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Investigating the modern renewable energy-environmental Kuznets curve (REKC) hypothesis for East Africa Community (EAC) countries

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Abstract

Purpose – The study aims to explore the validity of the modern renewable energy-environmental Kuznets curve (REKC) while considering the relevance of financial development in the consumption of modern renewable energy in East Africa Community (EAC). Modern renewable energy in this study includes all other forms of renewable energy except traditional use of biomass. The authors controlled for the effects of urbanization, governance, foreign direct investment (FDI) and trade openness.

Design/methodology/approach – Panel data of the five EAC countries of Burundi, Kenya, Rwanda, Tanzania and Uganda for the period 1996–2019 were used. The analysis relied on the use of the autoregressive distributed lag–pooled mean group (ARDL-PMG) model, and the data were sourced from the World Development Indicators (WDI), World Governance Indicators (WGI) and International Energy Agency (IEA).

Findings – The REKC hypothesis is supported for modern renewable energy consumption in the EAC region. Financial development positively and significantly affects modern renewable energy consumption, whereas urbanization, FDI and trade openness reduce modern renewable energy consumption. Governance is insignificant.

Originality/value – The concept of the REKC, although explored in other contexts such as aggregate renewable energy and in other regions, has not been used to explain the consumption of modern renewable energy in the EAC.

Keywords Modern renewable energy consumption (MREC), REKC, Panel ARDL-PMG, East African Community

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1. Introduction

Modern renewable energy is the fundamental component linking economic growth, social fairness and environmental sustainability (Jeuland *et al.*, 2021). However, the world's consumption of modern renewable energy is growing slowly, threatening the fulfillment of the global Sustainable Development Goal (SDG) 7. SDG 7 pushes for greater use of modern renewable energy. The global growth rate of modern renewable energy consumption (MREC) in 2021 was 9.7%, slower than the ten-year average of 13.4% p.a. from 2011 to 2021 (British Petroleum (BP) Statistical Review of World Energy, 2021). In East Africa, the use of modern renewables is equally low, having only risen by 0.6% on average for the last 10 years (IEA, 2022). Despite these challenges, numerous initiatives have been launched during the same period, such as the Sustainable Energy for All initiative initiated by the United Nations Secretary-General in 2012, aiming to achieve universal access to modern energy by 2030. When it comes to expanding the adoption of modern renewable energy, this situation presents a complex dilemma, which calls for a dynamic model to explain how a country or region can transition through the different stages of increasing MREC. The renewable energy-environmental Kuznets curve (REKC) can be used for this purpose. The REKC is predicated on the hypothesis that the use of renewable energy has a U-shaped relationship with economic growth (Yao *et al.*, 2019). Unfortunately, the low levels of MREC in the EAC show that consumption levels are still in the initial stages, which necessitates a large economic push to achieve a remarkable increase.

An examination of the literature reveals that investigations of the renewable energy and economic growth hypothesis (REKC) are still in their early stages. For instance, existing studies have examined aspects such as the consumption of energy and economic development in terms of the energy-environmental Kuznets curve (EEKC) in Latin America and the Caribbean (Pablo-Romero and De Jesús, 2016), EU27 countries (Pablo-Romero *et al.*, 2017), Ethiopia (Hundie and Daksa, 2019), Chinese Provinces (Shahbaz *et al.*, 2020), Egypt (Mahmood *et al.*, 2021) and Saudi Arabia (Mahmood *et al.*, 2021). The empirical literature barely shows the testing of this hypothesis among renewable energy sources, with the exception of a study that was conducted in a few developing and important developed countries (Yao *et al.*, 2019). This study did not include East African developing countries, and examined renewable energy in aggregate. The current study hopes to close this gap by studying the five EAC countries while disaggregating to only MREC. This is due to the fact that modern renewable energy sources, sometimes referred to as clean energy sources, are good for the environment and do not emit any carbon emissions. Nonetheless, these clean renewable energy resources are greatly available in EAC countries. For example, the region's potential solar energy average radiation is 5–6 kWh/m^2 per day, as opposed to the world's 3–5 kWh/m^2 (Amasi *et al.*, 2021). In addition, Pablo-Romero and De Jesús (2016) suggest that this model can be expanded to incorporate additional factors. In this study, financial development and the control variables of governance, urbanization, trade openness (Li *et al.*, 2020; Asongu and Odhiambo, 2021) and foreign direct investment (Asongu and Odhiambo, 2021) were included.

Modern renewable energy projects require strong financial development initiative by nature. This is because they are very expensive and require high start-up costs (Sonntag-O'Brien and Usher, 2006). With the establishment of an East African Member States Securities Regulatory Authority to facilitate capital market cooperation and integration (World Bank, 2007), and the gradual expansion of the EAC banking industry between 2018 and the first quarter of 2021 (Deloitte, 2022), there is undoubtedly development in the region's financial sector. A developed financial system is characterized by credit that can easily be effectively channeled to the renewable energy industry, whereas an underdeveloped financial system may hinder new renewable projects from being realized, even if there is a need for them. Therefore, the importance of financial development in enhancing modern renewable

energy consumption cannot be ignored. In response to this discussion, this study addresses the inquiries posed by the following research questions.

RQ1. Does the modern renewable energy-environmental Kuznets curve (REKC) hold for East African Community countries?

RQ2. Does financial development affect modern renewable energy consumption in East African Community countries?

