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Investigation of the environmental Kuznets curve for consumption-based carbon dioxide emissions in Kenya: the role of renewable energy and globalization

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ABSTRACT
Enhancing environmental quality is regarded as a major concern globally. Fossil fuel energy utilization and economic growth are the main sources of environmental pollution. Hence, a paradigm shift from fossil fuels to cleaner energy is proposed. Hence, the objective of this study is to examine the validity of the environmental Kuznets curve (EKC) hypothesis in Kenya by controlling the effect of globalization and renewable energy. Contrary to previous attempts, this study utilized consumption-based carbon dioxide (CO_2) emissions as an environmental pollution indicator. The autoregressive distributed lag (ARDL) technique and causality test are used with annual time series data spanning 1990-2018. The empirical results of the bound test revealed that globalization significantly enhances environmental quality, but renewable energy is insignificant in the long run. Economic growth impedes environmental quality, whereas squared growth boosts it. This result provides confirmatory evidence of the presence of the EKC hypothesis in Kenya. Besides, a unidirectional causality from consumption-based carbon emissions to economic growth, squared economic growth, and renewable energy is observed. The obtained findings underscore the need to prepare conducive environments that attract investments in clean energy sources, such as tax reductions and subsidies. Moreover, Kenya needs to enhance its involvement in the global commerce of commodities and services that exhibit minimal levels of greenhouse gas emissions.

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1. Introduction

Curbing climate change has become topical and has received a lot of attention from international organizations, governments, and other stakeholders. One of the main factors causing environmental pollution is the growing trend in greenhouse gases (GHGs) on a global level, which is linked to rising energy use. The trade-off between economic growth and the sustainability of the environment is one of the most pressing issues facing humankind. As a result, Sustainable Development Goals (SDGs 2015-2030) have been established to address climate change and its impacts, promote clean energy access for all people, and support sustainable agriculture and food security (Sarkodie & Ozturk, 2020; Warsame & Sarkodie, 2022).

African countries are more susceptible to climate change due to their weak adaptation capacity and massive dependence on agriculture, with a rise in temperature of 1.5 degrees Celsius. Notably, they contribute less than 3% of the world's carbon emissions, and climate change is posing severe risks to their economies, food security, agriculture, and livelihoods. It also undermines the continent's economic progress and pushes it even further into extreme poverty (African Development Bank, 2021). In Kenya, tourism and agriculture are the main economic drivers, which are both vulnerable to climate change and extreme weather events.

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Kenya has made significant economic and political reforms that have substantially contributed to sustained social development, political stability, and economic growth over the past decades. It is considered one of the fastest-growing economies in East Africa. It recorded an annual average growth rate of 5.9% during 2010-2018 and reduced poverty rates from 36.5% in 2005 to 27.2% in 2019. This substantial growth rate raised the standard of living of Kenyans, which promoted the country to be ranked as a lower-middle-income country (USAID, 2023). Despite this significant development in recent decades, the country still faces significant development challenges, including, inter alia, inequality, poverty, weak private sector investment, transparency and accountability, and climate change. Notably, sustained economic growth poses severe environmental risks, which increase the depletion and extraction of natural resources and the accumulation of emissions and waste (USAID, 2023). Kenya's consumption-based CO_2 emissions were recorded to have an upward trend since 1990, with some periodical reductions (see Figure 1). It declined from 18.3 million metric tons in 2019 to around 16 million metric tons in 2020 due to the COVID-19 breakout. Despite the slight drop, overall emissions from industry and fossil fuels have risen since 2000 (Statista, 2020). Moreover, The highest value of consumption-based CO_2 emissions were recorded in 2019 (27.86 million tons) and the lowest value in 1991 (7.226 million tons) (CEIC, 2023).

Climate change is topical in Kenya, where climatic consequences are observable. Climate change consequences in Kenya include, but are not limited to, more frequent severe flooding and prolonged droughts, sea level rise, conflicts over scarce resources, and shifts in rainfall seasons (National Environment Management Authority (NEMA) of Kenya, 2021). Fossil fuel energy utilization and unsustainable economic growth are attributed to the rise in GHG emissions that resulted in increasing temperatures and climate change (Hussein et al., 2023). For instance, wood fuel and other biomass energy represent 68% of the primary energy consumption in Kenya. Petroleum, electricity, and other fuels (including coal) account for 22%, 9%, and less than 1%, respectively. In 2019, the feedstock of nonrenewable energy was 75,559 terajoules (TJ). According to the reports on state air quality in 2019, it underscored that air pollution is the 8^{th} leading cause of premature deaths in Kenya. It is estimated that 19,000 people diedue to air pollution annually in Kenya. Further, as a result of catastrophic crop and livestock losses caused by climate change, Kenyan people are at risk of starvation, displacement, and other dangers to their health and well-being. In addition, Kenya's essentially low-lying coastline and the neighboring islands are at risk owing to sea level rise, leading to a significant threat to the fishing sector and increased storm protection (USAID, 2018). Consequently, the Ministry of Environment initiated environmental management and coordination regulations (EMCA) in 2014 to curtail air pollution. The regulation aimed to address ambient air pollution in residential and industrial areas to ameliorate air quality standards. However, the enacted regulations did not become fruitful because of the slow air quality deployment monitors and the available data (Desouza, 2020).

