) theory was developed by Ehrlich and Holdren (1972) and later modified to STIRPAT for empirical estimation (Dietz and Rosa, 1997; York et al., 2003) and Environmental Kuznets Curve theory or hypothesis (Grossman and Krueger, 1995). STIRPAT framework has received considerable attention among scholars, however, the effect of the drivers of environmental pollution using this framework has remained inconclusive (Shobande and Ogbeifun, 2022). The Environment Kuznets Curve (EKC), on the other hand, is based on the assumption that economic growth is the primary driver of environmental quality. As economic growth accelerates, carbon emissions rise until a certain level of output is reached, at which point emissions begin to fall, giving rise to the Environmental Kuznets Curve theory (Bhattacharyya, 2019).

The relationship between environmental pollution and economic growth has long been a source of consternation (Dogan and Inglesi-Lotz, 2020; Otim et al., 2022 Saint Akadiri et al., 2020). The studies have confirmed the existence of the inverted U shape environmental Kuznets Curve in Sub-Saharan countries (Kwakwa and Alhassan, 2018; Sarkodie and Ozturk, 2020; Tenaw and Beyene, 2021). However, other studies did not confirm the validity of the EKC theory (Beyene and Kotosz, 2020; Zoundi, 2017). Further, in terms of the cause-effect relationship, the empirical literature on energy- growth-environmental nexus have produced varied and inconclusive results. Several empirical studies show a unidirectional relationship running from economic growth to carbon emissions (Adebayo and Akinsola, 2020; Kirikkaleli and Adebayo, 2021; Munir et al., 2020). Abbasi et al. (2021) show a one-way causality running from CO_2 emissions to economic growth in Pakistan and other studies show bidirectional causality between CO_2 emission and economic growth (Halkos and Gkampoura, 2021; Rahman et al., 2020; J. Zhang and Zhang, 2021). In addition, most empirical studies on the EKC theory are in the context of advanced economies, and less attention is paid to developing countries (Işık et al., 2019; Leal and Marques, 2020). Table 1 provides a summary of the existing findings of the related variables under study. The empirical literature shows that there is no consensus on what drives environmental pollution and the results of the causality are mixed, varied and inconclusive.

3. EMPIRICAL FRAMEWORK, DATA AND METHODOLOGY

3.1. Empirical Framework

The IPAT identity describes the driving factors that lead to environmental changes. The IPAT model demonstrates how population, wealth, and technology are important determinants of environmental quality. The following is how the identity is expressed:

$$I = P.A.T \tag{1}$$

Where I denotes the impact of pollution on the environment and CO_2 emission is measured as a proxy of environmental pollution as in equation (1) besides other environmental indicators or pollutants that can be used (Ali et al., 2021; Grossman and Krueger, 1995; Murakami et al., 2020; Stern, 2004). P denotes population proxied by urbanization in our study, A denotes Affluence or wealth, proxied by gross domestic product and T is the technology index. Due to the IPAT model's mathematical flaws which indirectly test the hypothesis of environmental factors and the assumption of unitary elasticity (York et al., 2003) made Dietz and Rosa (1997) develop the STIRPAT model with the panel model specification as follows:

$$I_t = aP_t^b A_t^c T_t^d e_t \tag{2}$$

Where *t* denotes the time in years, *a* is a constant and *b*,*c* and *d* are the index elasticities for estimation and e is the stochastic disturbance term. Scholars have used STIRPAT to study the driving forces of CO_2 on the environment (Wu et al., 2021; Xu et al., 2020; Yang et al., 2021). Equation (4) can be transformed as follows:

$$lnI_t = ln\,a + blnP_t + clnA_t + dlnT_t + e_t \tag{3}$$

Population (P) is used in STIRPAT due to its ability to exert pressure on the environment (Adams et al., 2020; Usman and Hammar, 2021). Its effect is more felt through urbanization especially in Africa due to its growing population. To examine the effect of fossil fuels, urbanization and GDP on carbon dioxide emissions in Kenya, we employed the equation as follows:

$$CO_{2t} = \vartheta + \varphi LURB_t + \mu LGDP_t + \omega LFF + \varepsilon_t \tag{4}$$

Where CO_2 is carbon dioxide emissions, LURB: denotes the log of urbanization, LGDP: represents the log of the gross domestic product as a measure of a country's wealth or economic growth, and LFF: denotes the log of fossil fuel energy consumption.

Table 1: The global summary of causality tests, along with previous studies related to them