The research questions were addressed by employing secondary panel data from 1996 to 2019. The findings verify the U-shaped modern REKC hypothesis for EAC countries in the long run at the 5% significance level. Financial development positively influences the consumption of modern renewable energy, whereas urbanization, trade openness and FDI negatively influence it. The present study had several advantages. From an empirical standpoint, the results of this study confirm the MREC and economic growth nexus, and add to the body of knowledge in prior research by proving the existence of the modern REKC hypothesis among EAC nations, which was previously unknown. Furthermore, the paper ascertains the significance of financial progress in the MREC in EAC. Policy-wise, this research underscores the importance of simultaneously enforcing regulations on the utilization of modern renewable energy while fostering economic growth. In addition, the report offers explicit policy assistance for special loans and advantageous interest rates to alleviate the funding restrictions of modern renewable energy production. Methodologically, the aforementioned research questions have been successfully explored using the autoregressive distributed lag–pooled mean group (ARDL-PMG) model.

The rest of this paper is structured as follows. The second section is a review of literature. The approach employed in this investigation is described in Section 3. Section 4 summarizes and discusses our findings. In Section 5, we draw conclusions and discuss policy consequences.

2. Review of literature

2.1 Renewable energy-environmental Kuznets curve (REKC)

This study is based on the REKC model, founded on the environmental kuznets curve (EKC) framework. The EKC was originally introduced by Grossman and Krueger (1991), with the objective of elucidating the connection between economic expansion and its influence on the environment. According to the EKC, there is a favorable relationship between economic growth and environmental pressure until a certain income per capita threshold, beyond which additional economic expansion contributes to increased environmental quality.

Various studies have employed energy consumption to gauge environmental pressure within the context of the EKC. For example, Aslanidis (2009) argues that utilizing energy consumption as a measure of environmental pressure is logical given the direct correlation between CO_2 emissions and energy usage. Saboori and Sulaiman (2013) added that there is substantial evidence pointing to energy consumption, as the primary driver behind the rise in CO_2 emissions. Furthermore, Zilio and Recalde (2011) discovered that energy use accounts for roughly 77% of total CO_2 emissions, as virtually every economic endeavor necessitates the direct or indirect use of energy for operation.

The consistent measurement of environmental stress using energy consumption led to the discovery of the EEKC theory (Suri and Chapman, 1998; Luzzati and Orsini, 2009; Ahmed and Long, 2012). The EEKC theory suggests that the early stages of economic development are characterized by increased energy consumption. However, after achieving significant growth, economies work to reduce their carbon footprints by implementing energy policies and regulations that advocate for environmental sustainability, and thus the consumption of modern renewable energies (Ahmed and Long, 2012).

Furthermore, there has been a rising emphasis in recent years on researching the impact of employing renewable energy sources to improve environmental quality. Bolük and Mert (2014) were among the first to incorporate renewable energy as a variable when examining the EKC hypothesis. Numerous studies have confirmed that using renewable energy effectively reduces carbon emissions. This has given rise to the concept of the REKC. This concept of the REKC was originally introduced by Yao *et al.* (2019), who demonstrated a U-shaped relationship between income levels and renewable energy use.

The REKC U-shaped relationship is based on the idea that there is a negative relationship between economic growth and renewable energy consumption in the early phases of development. This is because during this developmental stage, the expense associated with the consumption of modern renewable energy sources such as photovoltaic exceeds that of fossil fuels and traditional renewable biomass energy. As economies continue to expand and approach a specific income per capita threshold, the costs associated with modern renewable energy sources begin to decrease (Gielen *et al.*, 2019). At this point, countries tend to increase their consumption of modern renewable energy to cut carbon emissions and enhance environmental sustainability. However, no study has tested the REKC hypothesis for modern renewable energy consumption (without the traditional use of biomass). Following this line of reasoning, we present our initial hypothesis as follows:

H1. A U-shaped modern renewable energy–environmental Kuznets curve exists in the EAC.

2.2 Financial development and modern renewable energy consumption

Financial development is the improvement in the operations of a bank, capital markets and other financial sectors (Qamruzzaman and Jianguo, 2020). This advancement signifies improved stability and effectiveness of financial systems, encompassing initiatives to bolster banking, stock and bond market operations (Anton and Nucu, 2020). Notably, it entails reduced financial risk, heightened transparency, lowered borrowing costs and facilitated capital access (Sadorsky, 2010). However, the investigation of the effect of financial development on modern renewable energy consumption remains limited. Therefore, the study draws insights from a broader literature on aggregate renewable energy consumption to elucidate the effect of financial development on modern renewable energy consumption.

For instance, Lin *et al.* (2016) used the Johansen cointegration technique and vector error correction model to study the important factors influencing the consumption of renewable electricity in China between 1980 and 2011. Their results underscore the favorable enduring effect of financial advancement on the utilization of renewable electricity. Similarly, Ahmed (2017) examined the connection between financial development and renewable energy consumption using panel data from 1991 to 2013. Regardless of the measures employed, the research affirmed a persistent and positive connection between financial development and the consumption of renewable energy within the BRICS nations.

In Pakistan, from 1972 to 2014, Roubaud and Shahbaz (2017) discovered a feedback link between financial growth and the consumption of renewable energy. In contrast, Nkalu *et al.* (2020) detected one-way causality running from financial development to the consumption of renewable energy in sub-Saharan African nations during 1975–2017. Whereas Burakov and Freidin (2017) found no link between the two in Russia from 1990 to 2014.