The nexus between economic growth and environmental sustainability is rooted in the EKC hypothesis postulated by Grossman and Krueger (1991), which indicates an inverted U-shaped relationship between growth and environmental pollution. Environmental pollution deteriorates along with rising income until a specific threshold is reached. After the attainment of a specific threshold of income, environmental quality improves. Since the seminal work of Grossman and Krueger (1991), ample studies have tested the EKC hypothesis both in single-country and cross-country studies. These studies have produced

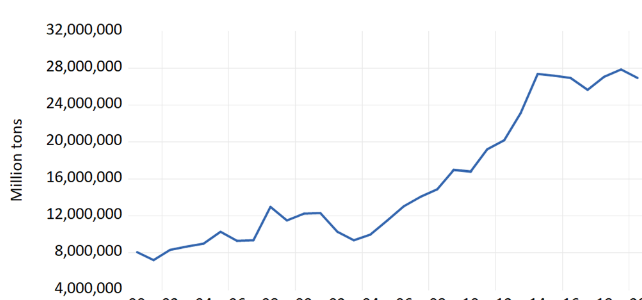

Figure 1. Consumption-based CO_2 emissions in Kenya.
Source: CEIC (2023).

blended results (Al-Mulali et al., 2016; Haq et al., 2016; Murshed et al., 2022). Some studies validated the EKC hypothesis, indicating an inverted U-shaped relationship between income and environmental sustainability (Kwakwa, 2023; Pata et al., 2023), whereas others found a U-shaped relationship between growth and environmental quality (Ozturk & Al-Mulali, 2015). The mixed findings could be attributed to the methodological approaches applied, the set of integrated parameters (such as urbanization, renewable energy, trade openness, population, and foreign direct investment) or the omission of key variables (Halliru et al., 2020). The blended results imply the need for adding additional environmental drivers to the empirical analysis to contribute to producing effective policies. Against this backdrop, renewable energy and globalization have emerged as essential parameters. The sustainable development goals (SDGs 2015-2030) have stressed the importance of clean energy access for all people in combating climate change (SDG 7). By considering the importance of clean energy for environmental sustainability, Kenya has embarked on programs to expand renewable energy generation to central and rural areas. Consequently, electricity generated from renewable energy sources has been increasing gradually, and it currently constitutes 69.5% of the total energy generation mix (National Environment Management Authority (NEMA) of Kenya, 2021).

Preserving environmental sustainability while not hurting sustainable economic growth requires a transition to a greener economy, and it should be at the forefront of development policy. The impulse to decouple GHG is one of the main notions of green growth – it is sustainable growth causing no or less environmental harm. This undertaking's contributions to the growing literature on emission reductions are threefold. First, the previous empirical examinations on emission reductions were based on production emissions (Och, 2017; Sarkodie & Ozturk, 2020; Warsame et al., 2022; 2023). More specifically, the few available studies on this theme in Kenya have utilized CO_2 emissions as an environmental pollution indicator (Al-Mulali et al., 2016; Sarkodie & Ozturk, 2020). Nevertheless, the driving factors of GHG emission changes are not well reflected in emissions from domestic production. Therefore, utilizing emissions from domestic production as an environmental pollution indicator would not be enough of a strategy to derive policies aimed at reducing emissions and climate change. In contrast, consumption-based CO_2 emissions are preferred over domestic production-based emissions, because the former incorporates emissions from local consumption and international trade. But unfortunately, consumption-based CO_2 emissions were embodied in theoretical arguments (Tenaw & Hawitibo, 2021) and scanty empirical examinations (Adebayo, Udemba, et al., 2021). Hence, we will utilize consumption-based CO_2 emissions as an environmental indicator. Second, we will incorporate renewable energy and globalization as determinants of consumption-based CO_2 dioxide emissions. Due to its decentralized nature, renewable energy is both environmentally friendly and economically efficient because it mitigates detrimental impacts of climate change, reduces pollution, provides energy security, and alleviates poverty by providing electricity to rural locations (Shah et al., 2020). Third, the study will also test the EKC hypothesis using consumption-based CO_2 emissions along with renewable energy and globalization in Kenya. The main objective of the study is to assess the impact of renewable energy, economic growth, squared growth, and globalization on consumption-based CO_2 emissions in Kenya, where there are scanty studies on this theme. We expect that renewable energy energy, squared economic growth, and globalization have significant negative effect on environmental pollution, whereas economic growth significantly increases environmental pollution.

The rest of the article is formulated as follows: Section two reviews the relevant empirical studies; Section three presents methods and data; Section four reports the results and discussion of the study; and the final section concludes the study and suggests relevant policy implications.

2. Literature review

2.1. Economic growth and consumption-based CO_2 emissions

The nexus between growth and pollution is extensively discussed by the EKC hypothesis, which identifies three main channels through which economic growth affects environmental quality: scale effect, composition effect, and technique effect. The scale effect underscores that growth affects the environment through increased economic activity and energy consumption. The composition effect posits the preference for clean goods over dirty ones that results from the changing economic structure. Finally, the technique effect underpins that an increase in income will result in using environmentally friendly technology that is favorable to the environment. Environmental pollution and economic growth nexus have been well documented in the empirical literature. Ample studies supported the EKC hypothesis (Ahmed et al., 2014; Kwakwa, 2021; Rahman, 2020; Waluyo & Terawaki, 2016), whereas others rejected it (Och, 2017; Warsame et al., 2022).