Authors	Country	Period	Methodology	Conclusion
Islam et al. (2022)	Bangladesh	1976–2014	VAR innovative accounting approach and ARDL bounds test	$GDP\leftrightarrow CO_2$ $CO_2\rightarrow CTI$
Hongxing et al. (2021)	Belt Road Initiative economies	1990–2018	Westerlund cointegration test and Pooled Mean Group-ARDL (PMG-ARDL)	$CO_2\rightarrow GDP$ $EC\leftrightarrow GDP$
Beşe and Kalayci (2019)	Kenya	1971–2014	VAR Granger causality; JJ cointegration	$EC\neq GDP$ $EC\rightarrow CO_2$
Rehman et al. (2019)	Pakistan	1990–2017	ARDL bounds cointegration approach	$GDP\leftrightarrow CO_2$ $FF\leftrightarrow CO_2$
Appiah (2018)	Ghana	1960–2015	Toda-Yamamoto causality test and ARDL bound testing technique	$EC\rightarrow GDP$ $GDP\neq EC$ $EC\rightarrow CO_2$
Hanif (2018)	Sub-Saharan Africa	1990–2015	Generalized methods of moments (GMM)	$FF\rightarrow CO_2$ $URB\rightarrow CO_2$ $GDP\rightarrow CO_2$
Mehdi and Slim (2017)	North African countries	1980–2011	Panel cointegration techniques and Granger Causality	$GDP\rightarrow CO_2$ $NRE\rightarrow GDP$ $RE\rightarrow CO_2$
Shahbaz et al. (2015)	Portugal	1971–2008	ARDL bounds cointegration approach	$URB\rightarrow CO_2$ $EC\rightarrow CO_2$
Wang et al. (2014)	China	1995–2011	Panel Granger causality, vector error correction model and Pedroni cointegration test	$URB\rightarrow CO_2$ $EC\rightarrow CO_2$ $URB\rightarrow EC$
Soytas et al. (2007)	USA	1960–2004	Toda –Yamamoto procedure and VAR model.	$GDP\neq CO_2$ $EC\rightarrow CO_2$

ARDL: Autoregressive distributed lag, VAR: Vector autoregressive, CTI: Composite trading intensity, EC: Energy consumption, FF: Fossil fuel consumption, urbanization, NRE: Non-renewable energy, CO2: Carbon dioxide emissions, GDP: Gross domestic product, URB: Urbanization. ≠ → and↔and no causality, unidirectional, and bidirectional respectively

3.2. Data

The details of the data, variables, references, and a priori expectations are in Table 2. The data used in the study spans a period of 44 years starting from 1971 to 2014. The period is used because the data is available for all the variables under investigation. Specifically, the data for fossil fuel energy consumption by the World Bank Development Indicator stopped in 2014 and was not updated during the time under study review.

3.3. Methodology

Our analysis starts with determining the optimal lag structure, follows by unit root tests, cointegration tests, estimating long-run ARDL and testing for Granger causality. The step-by-step of major estimation methods is provided in Figure 1.

3.3.1. Optimal lag selection

The starting point is to determine the lag structure. The most important problem in time series analysis is how to choose the best lag given a limited number of data (Hamilton, 2020). It is empirically important to choose a lag structure when modelling time series because improper or improperly fitted lag models produce false results and negligible coefficients. For this study, we consider three information criteria, the Hannan-Quinn information criterion (HQ) and Schwarz information criterion (SC), the Akaike information criterion (AIC), and the selection of the optimal lag structure. The next step is to estimate the unit root test to establish the stationarity of each series used in the study.

3.3.2. Unit root test

Macroeconomic time-series data always have a non-stationary component (Nelson and Plosser, 1982). As a result, the data generation process (DGP) is predicated on whether or not unit roots exist. A stationary time series has data that varies and centres on a constant mean, as well as a finite variance that is not time-dependent with a unit root. On the other hand, a time series with a unit root deviates from its long-run deterministic trend with no propensity to return to it. Such series follow a random walk process. Considering a simple AR (1) process following Augmented Dickey-Fuller (ADF) test (Dickey and Fuller, 1979) is given as follows:

$$y_t = \alpha + \rho y_{t-1} + \omega_t \qquad (5)$$

Where $\omega_t \sim iid(o,\sigma^2)$ and t the time trend. Adding autoregressive lags to control for serial correlations in the errors and adding a trend gives the test equation.

$$\Delta y_t = \alpha + \delta t + \theta y_{t-1} + \sum_{i=1}^{k} \varrho_i \Delta y_{t-i} + \omega_t \qquad (6)$$

Where t denotes the time index, α is an intercept representing a drift: Shows the time trend's coefficient, θ represents the coefficient for testing the presence of a unit root. The choice of the lag length k depends on the frequency of the data. The null hypothesis is $|\rho| = 1$: for homogeneous non-stationary. The hypothesis is $|\rho| < 1$ and where $\theta = (\rho - 1)$ therefore $\theta < 0$ (Wooldridge, 2012). In summary H_0: $\theta \geq 0$ against H_1: $\theta < 0$. The conclusion is that where the test statistic is larger in value than the critical value, we reject the null and conclude that the process in question is stationary.

Estimating a regression equation with data containing a non-stationary series without testing for a unit root or taking the first difference in the series may lead to spurious regression coefficient estimates. Such coefficients are inconsistent and biased and should not be used as a basis for policy. Some scholars have claimed, however, that due to their small power and size, unit root tests such as ADF do not provide accurate conclusions in the face of structural discontinuities(Glynn et al., 2007; Nelson and Plosser, 1982). Therefore, the study uses Zivot and Andrews's structural break unit root test for determining the breakpoints in the intercept, trend and/or both (Zivot and Andrews, 1992) for the robustness purpose. The next step is to estimate whether the long-run relationship exists in the specified models.