Beyond the focus on Granger causality, other studies have delved into the short- and long-term impacts of financial development on renewable energy consumption. Bass (2018) demonstrated that financial advancement positively influenced electricity consumption in Russia during 1990–2016. Similarly, Razmi *et al.* (2020) found that stock market development as a measure of financial development has a long-run positive effect on the consumption of renewable energy in Iran, using the ARDL estimation technique. Razmi *et al.*'s (2020) findings

were not any different from Shahbaz *et al.*'s (2021) in middle-class developing nations between 1994 and 2015, using the fully modified OLS (FMOLS) method.

Nonetheless, the findings were somewhat different between various indicators of financial development in EU countries (Anton and Nucu, 2020). Utilizing the panel fixed effects model, they discovered that between 1990 and 2015, the growth of the banking industry and the bond market had an advantageous effect on the use of renewable energy in Europe, although the growth of the capital market had no effect on it. In addition, when employing the ARDL-PMG technique, Wang *et al.* (2021) found that renewable energy consumption was influenced by economic growth and not financial development in China and Western China.

Therefore, insights from the literature suggest that financial development is important for understanding renewable energy consumption. However, these findings are inconclusive. Furthermore, no study has investigated the same considering modern renewable energy consumption (without the traditional use of biomass). And we believe that.

H2. Financial development positively affects modern renewable energy consumption in the EAC.

2.3 Control variables

To address the issue of variable omission bias, which is expected to have an unfavorable effect on the computed coefficients, this study employed the control variables of governance, urbanization, trade openness and FDI on modern renewable energy consumption (Bartov *et al.*, 2000). Good governance is crucial for developing environmental laws that encourage the utilization of renewable energy (Mahmood, 2021). For example, in Asian nations, it was found that good governance positively influenced renewable energy consumption between 1990 and 2016 (Kumaran *et al.*, 2020). Amoah *et al.* (2022) did point out that low levels of renewable energy use are connected with bad governance in African nations. In addition, Asongu and Odhiambo (2021) showed a negative connection between governance and the usage of renewable energy in sub-Saharan African nations.

Urbanization is recognized as a significant factor influencing renewable energy consumption. O'Neill *et al.* (2012), Liu *et al.* (2017) and Akintande *et al.* (2020) identified urbanization as a key factor of energy consumption in India, China and among populous African countries. Similarly, FDI, which is a critical means of transferring renewable energy resources, skills and expertise into a country's economy, has been examined in various aspects of renewable energy consumption (Ankrah and Lin, 2020; Anton and Nucu, 2020). However, the findings were inconclusive.

Finally, trade openness affects renewable energy consumption differently in developed and developing nations. In developed countries, trade openness promotes the consumption of renewable energies (Alam and Murad, 2020; Li *et al.*, 2020). By contrast, in developing countries, trade openness has been found to have a mitigating effect (Kwakwa *et al.*, 2020; Kumaran *et al.*, 2020). It is worth noting that previous research has predominantly focused on aggregate renewable energy usage, while this study specifically examines modern renewable energy consumption.

3. Model specification, data and estimation strategy

3.1 Model specification

The theoretical foundation model used for this study was derived primarily from the REKC (Yao *et al.*, 2019). The following is the general specification for evaluating various EKC types:

$$E = f\left(GDP, GDP^2, Z\right) \tag{1}$$

where E denotes environmental pressure, GDP represents gross domestic product, GDP^2 represents gross domestic product squared and Z represents other variables. In this study, modern renewable energy consumption was taken as the measure of environmental pressure; thus, the modern renewable energy-environmental kuznets curve (REKC) is expressed in expanded form with other variables (Pablo-Romero and De Jesús, 2016).

$$MREC = f\left(GDP, GDP^2, FD, GOV, URB, TOP, FDI\right) \tag{2}$$

where MREC represents modern renewable energy consumption, GDP denotes economic growth or gross domestic product, GDP^2 is the gross domestic product squared for endorsing the presence of the modern REKC assumption in the model, FD represents financial development, GOV represents governance, URB represents urbanization, TOP represents trade openness and FDI represents foreign direct investment. We then convert our equation into a panel log format to generate Eq. (3),

$$lnMREC_{it} = \mu_{it} + \alpha_1 lnGDP_{it} + \alpha_2 lnGDP_{it}^2 + \alpha_3 InFD_{it} + \alpha_4 InGOV_{it} + \alpha_5 InURB_{it} + \alpha_6 InTOP_{it} + \alpha_7 InFDI_{it} + \varepsilon_{it} \tag{3}$$

where μ is the intercept or the constant in the model, countries of the panel are indicated by i, $i = 1 \ldots 5$ and time series by t, $t = 1996 \ldots 2019$. ε_{it} is the stochastic error term. The REKC exists when $\alpha_1 < 0$ and $\alpha_2 > 0$, that is, when parameters change from negative to positive values (Mahmood *et al.*, 2021). Hence, the significant negative and positive coefficients of GDP and its squared term, respectively, would provide confirmation for the U-shaped modern REKC hypothesis as outlined in Equation (3).

3.2 Data

3.2.1 Dependent variable. This study focuses exclusively on modern renewable energy consumption, distinguishing itself from previous studies that consider it as a whole. Modern renewable energy includes non-carbonated energies like solar, hydro, wind and geothermal (Bhattacharyya, 2019; Yilanci and Gorus, 2021). The study's primary variable of interest is MREC, which is quantified as the proportion of modern renewables in total final energy consumption (percentage), excluding the traditional use of biomass (IEA, 2022).

3.2.2 Independent variables. The explanatory variables include economic growth which was measured by GDP per capita (GDPPC) in current US$ (Kwakwa and Aboagye, 2014). The GDPPC was squared to investigate the presence of the REKC hypothesis. This study expects a U-shaped relationship between GDPPC, its squared value and modern renewable energy consumption.