Based on single-country studies, Al-Mulali et al. (2016) evaluated the validity of the EKC hypothesis in Kenya using the ARDL bound test. It revealed the presence of the hypothesis in the under-study country. By the same token, Sarkodie and Ozturk (2020) confirmed the EKC hypothesis in Kenya using CO_2 emissions as an environmental pollution indicator. Similar results were observed by Pata et al. (2023) in Germany and Hussein and Warsame (2023) in Somalia. On the contrary, ample single-country studies failed to verify the validity of the EKC hypothesis. For instance, Och (2017) and Warsame et al. (2022) endeavored to examine the relationship between environmental degradation and economic growth in Mongolia and Somalia, respectively. Both of them reported the absence of the EKC hypothesis in their respective countries. In the same vein, Al-Mulali et al. (2015) endeavored to find the validity of the EKC hypothesis in Vietnam. Notably, it rejected the validity of the hypothesis. Moreover, Haq et al. (2016) and Ozturk and Al-Mulali (2015) reached similar conclusions in Morocco and Cambodia, respectively.

In cross-country studies, Culas (2007) examined the link between economic growth and deforestation in Asian, Latin American, and African countries by testing the EKC hypothesis. It was observed the validity of EKC in Latin American countries. Sarkodie and Strezov (2019) endeavored to find the nexus between growth and environmental quality in the top GHG emitters in developing countries. They underscored the validity of the EKC hypothesis in Indonesia and China but found a U-shaped relationship in South Africa and India. Similarly, Ssali et al. (2019) detected the validity of the EKC hypothesis in SSA countries. On the contrary, a plethora of studies have rejected the validity of the EKC hypothesis. For instance, using panel data from West African countries, Halliru et al. (2020) indicated that growth boosts environmental quality at the initial stage, but as the economy grows, environmental quality declines, which posited a U-shaped relationship between growth and environmental quality and the absence of the EKC hypothesis. The heterogeneous results of the growth-pollution nexus are displayed in Table 1.

2.2. Renewable energy and consumption-based CO_2 emissions

A wide range of empirical examinations have assessed the role of clean energy in environmental quality. The majority of these examinations underscored that renewable energy enhances environmental quality (Ike et al., 2020; Kwakwa, 2023). For instance, utilizing panel data from 32 African countries, Kwakwa (2023) endeavored to contend the impact of renewable energy on CO_2 emissions. They observed that clean energy enhances environmental quality. Bölük and Mert (2014) documented that renewable energy

Table 1. Environmental Kuznets curve literature table.

Author(s)	Country (ies)	Period	Method	Results
Ahmed et al. (2014)	Pakistan	1980-2014	ARDL technique	Supported the EKC hypothesis
Culas (2007)	Latin American countries	1972-1994	Static panel methods	supported the EKC hypothesis
Sarkodie and Strezov (2019)	Kenya	1971–2013	ARDL technique and Utest method	supported the EKC hypothesis
Rahman (2020)	10 panel countries	1971-2013	FMOLS & DOLS methods	supported the EKC hypothesis
Ssali et al. (2019)	6 SSA countries	1980-2014	Pedroni & Kao, PMG methods	supported the EKC hypothesis
Al-Mulali et al. (2016)	Kenya	1980-2012,	ARDL technique	supported the EKC hypothesis
Pata et al. (2023)	Germany	1974–2018	Fourier autoregressive distributive lag (FADL) and Wavelet causality	Supported the EKC hypothesis
Kwakwa (2023)	32 African countries	2002–2021	FMOLS method	Supported the EKC hypothesis
Ozturk and Al-Mulali (2015)	Cambodia	1996-2012	Generalized method of moments (GMM)	Rejected the validity of EKC hypothesis
Al-Mulali et al. (2015)	Vietnam	1981-2011,	ARDL technique	Not supported the EKC hypothesis
Warsame et al. (2022)	Somalia	1990-2017	ARDL technique	Not supported the EKC hypothesis
Haq et al. (2016)	Morocco	1971–2011	Johansen cointegration technique	Not supported the EKC hypothesis
Halliru et al. (2020)	Six West African countries	1970–2017	Panel Quantile Regression	Not supported the EKC hypothesis
Och (2017)	Mongolia	1981-2012	ARDL technique	Not supported the EKC hypothesis

consumption decreases GHG emissions in European countries. Usman et al. (2020) reported that renewable energy mitigates environmental footprint in the USA. In a follow-up study, Khan et al. (2021) revealed that the use of renewable energy improves environmental quality both in developed and developing nations. Also, Adebayo et al. (2022) argued that using renewable energy curbs CO_2 emissions in Turkey.

Ike et al. (2020) observed that a rise in clean energy reduces CO_2 emissions in G7 countries. Using annual time series data from China, Sarkodie et al. (2020) observed that a rise in renewable energy has a constructive role in reducing emissions and environmental degradation. This finding also corroborates the results of Sarkodie and Adams (2018), which showed that renewable energy improves environmental sustainability in South Africa. Using annual time series data and an ARDL bound test, Warsame et al. (2022) inspected the link between renewable energy and deforestation in Somalia. They found that renewable energy inhibits deforestation in the long run.

On the other hand, clean energy exerts a rise in environmental pollution in some countries, specifically in developing countries. Shifting to clean energy requires technological equipment and capital resource planning that is suitable for the utilization and installation of clean energy, but these nations could not meet these requirements, which is why renewable energy exacerbates the already polluted environment in some developing countries (Shah et al., 2020). For instance, Yurtkuran (2021) underscored that extracting renewable energy causes more pollution in Turkey. Further, Shah et al. (2020) demonstrated that the utilization of both renewable and non-renewable energy curbs environmental quality in the eight developing countries (D – 8).

2.3. Globalization and consumption-based CO_2 emissions

The empirical studies on globalization and environmental pollution have produced mixed results. Some studies claim that globalization hampers environmental quality (Le & Ozturk, 2020; Warsame et al., 2023), whereas others support that globalization improves environmental quality (Adebayo et al., 2021; Akadiri et al., 2019). The criticism against globalization claims that because of the strict environmental regulations in advanced economies, developed nations move their environmentally polluting industries to developing nations. Hence, globalization is damaging rather than decreasing environmental pollution since it increases production levels and energy use and instigates emissions (Le & Ozturk, 2020; Warsame et al., 2023).