3.3.3. Cointegration test

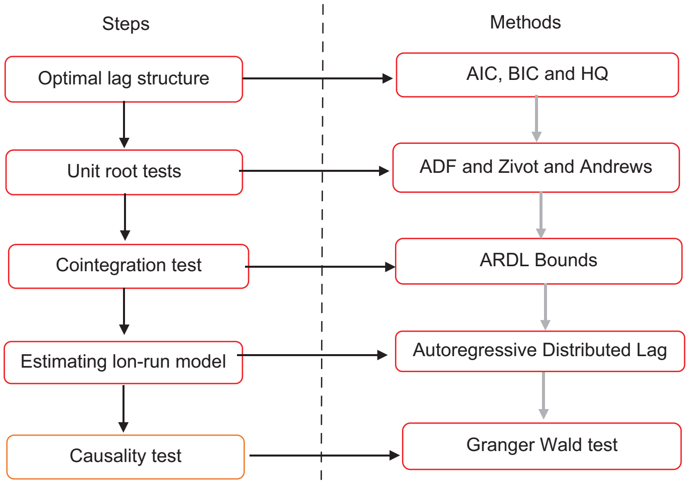
The study investigates whether there is a long-run relationship between fossil fuels, economic growth, urbanization, and CO_2 emissions in Kenya using two cointegration methodologies. The ARDL bounds cointegration and the Gregory-Hansen structural break cointegration approach were all used in the study. The ARDL method proposed by Pesaran et al. (2001) was used to check for long-run cointegration. The method is based on comparing the null hypothesis of no cointegration to the alternative hypothesis of cointegration's existence. If the estimated F-statistic is greater than the critical value for the upper bound I(1), we conclude that there is a long-run integrating relationship, reject the null hypothesis, and estimate the long-run association, which is the long-run error correction model. We estimate the short-run ARDL model if the null hypothesis is not rejected. The following are some of the advantages of employing the ARDL technique: (i) It can be used with a mixture of I(0) and I(1) as well as just I(0) or I(1), but not with the I(2) series. (ii) When the regressors are endogenous, it allows a small sample size. (iii) When proper lag orders are chosen, it eliminates the concerns of endogeneity and serial correlation. (iv) it uses a single reduced equation form, and (v) the findings are more reliable than other standard cointegration methods. The ARDL(p,q,…,q) model estimation is as follows:

Table 2: Data and variable description

Variables	Measurement	Expected Sign	Data source
Carbon dioxide emissions	Metric tons per capita	N/A	World Bank
Gross Domestic Product	GDP (constant 2015 US$)	+	World Bank
Fossil fuel energy consumption	(% of total)	+	World Bank
Urban population	(% of the total population)	+/-	World Bank

CO_2 is an indicator of environmental pollution like energy combustion in metric tons. GDP is the total of all resident producers' gross value-added output, plus any product taxes, minus any subsidies not included in the value of the items. FF is the share of non-renewable energy in the total primary energy consumption and URB is the share of urban residents in the total population

Figure 1: Estimation Framework.



Source: Authors' construction

$$\Delta \mathrm{CO}_{2\mathrm{t}} = \zeta_1 + \sum_{i=1}^{P1} \phi_{1i} \Delta CO_{2t-i} + \sum_{j=0}^{q1} \xi_{1j} \Delta \mathrm{LURB}_{t-j} + \sum_{m=0}^{q2} \theta_{1m} \Delta \mathrm{LGDP}_{t-m} + \sum_{k=0}^{q3} \gamma_{1k} \Delta \mathrm{LFF}_{t-k} + \mu_1 \mathrm{CO}_{2\mathrm{t}-1} + \mu_2 LURB_{t-1} + \mu_3 GDP_{t-1} + \mu_4 LFF_{t-1} + \varepsilon_{1t} \tag{7}$$

Where Δ denotes the first difference operator and $\varepsilon_{1\mathrm{t}}$ is a white noise component. The ideal lag orders p and q are found by minimizing model selection criteria based on the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) in most circumstances (BIC). We estimate a long-run and a short-run model as in equations (8) and (9) respectively in the presence of a long-run association between fossil fuels, urbanization, Economic growth, GDP, and CO_2 emissions in Kenya:

$$\mathrm{CO}_{2\mathrm{t}} = \zeta_2 + \sum_{i=1}^{p1} \phi_{2i} \mathrm{CO}_{2\mathrm{t}-i} + \sum_{j=0}^{q1} \xi_{2j} \mathrm{LURB}_{t-j} + \sum_{m=0}^{q2} \theta_{2m} \mathrm{LGDP}_{t-m} + \sum_{k=0}^{q3} \gamma_{2k} \mathrm{LFF}_{t-k} + \varepsilon_{2t} \tag{8}$$

$$\Delta \mathrm{CO}_{2\mathrm{t}} = \zeta_3 + \sum_{i=1}^{p1} \phi_{3i} \Delta \mathrm{CO}_{2\mathrm{t}-i} + \sum_{j=0}^{q1} \xi_{3j} \Delta \mathrm{LURB}_{t-j} + \sum_{m=0}^{q2} \theta_{3m} \Delta \mathrm{LGDP}_{t-m} + \sum_{k=0}^{q3} \gamma_{3k} \Delta \mathrm{LFF}_{t-k} + \lambda ECT_{t-1} + \varepsilon_{3t} \tag{9}$$

Where λ is the rate of adjustment toward long-run equilibrium, as well as the Error Correction Term's coefficient (hereafter ECT). ECT is defined as follows:

$$ECT_{t-1} = \mathrm{CO}_{2\mathrm{t}} - \zeta_2 - \sum_{i=1}^{p1} \phi_{2i} CO_{2t-i} - \sum_{j=0}^{q1} \xi_{2j} \mathrm{LURB}_{t-j} - \sum_{m=0}^{q2} \theta_{2m} \mathrm{LGDP}_{t-m} - \sum_{k=0}^{q3} \gamma_{2k} \mathrm{LFF}_{t-k} \tag{10}$$

In the next forecasting period, ECT illustrates how rapidly the disequilibrium will vanish. In other words, it refers to the notion that the last period of divergence from the long-run equilibrium has an impact on the dependent variable's short-run dynamics. The ECT coefficient λ, should have a negative sign, be statistically significant, and be less than one for a properly described model. In our model, λ measures the speed at which CO_2 returns to equilibrium after a change in fossil fuel consumption, urbanization and GDP. Besides ECT is important for showing bi-directional and unidirectional causality between variables.