Financial development (FD), the other explanatory variable, is represented by bank credit to bank deposits (Wu and Broad Stock, 2015), financial system deposits to GDP% (Raza *et al.*, 2020), domestic credit to private sector % of GDP (Rafindadi and Ozturk, 2016; Shabaz *et al.*, 2021) and deposit money banks and other financial institutions' private credit to GDP (%) (Khan *et al.*, 2021; Shahbaz *et al.*, 2021). To overcome the multicollinearity problem that may arise from using all the indicators, a composite index was constructed from them using the principal component analysis (PCA) technique (Anton and Nucu, 2020; Kassi *et al.*, 2020). This enabled us to find the overall impact of financial development on MREC of the EAC. This study expects a positive relationship between financial development and MREC.

To overcome omitted variable bias, other variables were also included in this study. These include governance, urbanization, trade openness and FDI. At the macro level, governance is

evaluated using six key metrics: voice and accountability, political stability, corruption control, government effectiveness, regulatory quality and the rule of law (World Governance Indicators, 2022). To address the potential issues of multicollinearity arising from the use of all these governance indicators, we created composite indices through principal component analysis (PCA) (Asongu and Nnanna, 2019; Kassi *et al.*, 2020). This allowed us to assess the overall impact of governance on MREC of the EAC. Our study anticipates a positive association between governance and MREC in the EAC.

Urbanization (URB) is defined as the percentage number of people living in urban areas out of the total population. It is measured by the annual growth rate of the urban population (Kwakwa *et al.*, 2020; Salim and Shafiei, 2014). This study anticipates a positive relationship between the increase in urban population and MREC because grid-based electricity is predominantly available in the urban areas of the EAC.

Trade openness was determined by summing the country's exports (% GDP) and imports (% GDP) (Kumaran *et al.*, 2020). A favorable affiliation is expected between trade openness and MREC. This expectation results from the fact that trade openness makes it easier for countries to acquire renewable energy technologies, potentially encouraging the uptake of modern renewable energy sources.

FDI occurs when a foreign entity or another nation holds ownership control over a business within a host country. This was quantified as the net inflow of FDI % of GDP (Kumaran *et al.*, 2020). We expect a positive affiliation between FDI and MREC. This expectation arises from the fact that FDI is linked to the transfer of technology into the EAC, which may encompass modern renewable energy technologies.

The aforementioned data were obtained from the World Bank, World Development Indicators (WDI) (2022) for most variables, except for modern renewable energy consumption, financial development and governance measures, which were obtained from the International Energy Agency (IEA) (2022), World Bank's Global Financial Development Database (2022) and World Governance Indicators (WGI) (2022) databases, respectively. All variables were converted into natural logarithms and checked for multicollinearity before the data analysis. Since the variance inflation factor (VIF) results for all variables were below 10 (as shown in Appendix Table A1), multicollinearity among the variables was ruled out, in accordance with Studenmund (2001).

3.3 Estimation strategy

The dynamic panel ARDL approach by Pesaran *et al.* (2001) was used to evaluate the relationships between the variables. The ARDL model detects the long- and short-term relationships between variables. The ARDL model also avoids endogeneity problems by taking into account the lag length of the response and explanatory variables. The study applied the ARDL-PMG approach, which assumes that only the long-term coefficients are identical, while acknowledging noticeable deviations in the error variances and short-run coefficients (Pesaran *et al.*, 1999). A Hausman test to determine the most suitable estimator was conducted.

However, before applying the ARDL panel model estimator, we had to assess whether the variables are stationary by carrying out unit-root tests. Establishing the stationarity of the data is a very important concept that helps to know whether the data are stable. If the data are not stable, then we may have to transform it by differencing in order to make it stable. Panel unit root tests of Im *et al.* (IPS) (2003), Phillips and Perron (PP) (1988) and Augmented Dickey and Fuller (ADF) (1979) were employed.

Once the stationarity of the variables has been identified, the long-term relationship between the variables is derived through cointegration tests. Nguyen and Kakinaka (2019) note that Pedroni's (1999, 2004) cointegration test is widely employed in research because it provides model heterogeneity. In this study, we utilized the panel cointegration tests

developed by Pedroni (1999, 2004) and Kao (1999). The Pedroni tests accommodate variations among each member of the panel, encompassing differences in the long-term cointegration vectors and dynamics. Thus, Pedroni permits different intercepts and slopes. The Kao (1999) test adopts a methodology similar to the Pedroni tests, but it delineates intercepts specific to each cross-section while maintaining uniform coefficients on the first-stage regressors. Having confirmed the long-term association among the variables, we employ the ARDL model to obtain short- and long-term estimates between the study variables (Al-Mulali *et al.*, 2013). The ARDL model (p, q) is indicated here, "p" and "q" are the response and explanatory variable lags, respectively.

$$\Delta Y_{it} = \mu_i + \beta_i Y_{i,t-1} - \alpha X_{it} + \sum_{j=1}^{p-1} \lambda_{ij}^{*} \Delta Y_{i,t-j} + \sum_{l=0}^{q-1} \delta_{il}^{*'} \Delta X_{i,t-l} + \varepsilon_{it} \tag{4}$$

where Δ stands for difference operator, Y_{it} stands for the response variable, X signifies the explanatory variables, λij, and δil are short-run coefficient vectors, together with the lagged response variable Y_{it-j} and the independent variables $X_{i,t-l}$, while β_i represents the coefficient pertaining to the speed of adjustment for modern renewable energy to the long-term status, and α represents the long-term estimates of the lagged independent variables X_{it}. Then, p and q denote the lags for the response and explanatory variables, respectively, μ_i is a constant and ε_{it} stands for the error term.