Rafindadi and Usman (2019) found that globalization increases environmental degradation in South Africa. By the same token, Destek (2019) demonstrated that overall globalization, and social and economic globalization impede environmental quality by raising CO_2 emissions in Central and Eastern European countries. Also, Sabir and Gorus (2019) observed that globalization leads to an increase in ecological footprint in South Asian countries, utilizing various measurements of globalization – FDI, KOF index, and trade openness. With the process of globalization, environmental issues such as deforestation, climate change, desertification, and depletion of natural resources have emerged. Through globalization, many countries aspire to boost their economies by enhancing their industrial structures and expanding urban areas (Doytch & Uctum, 2016).

On the other hand, proponents of globalization contend that it lowers CO_2 emissions by ensuring the transmission and adoption of environmentally friendly technologies, information, and best practices for environmental management (Zafar et al., 2019). For instance, Salahuddin et al. (2019) documented that globalization boosts environmental sustainability in South Africa by reducing CO_2 emissions. In the same vein, He et al. (2021) found that globalization exerts an increase in environmental quality in Mexico. Adebayo et al. (2021) indicated the negative relationship between globalization and CO_2 emissions in Argentina, implying that globalization improves environmental quality. Similar results have been observed in OECD countries (Zafar et al., 2019), emerging (E-7) countries (Onifade et al., 2021), and a panel of tourist destination countries (Akadiri et al., 2019). Notably, as countries become more globalized, better economic growth could be achieved via an increased flow of efficient and green technologies that enhance environmental quality. Globalization is associated with several benefits, including the efficient use of resources and advanced technology that lowers CO_2 emissions.

Based on the critical appraisal of the literature above, it could be noticed at several points. First, the results of previous empirical studies on the EKC hypothesis are mixed; hence, the validity of EKC needs to be looked into further in other situations. Second, renewable energy and environmental pollution nexus, and globalization and environmental pollution nexus are inconclusive; hence, further studies on these issues are also required to be examined. Third, most of the previous examinations have utilized GHG, CO_2 emissions, deforestation, and methane and nitrous oxide emissions as environmental pollution indicators, while few studies employed consumption-based CO_2 emissions. Therefore, this examination contributes to the existing body of knowledge by investigating the effect of globalization, renewable energy, economic growth, and squared growth on consumption-based CO_2 emissions in Kenya.

3. Methods and data

3.1. Data

To empirically assess the effects of economic growth, squared growth, globalization, and renewable energy on consumption-based CO_2 emissions, we utilize annual time series data over the period 1990-2018. Economic growth and renewable energy were extracted from the World Bank, whereas consumption-based CO_2 emissions were retrieved from Our World in Data. Globalization was sourced from the KOFF Swiss Institute. Most of the previous studies have utilized numerous environmental indicators such as CO_2, GHG emissions, deforestation, and ecological footprint. Contrary to the previous attempts, we use consumption-based CO_2 emissions, which capture direct and lifecycle GHG emissions of goods and services from the final consumers. The dependent variable is consumption-based CO_2 emissions (million tons), whereas renewable energy (% of total energy use), globalization (overall index), economic growth (real GDP per capita), and squared growth are the regressors.

3.2. Methods

To achieve the objective of this study, the ARDL technique is employed (Pesaran et al., 2001). It is a cointegration method that estimates the short- and long-run coefficients of the interested variables. It is better than other cointegration methods in several aspects. First, the ARDL method is capable of simultaneously estimating the short- and long-run parameters. Second, this method is robust for estimating with a small sample size like ours, whereas other cointegration methods require a large sample size. Third, the bound test could estimate variables that are stationary at all levels except variables that are integrated at the second difference I (2). We specify the model of the study as follows:

$$lnCC_t = \beta_0 + \beta_1 lnRE_t + \beta_2 GLO_t + \beta_3 lnRGDPC_t + \beta_4 lnRGDPC2_t + \varepsilon_t \quad (1)$$

$lnCC_t$, $lnRE_t$, $lnGLO_t$, $lnRGDPC_t$, and $lnRGDPC2_t$ stand for consumption-based CO_2 emissions, renewable energy, globalization, economic growth, and squared growth respectively. ε_t represents the error term.

Following the empirical studies of Adebayo et al. (2021) and Adebayo, Udemba, et al., (2021), the ARDL equation is specified as follows:

$$\begin{aligned}\Delta lnCC_t &= \delta_0 + \delta_1 lnCC_{t-1} + \delta_2 lnRE_{t-1} + \delta_3 lnRGDPC_{t-1} + \delta_4 lnRGDPC2_{t-1} + \delta_5 lnGLO_{t-1} + \sum\nolimits_{i=0}^{q}\gamma_1 \Delta lnCC_{t-k} \\ &+ \sum\nolimits_{i=0}^{w}\gamma_2 \Delta lnRE_{t-k} + \sum\nolimits_{i=0}^{w}\gamma_3 \Delta lnRGDPC_{t-k} + \sum\nolimits_{i=0}^{w}\gamma_4 \Delta lnRGDPC2_{t-k} + \sum\nolimits_{i=0}^{w}\gamma_5 \Delta lnGLO_{t-k} + \varnothing ECT_{t-1}\end{aligned} \quad (2)$$

Where δ_0 is the intercept, $\delta_1 - \delta_5$ represent the long-run slopes of the interested parameters, $‡_1 - ‡_7$ stands for the short-run regressors. Q, and w represent the best lag length of the regressand and regressors, respectively, Δ show short-run variables and $\varnothing$ is the slope of the error correction term.