A common cointegration test, such as the ARDL bounds test cointegration test, is based on the null hypothesis of no cointegration. These tests are appropriate for the standard cointegration model with a trend but no structural change. Gregory and Hansen (1996) in their empirical paper demonstrate that the conventional cointegration test may not hold when there are structural breaks or regime shifts because of the distributional theory, which evaluates the residual-based tests. To cope with the challenge of potential structural breaks in our data, we employed Gregory-Hansen (1996) test for structural breaks. The next step is to test the causality between the series when cointegration exists in the model.

3.4. Causality Analysis

The ARDL bounds and Gregory-Hansen cointegration methods examine whether a long-run relationship exists between fossil fuel consumption, urbanization, economic growth, and CO_2 emissions. The cointegration approaches do not test for the existence of causality between variables. Therefore, we applied the VECM Granger causality test based on the view that the past can predict the future but the future cannot predict the past (Granger, 1988; Odhiambo, 2009). The causality is therefore defined as follows when X_t Granger causes Y_t where X_t and Y_t are both time series, which means that Y_t can be predicted well with a small variance of forecast error using its lagged values than by not doing so. In other words, if the lagged values of X_t significantly contribute to predicting Y_t, then it is said to Granger causes Y_t. This applies to the causality running from Y_t to X_t. With this definition, two types of causality emerged: (i) when $X_t \rightarrow Y_t$ only, or $Y_t \rightarrow X_t$ only is termed as a unidirectional causality or a one-way causality. (ii) When $X_t \rightarrow Y_t$ and also $X_t \rightarrow Y_t$ denoted as $X_t \leftrightarrow Y_t$ is termed as feedback causality or bidirectional causality. The vector error correction model formulation is expressed as in equation (11) as follows:

$$\begin{bmatrix} \Delta \mathrm{CO}_{2\mathrm{t}} \\ \Delta \mathrm{LURB}_t \\ \Delta \mathrm{LGDP}_t \\ \Delta \mathrm{LFF}_t \end{bmatrix} = \begin{bmatrix} \xi_1 \\ \xi_2 \\ \xi_3 \\ \xi_4 \end{bmatrix} + \begin{bmatrix} \omega_{11.1} & \omega_{12.1} & \omega_{13.1} & \omega_{14.1} \\ \omega_{21.1} & \omega_{22.1} & \omega_{23.1} & \omega_{24.1} \\ \omega_{31.1} & \omega_{31.1} & \omega_{33.1} & \omega_{34.1} \\ \omega_{41.1} & \omega_{42.1} & \omega_{43.1} & \omega_{44.1} \end{bmatrix} \begin{bmatrix} \Delta \mathrm{CO}_{2\mathrm{t}-1} \\ \Delta \mathrm{LURB}_{t-1} \\ \Delta \mathrm{LGDP}_{t-1} \\ \Delta \mathrm{LFF}_{t-1} \end{bmatrix} + \ldots \begin{bmatrix} \omega_{11.k} & \omega_{12.k} & \omega_{13.k} & \omega_{14.k} \\ \omega_{21.k} & \omega_{22.k} & \omega_{23.k} & \omega_{24.k} \\ \omega_{31.k} & \omega_{31.k} & \omega_{33.k} & \omega_{34.k} \\ \omega_{41.k} & \omega_{42.k} & \omega_{43.k} & \omega_{44.k} \end{bmatrix} \begin{bmatrix} \Delta \mathrm{CO}_{2\mathrm{t}-k} \\ \Delta \mathrm{LURB}_{t-k} \\ \Delta \mathrm{LGDP}_{t-k} \\ \Delta \mathrm{LFF}_{t-k} \end{bmatrix} + \begin{bmatrix} \lambda_1 \\ \lambda_2 \\ \lambda_3 \\ \lambda_4 \end{bmatrix} ECT_{t-1} \begin{bmatrix} \epsilon_{1t} \\ \epsilon_{2t} \\ \epsilon_{3t} \\ \epsilon_{4t} \end{bmatrix} \tag{11}$$

Table 3: The null hypothesis for granger causality in the short and long run

Variables	Short-run				Long-run
	ΔCO_2	$\Delta LURB$	$\Delta LGDP_t$	ΔFF_t	λ_i
ΔCO_2	-	$\omega_{12.1}=\ldots=\omega_{12.k}=0$	$\omega_{13.1}=\ldots=\omega_{13.k}=0$	$\omega_{14.1}=\ldots=\omega_{14.k}=0$	$\lambda_1=0$
$\Delta LURB$	$\omega_{21.1}=\ldots=\omega_{21.k}=0$	-	$\omega_{23.1}=\ldots=\omega_{23.k}=0$	$\omega_{21.1}=\ldots=\omega_{21.k}=0$	$\lambda_2=0$
$\Delta LGDP_t$	$\omega_{31.1}=\ldots=\omega_{31.k}=0$	$\omega_{32.1}=\ldots=\omega_{32.k}=0$	-	$\omega_{31.1}=\ldots=\omega_{31.k}=0$	$\lambda_3=0$
ΔFF_t	$\omega_{41.1}=\ldots=\omega_{41.k}=0$	$\omega_{42.1}=\ldots=\omega_{42.k}=0$	$\omega_{43.1}=\ldots=\omega_{43.k}=0$	-	$\lambda_4=0$