The specific ARDL model adopted in this study, including its dependent and independent variables, is presented as follows:

$$\begin{aligned}
\Delta lnMREC_{it} = {} & \mu_{it} + \beta lnMREC_{i,t-1} + \alpha_1 lnGDP_{it} + \alpha_2 lnGDP_{it}^2 + \alpha_3 lnFD_{it} + \alpha_4 lnGOV_{it} \\
& + \alpha_5 lnURB_{it} + \alpha_6 lnTOP_{it} + \alpha_7 lnFDI_{it} + \sum_{j=1}^{p-1} \lambda_{ij}^{*} \Delta lnMREC_{i,t-j} \\
& + \sum_{l=0}^{q-1} \delta_{1l}^{*'} \Delta lnGDP_{i,t-l} + \sum_{l=0}^{q-1} \delta_{2l}^{*'} \Delta lnGDP_{i,t-l}^2 + \sum_{l=0}^{q-1} \delta_{3l}^{*'} \Delta lnFD_{i,t-l} \\
& + + \sum_{l=0}^{q-1} \delta_{4l}^{*'} \Delta lnGOV_{i,t-l} + \sum_{l=0}^{q-1} \delta_{5l}^{*'} \Delta lnURB_{i,t-l} + \sum_{l=0}^{q-1} \delta_{6l}^{*'} \Delta lnTOP_{i,t-l} \\
& + \sum_{l=0}^{q-1} \delta_{7l}^{*'} \Delta lnFDI_{i,t-l} + \varepsilon_{it}
\end{aligned} \tag{5}$$

4. Empirical results and discussion

4.1 Principal component analysis (PCA)

We obtained composite governance indices and a financial development index by employing a PCA. The PCA outcomes are shown in Tables 1 (governance) and 2 (financial development). Two principal components of governance (GOV) with eigenvalues of 3.99 and 1.12 greater than 1, and accounting for 85.4% (66.7% plus 18.7%) of the variance in the original indicators of governance, were chosen. One principal component of financial development (FD) with eigenvalues of 3.24 greater than 1, accounting for 81% of the variance in the original indicators of financial development was, chosen. These component indexes explain up to 85.4% of the information on governance and 81% of the information on financial development, which is above 80% and is considered to describe the data well (Tarverdi *et al.*, 2019) (see Table 1 and Table 2).

4.2 Cross-sectional dependence

The results of the cross-sectional dependence tests are presented in Table 3. The Breusch-Pagan LM test was deemed appropriate for assessing cross-sectional dependence because the sample years are more than the cross-sections in this study (Breusch and Pagan, 1980). The Pesaran CD test by Pesaran (2004) was also utilized for robustness check. Both tests did not reject the null hypothesis and showed that the cross-sectional residuals were independent. A *p*-value above 0.05 implies that no indication of cross-sectional dependence among the variables under investigation exists. As a result, Im *et al.* (IPS) (2003), Phillips and Perron (PP) (1988) and augmented Dickey and Fuller (ADF) (1979) first-generation panel unit root tests are suitable for producing credible results.

4.3 Unit root tests

Table 4 demonstrates the outcomes of the unit root tests and indicates that all variables exhibit stationarity either at levels or first difference. At levels, only three variables are stationary in the Im, Pesaran and Shin test (LNMREC, LNFDI and LNURB) and Phillips and Perron test (LNMREC, LNFDI and LNGOV). Four are stationary at levels for the augmented Dickey and Fuller test (LNMREC, LNFD, LNFDI and LNURB). However, they all became stationary after the first difference. Therefore, panel ARDL analysis is a viable option for deriving the short- and long-run elasticities of the model. However, the long-term cointegration relationships between the variables must be determined.

Table 1. Principal component analysis-governance

Principal components	Eigenvalues	Percentage of variance extracted	Cumulative percentage of variance extracted
Comp1	3.999	0.667	0.667
Comp2	1.119	0.187	0.853
Comp3	0.439	0.073	0.926
Comp4	0.245	0.042	0.968
Comp5	0.124	0.021	0.989
Comp6	0.069	0.012	1.000

Source(s): Authors' computation

Table 2. Principal component analysis – financial development

Principal components	Eigenvalues	Percentage of variance extracted	Cumulative percentage of variance extracted
Comp1	3.237	0.809	0.809
Comp2	0.691	0.173	0.982
Comp3	0.061	0.015	0.997
Comp4	0.011	0.003	1.000

Source(s): Authors' computation

Table 3. Cross-sectional dependence results

Test	Statistic	Prob
Breusch-Pagan LM	14.273	0.161
Pesaran CD	0.143	0.886

Source(s): Authors' computation

Variable	Im, Pesaran and Shin (IPS) I(0)	Im, Pesaran and Shin (IPS) I(1)	Fisher ADF I(0)	Fisher ADF I(1)	Fisher PP I(0)	Fisher PP I(1)
LNMREC	−1.697**	–	3.687***	–	17.284***	–
LNFD	−1.021	−5.372***	2.065**	–	1.118	46.879***
LNGDP	1.777	−3.632***	−1.504	8.345***	−1.282	7.576***
LNGDPSQ	1.966	−3.383***	−1.641	7.107***	−1.509	7.785***
LNFDI	−1.886**	–	2.120**	–	5.298***	–
LNTRADE	1.176	−5.901***	−0.682	12.997***	−0.653	15.450***
LNGOV	−0.570	−6.635***	0.615	17.018***	1.493*	–
LNURB	−4.785***	–	19.262***	–	−0.765	3.541***