To find out the existence of long-run cointegration between the regressand and regressors, we specify the null hypothesis test (H_o: $\delta_1 = \delta_2 = \delta_3 = \delta_4 = \alpha_5 = 0$) as the sampled variables do not share a long-run movement among them against the alternative hypothesis ($H_1 : \delta_1 \neq \delta_2 \neq \delta_3 \neq \delta_4 \neq \delta_5 \neq 0$) that the interested variables share a long-run movement among them.

4. Empirical results and discussion

4.1. Summary statistics

The characteristics of the interested variables are shown in Table 1. The mean values of environmental pollution (16), economic growth (6.8), globalization (3.9), and renewable energy (4.3) are established. Consumption-based CO_2 emissions have the highest standard deviation value of 0.42 compared to other variables, which implies that its values are scattered. All the variables are independently and identically distributed, as shown by the probability of Jarque-Bera, except renewable energy, which is statistically significant. In the same vein, most of the interested parameters have a positive skewness except renewable energy, which has a negative skewness. In contrast, the correlation of the variables is also reported in Table 2. Economic growth and globalization are positively related to consumption-based CO_2 emissions. On the contrary, consumption-based CO_2 emissions and renewable energy are negatively correlated.

To find robust results, we test the integration order of the interested parameters. The unit root result, displayed in Table 3, revealed that all the parameters have a unit root problem at level I (0). But at the first difference, they are stationary, hence confirming that the characteristics of the series are suitable for the ARDL. Nevertheless, the application of ADF and PP could lead to misleading results by ignoring the presence of structural breaks in the series. Hence, to address this issue, we utilize Zivot and Andrews (1992). The advantage of the Zivot and Andrews unit root test is that it captures the stationarity and a single break in the series. The results of the ZA test are also portrayed in Table 3. It revealed that all the parameters contain a unit root problem at level I (0). But after differencing the parameters in the first order, consumption-based CO_2 emissions, globalization, renewable energy, economic growth, and squared growth are all stationary having break years in 2002, 2008, 2001, 2005, and 2005, respectively.

Table 2. Summary statistics.

	lnCCO	lnGLO	lnRE	lnRGDPC
Mean	16.429	3.916	4.359	6.820
Median	16.326	3.917	4.375	6.786
Maximum	17.124	4.006	4.422	7.091
Minimum	15.793	3.847	4.262	6.696
Std. Dev.	0.422	0.048	0.042	0.115
Skewness	0.422	0.251	−1.125	0.968
Kurtosis	1.879	1.666	3.426	2.723
Jarque-Bera	2.374	2.453	6.344	4.625
Probability	0.305	0.293	0.042	0.099
Correlation				
lnCCO	1			
lnRE	−0.78	1		
lnGLO	0.529	−0.406	1	
lnRGDPC	0.865	−0.912	0.524	1

Table 3. Result of the unit root tests.

			ZA Structural break unit root test	
Variable	ADF	PP	T-statistics	Time break
lnCCO	−2.159	−2.21	−4.78	2002
ΔlnCCO	−5.62***	−5.61***	−6.939***	2005
lnGLO	−2.237	−2.379	−4.317	1996
ΔlnGLO	−5.139***	−5.139***	−6.123***	2008
lnRE	−1.723	−1.556	−5.402**	2003
ΔlnRE	−4.626***	−3.335*	−5.304**	2001
lnRGDPC	−1.379	−1.720	−3.896	2002
ΔlnRGDPC	−4.522***	−5.006***	−5.196**	2005
$lnRGDPC^2$	−1.305	−1.636	−3.777	2002
$\Delta lnRGDPC^2$	−4.547***	−5.429***	−5.203**	2005

***, and * represent significance level at 1%, and 10%. Δ represents the differenced variables at the first level.

4.2. Unit root test

We, subsequently, examine the presence of a long-run association between the regressand and regressors. The result of thebound test, displayed in Table 4, revealed that the Wald F-statistics (4.78) fall above the upper bound critical value (4.22) at the 5% significance level. Hence, we conclude that renewable energy, globalization, economic growth, and squared growth are cointegrated into consumption-based CO_2 emissions in Kenya in the long run.

4.3. Bound test and long-run results

The long-run result of the study is displayed in Table 5. It indicated that economic growth, squared growth, and globalization are statistically significant, whereas renewable energy is insignificant in the long run. Globalization and squared growth significantly improve environmental quality, but economic growth hampers it in the long run. A 1% increase in globalization is associated with an environmental quality increase of about 1.07% in the long run On the contrary, a 1% increase in economic growth is translated into a 74% reduction in environmental quality in Kenya in the long run. However, squared growth improves environmental quality by about 5.3% for a 1% increase in squared growth in the long run. Our study, hence, verified the presence of the EKC hypothesis in Kenya.

Kenya is considered one of the emerging nations in Africa and has the largest economy in the East Africa region. It also serves as the entry gate to the larger East African market (USAID, 2023). Globalization significantly improves environmental quality in Kenya. It could be attributed that globalization boosts environmental sustainability in Kenya by importing energy-efficient technologies and products that are environmentally friendly. Globalization reduces emissions by facilitating the dissemination and acceptance of eco-friendly technologies, knowledge, and optimal strategies for environmental stewardship. This result is in line with the previous study of Yameogo et al. (2021) in Sub-Saharan African countries, which revealed that globalization improves environmental quality in the region. It also agrees with several other previous studies that concluded that globalization improves environmental quality by lowering environmental pollution and degradation. He et al. (2021) endeavored to find that globalization underpins environmental sustainability by reducing consumption-based CO_2 emissions in Mexico. Adebayo et al. (2021) documented that globalization dampens CO_2 emissions in Argentina. A similar finding was found by Zafar et al. (2019) in OECD countries. Our result disagrees with other studies that have found that globalization dampens environmental quality, such as Destek (2019) in Central and Eastern European countries (CEECs); and Akadiri et al. (2019) in a panel of 15 nations.