LURB: Log of urbanization, LGDP: Log of the gross domestic product, CO_2: Carbon dioxide emissions, FF: Fossil fuel consumption

Table 4: Variable description

Variables	Obs	Mean	SD	Min	Max
CO_2 emissions (metric tons per capita)	44	0.269	0.054	0.188	0.383
Urban population (% of the total population) log	44	2.872	0.219	2.378	3.228
Gross domestic product (constant 2015 US$) log	44	24.116	0.461	23.170	24.925
Fossil fuel (% share of total energy consumption) log	44	2.879	0.119	2.565	3.078

Table 5: Matrix of correlations

Variables	(1)	(2)	(3)	(4)
(1) CO2	1.000			
(2) LURB	−0.391	1.000		
(3) LGDP	−0.410	0.986	1.000	
(4) LFF	0.756	−0.586	−0.569	1.000

The disturbance terms, ϵ_{1t}, ϵ_{2t}, ϵ_{3t} and ϵ_{4t} are independently normally distributed with zero mean and constant variance. The selection of optimal lag structure is based on AIC and BIC. For the short-run analysis, the formulation in Eq. (11) is first estimated using VECM, and then Granger causalities are tested using the Wald test with χ^2 distribution. The long-run causalities were examined using a 5% significance level for the coefficient of error correction representation term. Table 3 depicts the null hypothesis for Granger causality in both the short and long run. The Granger causality technique applied in the study is more appropriate in both small and large samples than other alternative techniques for testing for causality between variables (Odhiambo, 2009).

4. RESULTS AND DISCUSSION

4.1. Descriptive Statistics

Table 4 shows the descriptive statistics for all of the study variables. CO_2 emissions have a mean of 0.269 and a maximum of 0.383 metric tons per capita, with a standard deviation (SD) of 0.054 metric tons per capita. In log form, the mean value of urbanization is 2.872, with a minimum of 2.378, a maximum of 3.228, and a standard deviation of 0.219. The mean GDP is 24.116, with a standard deviation of 0.462, a minimum value of 23.17, and a maximum value of 24.925 in log form. The log of fossil fuel energy consumption has a mean of 2.87, a standard deviation of 0.119, a minimum of 2.565, and a maximum of 3.078. All of the variables' data show no significant departure from their mean values. The correlation between the variables was investigated, with the results shown in Table 5. In Kenya, there is a 98.6% positive correlation between GDP and urbanization. Furthermore, 75.6% of CO_2 emissions are linked to the use of fossil fuels. Other variables have moderate relationships with each other.

4.2. Unit Root Test Results

When non-stationary time series variables are estimated, the parameters are frequently misleading. We used ADF and Zivot-Andrew unit root tests to ensure that the variables are stationary. The validity of the test results, on the other hand, is dependent on the careful selection of the best lag structure. Based on AIC and HQIC, three lags were chosen as appropriate for the empirical estimation used in this research. Table 6 shows the outcomes of the lag selection criteria. The ADF test's null hypothesis is that the series has a unit root, and the test results are shown in Table 7.

All variables were non-stationary and integrated of order one, I(1) except for urbanization, I(0). Before running the cointegration tests, the Zivot-Andrews unit root structural break tests are run as a robustness check to ensure that each series is stationary. The Zivot-Andrews structural break test results are based on AIC are shown in Table 8. The cointegration order that results is mixed, with I(0) and I(1). Table 8 shows that structural changes began in Kenya in the 1980s, as evidenced by the Zivot-Andrews test findings. Kenya's government secured a structural adjustment loan with the World Bank, resulting in significant changes in trade policy. The government replaced import substitution policies with an export promotional programme (Gertz, 2008). Kenya's trade liberalization within this period failed to drive sustained economic growth and became subject to policy reversals. Kenya's export performance as a percentage of GDP has been declining with ever-increasing imports (Kimenyi et al., 2016). Shifts in the policy regime could have had an impact on the variables under our investigation. The ADF unit root tests were confirmed by the Zivot-Andrews unit root tests. Cointegration tests can now be run because all variables are stationary at either level or first difference.

4.3. Cointegration Test Results

The cointegration tests determine whether a long-run relationship exists, and if it does, ECT can be obtained. It also enables the testing of both short- and long-run Granger causality. The F-test statistic of 19.457 in Table 9 is considerably greater than the I(1) of 5.61 at a 1% critical value bound, therefore, the ARDL bound reveals the existence of cointegration. When there are structural breaks in the data, ARDL bounds cointegration test results can be doubtful and even misleading. In the event of a regime shift

Table 6: Optimal lag selection criteria

Lag	LL	LR	FPE	AIC	HQIC	SBIC
0	180.128		1.8e-09	−8.80642	−8.74536	−8.63753
1	389.383	418.51	1.1e-13	−18.4692	−18.1638	−17.6247
2	429.843	80.919	3.4e-14	−19.6922	−19.1426	−18.1722*
3	454.035	48.384*	2.4e-14*	−20.1018*	−19.3079*	−17.9062
4	466.449	24.827	3.3e-14	−19.9225	−18.8844	−17.0514