Note(s): IPS (Im, Pesaran and Shin), Fischer ADF (augmented Dickey and Fuller) test, Fischer PP (Phillips and Perron) test, *, ** and ***represent significance at the 10, 5 and 1% levels, respectively. (For Fischer ADF and Fischer PP, we report the modified inv. chi-squared statistics)
Source(s): Authors' computation

Table 4.
Panel unit root test

4.4 Cointegration test results

Table 5 reports the outcomes of the cointegration tests. The Pedroni (1999, 2004) test results show three separate statistical tests: modified Phillips-Perron, Phillips-Perron and augmented Dickey-Fuller (ADF). The null hypothesis of no cointegration in the panel is rejected, with all three statistics at the 99% significance level. Similarly, in the results of the Kao (1999) tests, the null hypothesis of no cointegration in the panel is rejected, with all five statistics at the 99% significance level. The cointegration tests show a long-term relationship between variables.

4.5 Estimation results

After successfully identifying panel cointegration among the variables, we estimated the short- and long-term elasticities among the variables. However, before proceeding to the formal modeling of MREC, we performed diagnostics, including heteroskedasticity and normality tests, to ensure the model's dependability. The results are presented in Table A2 of the Appendix. The different outcomes for the diagnostic tests designate that the null hypothesis of heteroskedasticity and normality are rejected. This implies that the data are not heteroscedastic and are normally distributed. Hence, the data can be relied upon to provide reliable results.

Statistics	Value	*p*-value
Pedroni test		
Ho: no cointegration – Ha: all panels were cointegrated		
Modified Phillips-Perron regression	2.423	0.008***
Phillips-Perron regression	(4.341)	0.000***
Augmented Dickey-Fuller regression	(4.030)	0.000***
Kao test		
Ho: no cointegration – Ha: all panels were cointegrated		
Modified Dickey-Fuller t	−8.811	0.000***
Dickey-Fuller t	−5.687	0.000***
Augmented Dickey-Fuller t	−5.837	0.000***
Unadjusted modified Dickey-Fuller t	−8.949	0.000***
Unadjusted Dickey-Fuller t	−5.701	0.000***

Note(s): ***Represents significance at the 1% level. The null and alternative hypotheses were Ho and Ha, respectively
Source(s): Authors' computation

Table 5.
Cointegration tests

We estimated the model using both the ARDL-PMG and ARDL-MG estimators to explore the existence of the modern REKC hypothesis and the effect of GDP per capita, financial development, governance, urbanization, trade openness and FDI on MREC in selected EAC nations. The outcomes are presented in Tables 6 and 7, respectively.

To choose the most appropriate estimator between ARDL-PMG and ARDL-MG estimators, we applied the Hausman test by Hausman (1978). The p-value results were 0.0648, which is greater than 0.05, indicating that ARDL-PMG was the most accurate estimator. Consequently, only the PMG results were considered and interpreted.

Table 6 presents the ARDL-PMG short-run findings on the impact of GDP per capita, GDP per capita squared, financial development, governance, urbanization, trade openness and FDI on the MREC in five selected countries in the EAC. First, the REKC hypothesis is not supported for any country in the short run. This is because the transition from traditional renewable and fossil fuel energy consumption to MREC is a long-term process (Yao *et al.*, 2019).

Furthermore, the results in the short run indicate that a 1% increase in GDPPC raises MREC in Kenya by 9.5%. This implies that as GDPPC increases in Kenya, which leads to greater attainment of income by individuals and businesses, they find it more appropriate to invest in modern renewable energy technologies. This finding agrees with findings of Bass (2018) in Russia but contradicts findings of Akpanke *et al.* (2023) in West African countries. However, the study in West Africa looked at renewable energy consumption in aggregate, whereas the current study only considered modern renewable energy, excluding the traditional use of biomass. Still in the short-run, the study revealed that a 1% increase in financial development leads to an increase in MREC in Burundi by 0.09%, and in Kenya by

Table 6.
Short-run estimation results

	Pooled mean group (ARDL-PMG)					
Variables	EAC coefficient	Burundi coefficient	Kenya coefficient	Rwanda coefficient	Tanzania coefficient	Uganda coefficient
LNTRADE	−0.174	−0.017	0.483	−1.380	0.030	0.014
LNFDI	0.036	0.030**	0.027	0.131*	−0.001	−0.004
LNGDPPC	0.166	−3.943	9.535*	−4.181	0.109	−0.687
LNGDPPCSQ	0.122	0.960	−1.345	0.849	−0.004	0.152
LNFD	0.005	0.087*	0.133**	−0.134	0.001	−0.063***
LNGOV	−0.037	−0.077***	0.113	−0.262***	0.020*	0.021
LNURB	−1.803	−0.900**	−7.768***	0.409***	0.041	−0.796***
ECT_{t-1}	−0.472***	−0.206***	−0.752***	−0.352***	−0.065***	−0.987***

Note(s): ***, ** and *denote statistically significant levels at 1, 5 and 10%, respectively
Source(s): Authors' computation

Table 7.
Long-run estimation results

Variables	Coefficient	Std. Error
LNTRADE	−0.337***	0.104
LNFDI	−0.064*	0.037
LNGDPPC	−2.146**	0.837
LNGDPPCSQ	0.351**	0.155
LNFD	0.135***	0.018
LNGOV	−0.065	0.056
LNURB	−0.630***	0.121

Note(s): ***, ** and *denote statistically significant levels at 1, 5 and 10%, respectively
Source(s): Authors' computation

0.13%, which is in agreement with Wang *et al.* (2021) in China, Prempeh (2023) in Ghana and Rafindadi and Ozturk (2016) in Japan. However, in Uganda, an increase in financial development instead reduces MREC by 0.06%. This may be due to the substantial initial investment required for modern renewable energy technology projects. Thus, even if financial development leads to increased access to capital, these costs remain prohibitive for many individuals and businesses in the short run.