Further, the results of the study also validated the presence of the EKC hypothesis in Kenya. We observe that economic growth increases emissions in the initial phase of growth, but at a specific threshold, growth

Table 4. F-bounds cointegration tests.

Model	F-statistic	Significance level	Bounds test critical values	
LnCCO =*f*(lnRGDP, lnRGDP², lnRE, lnGLO)			K (4)	
			I (0)	I (1)
		1%	4.28	5.84
	4.78	5%	3.058	4.223
		10%	2.525	3.560

Table 5. Long-run results.

Explanatory Variable	Coefficient
lnGLO	−1.071[a]
	(−2.533)
lnRGDPC	74.099[a]
	(3.297)
lnRGDPC²	−5.318[a]
	(−3.235)
lnRE	−0.251
	(−0.295)
Constant	−247.3[a]
	(−3.323)

Notes: "a" shows a 1% significance level. Values in parenthesis are the t-statistics.

improves environmental quality. Kenya has recorded an annual average growth rate of 5.9% during 2010-2018. This substantial growth rate raised the standard of living of Kenyans which promoted the country to be ranked as a lower-middle income country but at the cost of environmental quality (USAID, 2023). But as the income of Kenyans increases, people shift from the consumption of polluted products to more modern and efficient products. This result is in line with ample previous studies that verified the EKC hypothesis. For instance, Culas (2007) found the presence of the EKC hypothesis in a panel of Latin American countries. Waluyo and Terawaki (2016) also verified the EKC hypothesis in Indonesia, utilizing deforestation as an environmental degradation indicator. Kwakwa (2023) also validated the presence of an inverted U-shaped relationship between economic growth and environmental pollution in a panel of 32 countries, thereby confirming the validity of the EKC hypothesis. Similar findings were established by Ahmed et al. (2014) in Pakistan. Other studies found a U-shaped nexus between growth and pollution. For instance, Halliru et al. (2020) detected that economic growth improves environmental quality, but when economic growth reaches a specific threshold, it offsets and dampens environmental quality in a panel of West African countries. Further, ample previous studies produced contradictory results to our findings. Al-Mulali et al. (2015) endeavored to assess the validity of the EKC hypothesis in Vietnam, and they found the invalidity of the EKC hypothesis. Similarly, Haq et al. (2016) and Ozturk and Al-Mulali (2015) reached similar conclusions in Morocco and Cambodia respectively, hence confirming the absence of the EKC hypothesis. On the other hand, we found that renewable energy mitigates environmental pollution in Kenya even though it is statistically insignificant. The insignificant impact of clean energy on environmental pollution could be explained by its small share in the total energy mix in the country.

In a nutshell, both globalization and clean energy improve environmental quality by reducing consumption-based CO_2 emissions, even though clean energy is inconsequential in the long run. The hypothesis of globalization has failed to be rejected since it significantly improves environmental quality. The hypothesis of the significant effect of clean energy on environmental quality is rejected since it is insignificant. However, the insignificant effect of clean energy on environmental quality in Kenya could be attributed to the small share of clean energy in the total energy mix in the country. The renewable energy coefficient is insignificant but maintains its expected negative sign, which implies that it mitigates consumption-based CO_2 emissions. Nevertheless, we proposed the increase of clean energy in the total energy mix to have a significant effect on environmental quality. Economic growth and squared growth have a positive and negative effect on environmental pollution in the long run, hence confirming the validity of the EKC hypothesis in Kenya. This also verifies our hypothesis that growth impedes environmental quality, whereas squared growth improves it.

The result of the short-run dynamic effect, presented in Table 6, indicated that renewable energy and economic growth are statistically significant, whereas globalization and squared economic growth are statistically insignificant. A 1% increase in renewable energy results in environmental pollution being reduced by about 2.4% in the short run. On the contrary, a 1% increase in economic growth leads to a pollution increase of about 6.7% in the short run. Moreover, the ECT is significant and has a negative coefficient which implies that the model makes a convergence rather than a divergence. The interested parameters in the long run correct any shock deviations in consumption-based CO_2 emissions by 24.5% annually.

Further, diagnostic tests are performed to verify that the results of the study are unbiased and robust. The diagnostic test, reported in Table 7, indicated that the results of the model are robust and unbiased. The variances of the error term are not correlated to each other and they are constant as shown in the results of serial correlation and heteroskedasticity tests, respectively. Moreover, the data series is normally and identically distributed, as revealed by the normality test. The reset test result indicated that the model specification is correctly specified. The results of the study are also stable, as shown in Figure 2: Cusum and Cusum square tests.

4.4. Robust analysis

The Johansen and Juselius cointegration method is used to determine the long-run cointegration among the interested parameters as robustness (Johansen & Juselius, 1990). It indicated that there is at least one cointegrating vector shown by the Trace and Maximum-Eigen values (see Table 8). On the other hand, dynamic ordinary least squares (DOLS) is utilized to estimate the long-run coefficients of the sampled

Table 6. Short-run results.