*Lag order selected by criterion at a 5% level of significance. The unit root is conducted based on intercept and trend

Table 7: ADF unit root test

Variable	Augmented Dickey-Fuller test statistics				Order of integration
	In levels	P-value	In first difference	P-value	I (d)
CO2	−1.717	0.7433	−3.791	0.017**	I (1)
LURB	−4.520	0.001***			I (0)
LGDP	−2.131	0.529	−3.971	0.010**	I (1)
LFF	−2.567	0.295	−4.810	0.000***	I (1)

***,**Significance at 1% and 5% levels respectively

Table 8: Zivot-Andrews structural break unit root test

Variable	At levels				At first difference			I (d)
	Model	T-statistic	Critical value at 5%	Time break	T-statistic	Critical value at 5%	Time break	
CO$_2$	c	−5.676	−4.80	1982				I (0)
	t	−3.50	−4.42	1987	−6.893	−4.42	1983	I (1)
	c & t	−5.625	−5.08	1982				I (0)
LURB	c	−4.530	−4.80	1980	−11.027	−4.80	1980	I (1)
	t	−4.488	−4.42	1994				I (0)
	c & t	−7.326	−5.08	1980				I (0)
LGDP	c	−2.963	−4.80	1992	−6.433	−4.80	1991	I (1)
	t	−2.935	−4.42	1979	−5.866	−4.42	2000	I (1)
	c & t	−3.131	−5.08	1997	−6.286	−5.08	1991	I (1)
LFF	c	−6.490	−4.80	2004				I (0)
	t	−4.837	−4.42	1982				I (0)
	c & t	−3.315	−5.08	2006	−5.287	−5.08	2005	I (1)

c, t, and c & t are models that allow for breaks in intercept, trend, and both intercept and trend respectively

Table 9: Bound tests for cointegration

Variables	Test statistic	Value	k
CO$_2$|LURB, LGDP, LFE)	F	19.457	3
	Critical value bounds	I (0) lower bound	I (1) upper bound
	10%	2.72	3.77
	5%	3.23	4.35
	1%	4.29	5.61

or structural change, we use the Gregory-Hansen structural break cointegration as a robustness check for cointegration. Table 10 displays the results of the Gregory-Hansen cointegration tests, which show that the variables have a long-run relationship and thus estimating the long-run model is safe.

4.4. ARDL Estimation Results

Table 11 shows the long-run and short-run ARDL models with error correction representation. The finding shows that in the long- run a 1% increase in fossil fuel energy consumption results in a 0.297% point rise in CO$_2$ emissions, ceteris paribus. The result of a positive effect of fossil fuel consumption on CO$_2$ emissions is in line with Munir and Khan (2014) and Li and Haneklaus (2021). This implies that the increase in fossil fuel energy consumption increases the level of CO$_2$ emission in the atmosphere. Furthermore, a 1% increase in urbanization results in a 0.978% point reduction in CO$_2$ emissions, ceteris paribus, at a 1% level of statistical significance. The result is in line with a study by Balsalobre-Lorente et al. (2022) for BRICS countries. The study result implies the growth in the urban population stimulates a reduction in CO$_2$ emissions. This can be attributed to the use of modern cooking technologies and clean energies used by urbanites. In addition, economic growth has a positive impact on CO$_2$ emissions. The result shows that a 1% increase in economic growth is associated with a 0.535% point increase in CO$_2$ emissions and is statistically significant at 1%. The result is in line with Zafar et al. (2022). The finding is not surprising since Kenya is a developing country with a low level of technology and its economic growth is associated with pollution of the environment at a lower stage of development. Economic growth can only result in a reduction in emissions when renewable energies and modern technologies are used in the production process.

The short-run model depicts how CO$_2$ emissions in Kenya are affected by fossil fuel energy consumption, urbanization, and economic growth. The coefficient of the lagged ECT, which is the speed of adjustment towards long-run equilibrium, is negative, statistically significant at 5%, and lies between 0 and 1, which satisfies the model's requirements to converge or return to a stable long-run equilibrium per year after a short-run shock or innovation, as shown in Table 11. Using equation (10), the estimated coefficient

Table 10: Gregory-Hasen structural break cointegration test

Model	Procedure	Test statistic	Breakpoint	Asymptotic critical values		
				1%	5%	10%
C	ADF	−6.91	1982	−5.77	−5.28	−5.02
	Zt	−6.99	1982	−5.77	−5.77	−5.02
	Za	−47.92	1982	−63.64	−53.58	−48.65
C &T	ADF	−7.02	1982	−6.05	−5.75	−5.33
	Zt	−7.11	1982	−6.05	−5.75	−5.33
	Za	−48.62	1982	−70.27	−59.76	−54.94
R	ADF	−6.23	1982	−6.51	−6.00	−5.75
	Zt	−6.30	1982	−6.51	−6.00	−5.75
	Za	−43.32	1982	−80.94	−68.94	−6.42

C is the change in Level, C&T denotes a change in level and trend and R refers to the change in Regime