Furthermore, a 1% improvement in governance leads to a 0.02% increase in the MREC in Tanzania. However, a 1% improvement in governance leads to a reduction in MREC in Burundi by 0.08% and Rwanda by 0.26%. Tanzania is the only country in the EAC where governance supports MREC in the short run. This might be because Tanzania outperforms its neighboring nations in terms of transparency, accountability and civil rights (USAID, 2023).

Urbanization significantly increases MREC in Rwanda but reduces it in Burundi, Kenya and Uganda. Technically, a 1% increase in urbanization increases MREC in Rwanda by 0.41%, and decreases the MREC in Uganda, Burundi and Kenya by 0.8%, 0.9 and 7.8%, respectively. This implies that even as people move to urban centers where the grid can be easily accessed in the EAC countries, they continue to consume traditional renewables, such as charcoal and firewood, especially in Kenya, where the reduction is higher. This is mainly because the urban population cannot afford modern renewable energy in the short term.

Finally, in the short run, a 1% increase in FDI increases MREC by 0.03% in Burundi and 0.13% in Rwanda. This indicates that foreign direct investors in Rwanda and Burundi bring in capital that supports modern renewable energy projects compared to other EAC countries. This finding contradicts those by Tariq *et al.* (2023), which was conducted in China's Belt and Road Initiative (BRI) countries. However, their study considered renewable electricity consumption and not the wide spectrum of MREC, as in the current study.

Based on the ECT values, the correction of shocks and deviation of variables from the short- to the long-run equilibrium is done at a considerable rate of 99% (Uganda), 75% (Kenya), 35% (Rwanda), 21% (Burundi) and 6% (Tanzania) within a year.

In Table 7, the results reveal that GDP per capita, although significant, negatively influences MREC in the long term, whereas GDP per capita squared positively influences it. A 1% growth in the economy (LNGDPPC) results in a decrease in the LNMREC by −2.14%, whereas a 1% increase in economic growth squared (LNGDPPCSQ) results in an increase of LNMREC by 0.35%. This outcome confirms the U-shaped modern REKC hypothesis. This conclusion can be explained as follows: as a country grows, MREC decreases as non-renewable and inexpensive traditional renewable energy use increases. This is because governments are more concerned with development and industrialization than with environmental quality at this moment. However, as a country advances in development, it becomes increasingly concerned about the environment and the health of its population. As a result, it begins to argue for lower carbon emissions, which utilizes MREC rather than traditional renewable and nonrenewable energy sources. Our findings agree with Zhao and Luo (2017) in China and Yao *et al.* (2019) among developed and developing countries, who discovered that the consumption of renewable energy was negatively affected by GDP but positively affected by its square. However, this study contradicts Pablo-Romero and De Jesús's (2016), who found that the REKC was not supported in the Caribbean and Latin America. Hence, governments in EAC member states should back initiatives to boost GDP along with MREC. The governments can subsidize the costs of modern renewable energies and make them accessible and affordable so that households and industries can afford to use them, and not the traditional biomass and non-renewables that have negative environmental and health impacts.

It was revealed that financial development positively and significantly influences MREC in EAC. Thus, a 1% improvement in financial development will improve MREC by 0.13% in the long run. This is not surprising since the production of modern renewable energy requires huge investment. Therefore, a deep and well-structured financial system enables EAC countries to make the consumption of modern renewable energy possible. These

discoveries align with those of Khan *et al.* (2021), among the 69 countries of the "Belt and Road Initiative." They also correspond with studies by Prempeh (2023) in Ghana and Shahbaz *et al.* (2021) among developing countries with high and moderate incomes. However, they contradict with Raza *et al.*'s (2020) study in the low financial development regime countries. Nonetheless, this study considered MREC (without the traditional use of biomass). As a result, the EAC governments should promote the development of green financial systems through legislation and financial and monetary policies that encourage the use of modern renewable energy.

On the other hand, urbanization has a major and detrimental impact on the MREC in the long run. In technical terms, a 1% increase in urbanization will lead to a 0.63% reduction in MREC. This implies that an increase in the urban population of EAC countries does not lead to an increase in the MREC. Even as there is easy access to modern renewable energy due to the extended hydroelectricity grid in urban centers, it remains expensive for the urban population. Therefore, the population in urban areas may increase but still consume dirty energy sources such as charcoal in EAC countries. Indeed, this finding agrees with earlier studies (e.g. Salim and Shafiei (2014) in OECD countries, but contradicts with studies by Akintande *et al.* (2020), Mehrara *et al.* (2015) and Kumaran *et al.* (2020) who found urbanization as a main cause of increased renewable energy consumption. However, these studies examined renewable energy in total, including the traditional use of biomass, which is not the case in the current study. Thus, as a solution, governments and pertinent domestic institutions should establish income-generating initiatives aimed at urban residents, enabling them to enhance their earnings and access modern renewable energy options.