Variable	Coefficient (t-Statistic)
Constant	2.587**
	(2.509)
ECT (-1)	−0.245**
	(-2.539)
Δ (lnCCO (-2))	0.669**
	(2.174)
Δ (lnRE)	−2.438*
	(-1.947)
Δ (lnRE(-1))	3.389*
	(1.983)
Δ (lnRGDPC)	6.746***
	(3.279)
Δ (lnRGDPC(-1))	−1.723
	(-1.404)
Δ ($lnRGDPC^2$)	−88.443
	(-1.672)
Δ ($lnRGDPC^2$(-1))	83.828
	(1.721)
Δ ($lnRGDPC^2$(-2))	36.608
	(0.954)
Δ (lnGLO)	1.150
	(1.266)
Δ (lnGLO(-1))	−1.268
	(-1.758)
Δ (lnGLO(-2))	−1.574**
	(-2.504)

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

Table 7. Diagnostic test.

Reset test	0.098 [0.757]
Adjusted R-square	0.468
Heteroskedasticity test	0.861 [0.491]
Correlation test	1.245 [0.114]
Normality	2.781 (0.249)

T-statistics values are in (.) parenthesis. P-values are in [.].

variables as robustness for the ARDL long-run results, as presented in Table 9. The DOLS result revealed that globalization and squared growth significantly enhance environmental quality in Kenya, whereas economic growth significantly hampers it in Kenya. Renewable energy is inconsequential in the long run. However, the DOLS result has verified the long-run ARDL results.

4.5. Granger causality

The ARDL bound test could not examine the causality among the variables. Hence, to address this shortfall, we use Granger causality to assess the direction of causality among the interested parameters. Its result reported in Table 10 revealed unidirectional causality from consumption-based CO_2 emissions to renewable energy, economic growth, and squared growth. An increase in environmental pollution is related to increased productivity, which induces economic growth. In the same vein, there is unidirectional causality from globalization to renewable energy. Finally, both economic growth and squared economic growth cause renewable energy but not the other way around. An increase in income stimulates more energy demand, specifically renewable energy, which is favorable to the environment.

5. Conclusion and policy implication

This study aimed to examine the validity of the EKC hypothesis in Kenya by controlling the effects of globalization and renewable energy. Contrary to previous attempts, this study utilized consumption-based carbon dioxide (CO_2) emissions as an environmental pollution indicator. Contrary to previous attempts, this

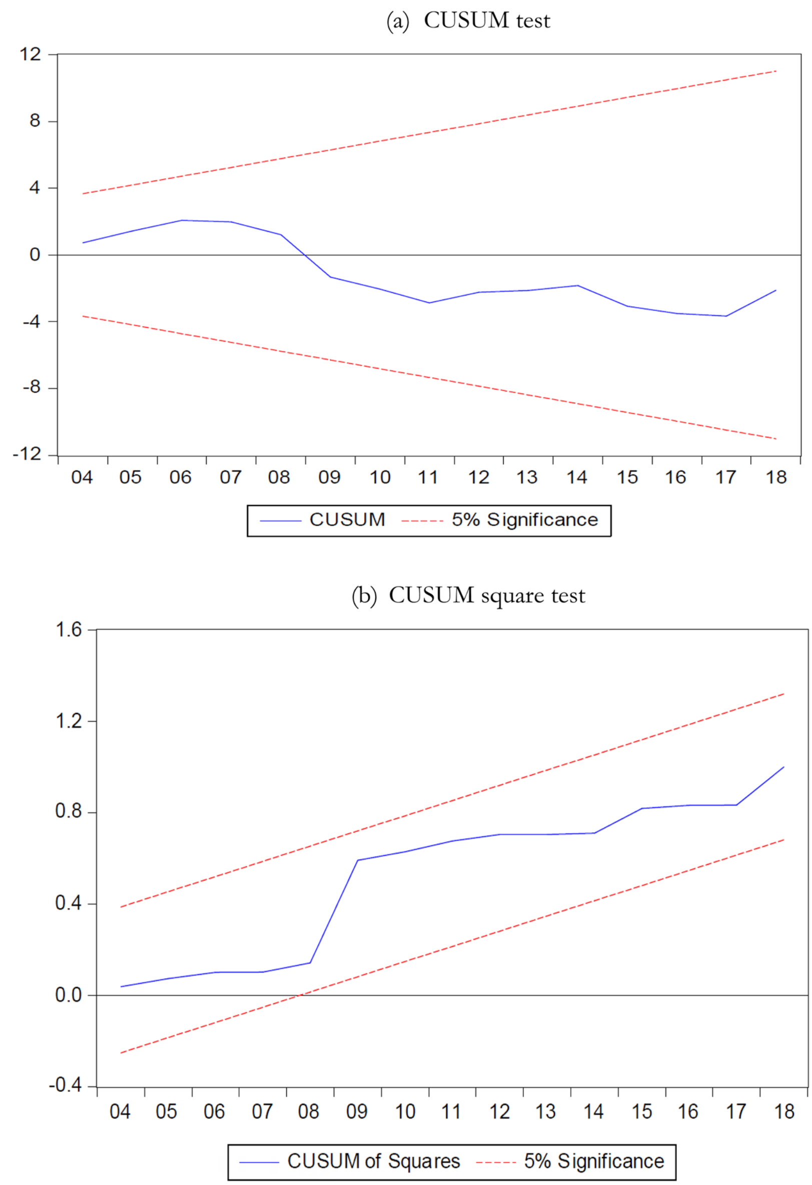

Figure 2. Model stability test.

Table 8. Johansen cointegration test.