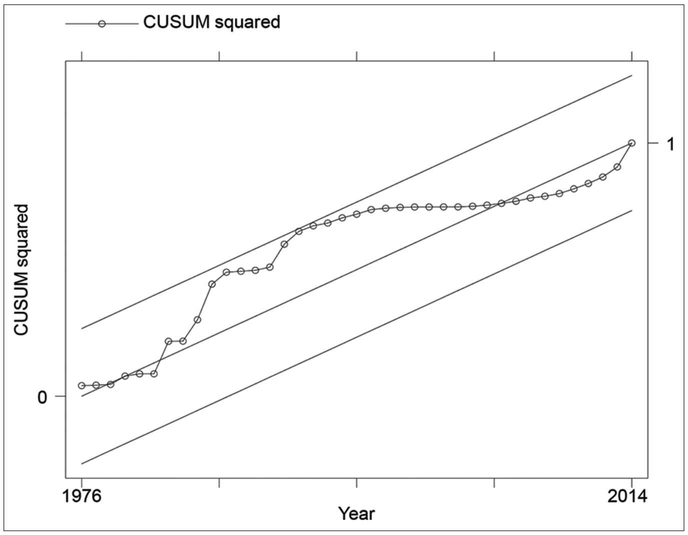
Table 11: Autoregressive distributed lag results for the short-run and long-run dynamics

D.CO_2	Coefficient	SE	t-statistic	P
ADJ				
CO_2				
L1	−0.479	0.074	−6.440	0.000***
LR				
LURB	−0.978	0.283	−3.450	0.002***
LGDP	0.535	0.144	3.720	0.001***
LFF	0.297	0.057	5.220	0.000***
SR				
CO_2				
LD	−0.299	0.090	−3.310	0.002***
L2D	−0.329	0.081	−4.050	0.000**
LURB				
D1	−1.027	0.474	−2.170	0.038**
LD	0.337	0.698	0.480	0.632
L2D	3.005	0.560	5.360	0.000***
Constant	−5.172	0.807	−6.410	0.000***
R^2	0.8482			
Adjusted R^2	0.8041	Diagnostics	χ^2	
LL	123.001	LM	0.093	0.7605
RMSE	0.0139	HET	40.00	0.4260
ARDL	3, 3, 0, 0	ARCH	1.049	0.7893

***,**Significance at 1% and 5% levels respectively. LM is the Lagrange Multiplier test with χ^2 distribution. HET is the White Heteroskedasticity test with χ^2 distribution. ARCH is the LM test for autoregressive conditional heteroscedasticity with χ^2 distribution. LL: Log likelihood, LURB: Log of urbanization, LGDP: Log of the gross domestic product, LFF: Log of fossil fuel energy consumption, CO_2: Carbon dioxide emissions, SE: Standard error, RMSL: Low root means squared errors, ARDL: Autoregressive distributed lag, ARCH: Autoregressive conditional heteroskedasticity, LM: Lagrange Multiplier, HET: High efficiency translucence

is −0.479. According to the ECT, any deviation from the long-run equilibrium between the variables under investigation is corrected at a rate of around 48% for each period, and it takes about two periods to return to the long-run stable equilibrium following a shock. Further, the result shows that the past values of CO_2 emissions negatively affect CO_2 emissions because it shrinks its growth by 0.299% and 0.329% points yearly for the first and second lagged values respectively. Additionally, the present value of urbanization has a strong influence on CO_2 emissions since it lessens CO_2 emissions by 1.027% points. By contrast, the first and second past lag values of urbanization in the short run have incremental effects by 0.337 and 3.005% points respectively. The mixed effects of urbanization on CO_2 emissions confirm a study by Zhang (2021) in China. Generally, the estimated model has a strong explanatory power in examining contributing factors of emissions in Kenya as seen by its high adjusted R^2 and low root means squared errors (RMSE).

Figure 2: The plot of CUSUM squares of recursive residual fitted at a 5% level of significance



The diagnostic tests are used to check the robustness of the estimated model, and the results are shown in Table 11. To check for serial correlation, the LM test for autocorrelation is utilized (Breusch and Pagan, 1980). The LM tests show that the residual errors are not serially associated. The model residuals are homoskedastic, according to the white and ARCH tests for heteroskedasticity. We also examined the model Cumulative Sum of Squares of Recursive Residual (CUSUMSQ) test established by Brown et al. (1975) for any potential instability. This is a very robust test when the explanatory variables are endogenous and cointegrated (Caporale and Pittis, 2004). Figure 2 shows that there is stability in the regression error variance since CUSUMSQ plots fall inside the critical bound of the 5% level of significance. Therefore, the model is stable.

4.5. Granger Causality

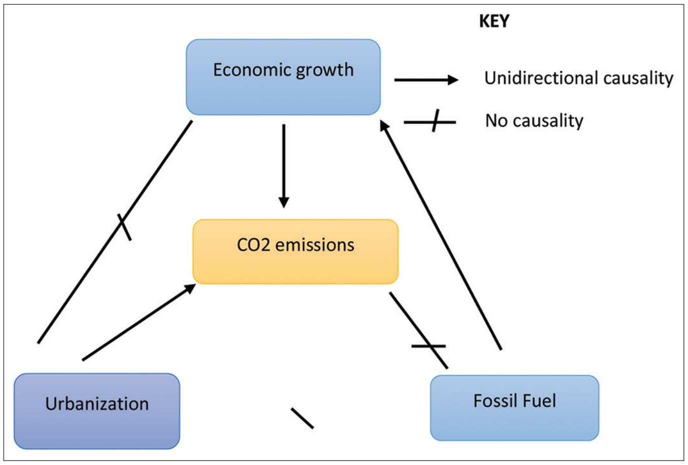
The study establishes a causal relationship between the variables under investigation using the Granger causality test. For both short-run (weak) and long-run Granger causalities, it deduces causality. The results for both the short-run and long-run models are presented in Table 12. The Granger causality results are summarized in Figure 3 and briefly explained as follows:

Table 12: Granger causality test results

Variables	Short-run (or weak) Granger causality				Long-run granger causality λ_i=1,2,3,4
	ΔCO_2	ΔURB	ΔLGDP	ΔLFF	
ΔCO_2	-	−0.404 (0.000)***	5.44 (0.066)*	2.21 (0.332)	−0.404 (0.000)***
ΔURB	2.29 (0.334)	-	2.60 (0.272)	1.04 (0.595)	−0.010 (0.537)
ΔLGDP	2.78 (0.249)	0.79 (0.673)	-	7.39 (0.025)**	−0.020 (0.754)
ΔLFF	0.79 (0.6743)	0.55 (0.7604)	0.48 (0.7856)	-	−0.099 (0.666)

The null hypothesis is that there is no Granger causality between variables. Variables in parenthesis are P-values for the Wald test with a χ^2 distribution in the short run and the coefficient of ECT in the long run. ***,**,*Indicate 1%, 5% and 10% significance levels respectively.

Figure 3: Granger based causality test results



(i) Fossil fuel energy consumption Granger causes economic growth, and it is a one-way causality. Therefore, our result supports the growth hypothesis implying that using fossil fuels has a favourable impact on Kenya's economic growth. The study result is in line with Mehdi and Slim (2017) in North Africa. Therefore, the energy conservation hypothesis may stifle the economic growth of Kenya.

(ii) Economic growth Granger causes CO_2 emissions in Kenya and it is a one-way causality implying that Economic growth has a positive effect on increasing the level of CO_2 emission. The finding is in line with Hanif (2018) in Sub-Saharan Africa and Mehdi and Slim (2017).

(iii) Urbanization Granger causes CO_2 emissions in the short-run and shows one-way causation. The result is in line with Shahbaz et al. (2016) in Malaysia and Hanif (2018) in Sub-Saharan Africa.

(iv) Interestingly, there is no direct causal relationship between fossil fuel energy consumption and CO_2 emissions and the study result is in line with Gokmenoglu and Sadeghieh (2019) in Turkey. The finding could imply that there other factors that are responsible for causing CO_2 emissions other than the use of fossil fuels. These factors need more empirical investigations.

(v) Other results show that there is little evidence of a link between urbanization and the consumption of fossil fuels. Besides, there is no evidence of a causal association between urbanization and Economic growth, according to the study.

5. CONCLUSION AND POLICY IMPLICATIONS

The paper examines the effects of fossil fuel energy consumption, economic growth, and urbanization on CO_2 emissions in Kenya using time series data from 1971 to 2014. The study employs ADF and Zivot-Andrews's structural break to test for unit roots. In addition, the study examines the long-run relationship using ARDL bounds and Gregory-Hansen structural break cointegration approaches. It investigates the Granger causality among the variables under review based on the Wald test with χ^2 distribution. The result of the short-run Granger causality reveals that economic growth predicted by fossil fuel energy consumption, thereby supporting the growth hypothesis. Fossil energy consumption is a major input in Kenya's output function. We conclude that any policy that reduces the consumption of fossil fuels in Kenya without increasing energy efficiency may hurt the country's economic growth. Further, urbanization was found to reduce CO_2 emissions in Kenya, implying that encouraging urbanization will go a long way in reducing the level of CO_2 emissions the country generates. As a result, metropolitan areas should be designed to reduce traffic congestion, which is linked to significant CO_2 emissions. It is important to promote the use of energy-efficient transportation and public transit, as well as the use of clean energy in residential buildings. Modern cooking technologies should be encouraged and dirty fuels like charcoal and firewood should be discouraged. Economic growth was found to have a positive effect on CO_2 emissions. Since economic growth induces CO_2 emissions, green growth should be encouraged if the environmental quality is to be maintained in the face of economic expansion.

Kenya ratified the United Nations Framework Convention on Climate Change (UNFCCC) in 1994 as a member of the Common Market for Eastern and Southern Africa (COMESA). As part of her mandate, the government decided to adopt the clean development mechanism, which aims to reduce CO_2 emissions from fossil fuel combustion and deforestation (The Republic of Kenya, 2001). In addition, the government of Kenya can reduce CO_2 emissions by increasing the production and uptake of renewable energy consumption. There should be phasing out subsidies for conventional energy supply slowly since fossil fuel consumption promotes growth. Besides, the government can promote the development of clean energy technologies, and energy efficiency and build strong institutions and human capacity to handle the challenges that come with adopting renewable technologies such as solar, hydropower and wind energy, reducing its overreliance on fossil fuel by encouraging the use of biofuels, geothermal, wind power and other green energies. The government should create public awareness of the importance of environmental protection and internalize externalities. The proposed measures can be adopted by other countries to promote sustainable growth and environmental protection.

The study is limited due to the availability of up-to-date data that extends over a long period. The use of panel data techniques with more countries in Sub-Saharan Africa may remedy this problem. The study uses a lin-log model and future research should consider nonlinearity in modelling CO_2 emissions for Kenya to allow for the comparison and the robustness check.

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