Hypothesis	Test Statistic	Critical Value	P-value
Trace test			
$r \leq 0$	103.5745	69.81889	0.0000
$r \leq 1$	56.78170	47.85613	0.0058
$r \leq 2$	30.06169	29.79707	0.0466
$r \leq 3$	7.090425	15.49471	0.5671
$r \leq 4$	0.748266	3.841466	0.3870
Maximum Eigenvalue			
$r \leq 0$	46.79284	33.87687	0.0009
$r \leq 1$	26.72001	27.58434	0.0642
$r \leq 2$	22.97127	21.13162	0.0273
$r \leq 3$	6.342159	14.26460	0.5697
$r \leq 4$	0.748266	3.841466	0.3870

Trace and Max-eigenvalue tests indicate 1 cointegrating equation at the 1% level.

study utilized consumption-based CO_2 emissions, which incorporate emissions from local consumption and international trade. The ARDL bound test is used with annual time series data spanning 1990-2018. The empirical results of the bound test indicated that renewable energy, economic growth, squared growth,

Table 9. Dynamic ordinary least square (DOLS).

Variable	Coefficient	Std. Error	t-Statistic	Prob
lnGLO	−5.338	1.005	−5.312	0.0005
lnRE	2.818	4.081	0.691	0.5074
lnRGDPC	322.942	55.311	5.838	0.0002
lnRGDPC^2	−23.438	4.037	−5.805	0.0003
Constant	−1087.217	189.8036	−5.728118	0.0003

Adjusted R-squared 0.94.

Table 10. Granger causality tests.

Null Hypothesis:	F-Statistic	Prob
lnGLO ⇏ lnCCO	1.02365	0.3213
LCCO ⇏LGLO 0.39641	0.5347	
lnRE ⇏lnCCO	0.84982	0.3654
lnCCO ⇏ lnRE 12.3748	0.0017	
lnRGDPC ⇏ lnCCO	0.47274	0.4981
lnCCO ⇏ lnRGDPC 10.8234	0.0030	
lnRGDPC^2 ⇏ lnCCO	0.45361	0.5068
lnCCO ⇏ lnRGDPC^2 10.8837	0.0029	
lnRE ⇏ lnGLO	0.25494	0.6180
lnGLO ⇏ lnRE 6.56591	0.0168	
lnRGDPC ⇏ lnGLO	1.32845	0.2600
lnGLO ⇏ lnRGDPC 2.61985	0.1181	
lnRGDPC^2 ⇏ lnGLO	1.29889	0.2652
lnGLO ⇏ lnRGDPC^2 2.61174	0.1186	
lnRGDPC ⇏ lnRE	8.99714	0.0060
lnRE ⇏ lnRGDPC 0.80961	0.3768	
lnRGDPC^2 ⇏ lnRE	9.00813	0.0060
lnRE ⇏ lnRGDPC^2 0.81504	0.3753	
lnRGDPC^2 ⇏ lnRGDPC	0.41428	0.5257
lnRGDPC ⇏ lnRGDPC^2	0.42306	0.5213

⇏ indicates that the variables do not granger cause.

and globalization are cointegrated into consumption-based CO_2 emissions in the long run. Further, globalization significantly boosts environmental sustainability in the long run, but renewable energy is insignificant. It was established that there is an inverted U-shaped relationship between growth and environmental quality in Kenya, hence confirming the presence of the EKC hypothesis. The EKC hypothesis posits that in the initial phase of growth environmental quality deteriorates, but at a specific threshold of growth, it offsets the adverse effect, and environmental quality improves. In contrast, a unidirectional causality from consumption-based CO_2 emissions to renewable energy, economic growth, and squared growth is observed. In the same vein, there is unidirectional causality from globalization to renewable energy. Finally, both economic growth and squared economic growth cause renewable energy but not the other way around.

The findings of this study align with the sustainable development goal 13 (SDG 13: climate action). From a policy perspective, first, to mitigate environmental degradation while not hindering sustainable economic growth, the production and consumption of clean energy in the energy mix should be increased. Policymakers should create conducive environments that encourage investments in clean energy sources. For instance, tax reductions and subsidies should be given to businesses that utilize clean energy and technologies in their production. Moreover, carbon tax should be imposed that discourages the consumption of fossil fuel energy. Second, policymakers should not wait for economic growth to fix environmental problems. Promoting sustained economic growth is not sufficient, and it should be backed by policies such as increasing cleaner production and environmentally friendly technologies. This will not only improve sustainable economic growth but also environmental quality. Moreover, we also suggest that the government budget related to clean energy should be increased. Third, since globalization enhances environmental quality, Kenya needs to enhance its involvement in the global commerce of commodities and services that exhibit minimal levels of greenhouse gas emissions, import environmentally friendly cleaner technologies, and attracts foreign investments that lead to a sustainable environment and economic growth.

This study only evaluated the effects of growth, globalization, and renewable energy on consumption-based CO_2 emissions. Future studies should explore other significant variables, such as institutional quality and trade openness, in relation to consumption-based emissions. It incorporates emissions from local consumption and international trade. Hence, analyzing the role of trade openness has paramount importance for deriving emission reduction policies.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Credit author statement

Abdimalik Ali: Conceptualization, data collection, writing the original draft. Abdullahi Abdirahman: Writing the literature. Hassan Abdikadir: Writing the introduction. Mohamed Ahmed Salad: Reviewing and editing.

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Data availability statement

The datasets used for the study are available from the links below: https://data.worldbank.org/country/KE; https://ourworldindata.org/country/kenya; https://kof.ethz.ch/en/forecasts-and-indicators/indicators/kof-globalisation-index.html

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