Trade openness and FDI exhibited negative significant impacts on MREC in the long run as shown in Table 7. Technically, a 1% increase in LNTRADE reduces LNMREC by 0.34% and a 1% increase in LNFDI reduces LNMREC by 0.06%. The negative influence of trade openness has to do with the fact that even as trade openness is associated with the importation of clean, renewable technology into the EAC, most of it that comes in is counterfeit, which discourages the utilization of modern renewable energies. Therefore, there is a need for the EAC governments to come up with the agreed standards for the renewable energy products to be imported into the region. However, this finding agrees with Kumaran *et al.* (2020), who conducted research in selected Asian nations, and Adom and Kwakwa (2019) in Ghana, but disagrees with Qamruzzaman and Jianguo (2020), who conducted research in countries at different levels of development, and Alam and Murad (2020) who conducted research in 25 OECD countries.

Similarly, although numerous foreign companies have invested in the modern renewable energy sector within the EAC, such as SolarNow and M-kopa, there is still a lack of awareness about modern renewable sources, particularly solar energy, and their potential in the region. Many potential customers in the area perceive solar energy as being limited in power and suitable only for meeting low-energy needs, such as lighting and charging phones. This finding contrasts with studies by Shahbaz *et al.* (2020) and Kutan *et al.* (2018), which focused on emerging market economies like China, South Africa and India. Although these studies considered aggregate renewable energy consumption, including the traditional consumption of biomass, the current study considered MREC (without the traditional use of biomass). Consequently, the government should prioritize the need to cultivate modern renewable energy awareness as well as effective policies to attract FDI and promote the consumption of modern renewable energy by EAC countries.

5. Conclusions and policy recommendations

Using the REKC model and panel data for a sample of five EAC nations, this study investigates the relationship between MREC and economic growth. Other elements like

financial development, urbanization, governance, FDI and trade openness, as well as their influence on MREC, were investigated.

The findings confirm the existence of the U-shaped modern REKC hypothesis among countries in the EAC region. Additionally, financial growth has a substantial positive impact on MREC, whereas GDP per capita, urbanization, trade openness and FDI have a major negative impact on it in the long run. The long-run elasticity results also reveal that governance is not significant in influencing MREC in the EAC.

Individual EAC members present mixed data about short-run elasticities; however, the EAC group's short-run elasticities show that none of the characteristics affected modern renewable energy usage.

We provide the following policy recommendations based on the empirical findings. First, we recommend that policymakers in EAC nations prioritize recognizing the impact of financial development in advancing the adoption of modern renewable energy. This is because financial institutions have the potential to provide consistent and ample funding, which can facilitate the growth and technological enhancements of modern renewable energy ventures. Building on this foundation, governments can extend targeted policy assistance, such as offering specialized loans and favorable interest rates, to alleviate the financial barriers associated with the production of modern renewable energy.

Second, despite empirical findings indicating that the overall impact of governance on EAC economies is minimal, it is clear that enhancing governance efficiency significantly affects the adoption of renewable energy sources (Huang *et al.*, 2022; Kumaran *et al.*, 2020). Nevertheless, the Transparency International report for 2021 reveals that governance levels, particularly in terms of corruption control, are exceptionally low in Africa. This suggests that a deliberate effort to enhance governance in these nations could potentially yield favorable outcomes in the MREC (Asongu and Odhiambo, 2021). Therefore, we recommend that policymakers in developing economies consider improving governance as a valuable strategy for promoting the use of modern renewable energy sources.

Third, as urbanization continues to rise in the EAC region, policymakers should advocate cooperation between local authorities, private sector entities and international organizations to harness resources and expertise for the advancement of modern renewable energy. This collaboration can promote awareness of the advantages of modern renewable energy utilization and facilitate income-generating projects to empower urban inhabitants, thereby enabling them to improve their income levels to access modern renewable energy alternatives.

In conclusion, the adoption of modern renewable energy consumption can be fostered when these nations actively engage in the global market. As a result, governments should introduce new policies aimed at stimulating increased levels of both exports and imports within their borders. This entails engaging in negotiations and formalizing trade agreements and treaties with other nations to cultivate advantageous trade partnerships. Such agreements serve to diminish tariffs and quotas, and ensure adherence to quality standards for modern renewable energy products exchanged within the region. Furthermore, the implementation of policies conducive to FDI, including the protection of foreign investors' rights and interests through the enactment of the Foreign Investment Law, can transform the formerly negative impact of FDI on modern renewable energy consumption into a positive and significant force.

The study has the following limitations: it only examined the five EAC countries of Burundi, Kenya, Tanzania, Rwanda and Uganda for 24 years, from 1996 to 2019. This was due to data availability, but future studies may consider more years and more EAC countries. The current study considers modern renewable energy as a whole. Future studies could benefit from examining distinct types of modern renewable energy sources like solar, hydro and wind. This method can provide a more concrete understanding of MREC. Also, future research may focus on the population's educational level and environmental awareness at a macro level.

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Further reading

Rafindadi, A.A., Muye, I.M. and Kaita, R.A. (2018), "The effects of FDI and energy consumption on environmental pollution in predominantly resource-based economies of the GCC", *Sustainable Energy Technologies and Assessments*, Vol. 25, pp. 126-137.

Appendix

Variables	VIF	1/VIF
LNGOV	3.76	0.27
LNFDI	3.00	0.33
LNGDPPC	2.93	0.34
LNFD	2.76	0.36
LNTRADE	2.20	0.45
LNURB	1.19	0.84
Mean VIF	2.64	

Note(s): The VIF values are less than 10, signifying the absence of multicollinearity
Source(s): Authors' computation

Table A1. The multicollinearity results

Test	*p*-value
Heteroskedasticity	0.677
Serial correlation	0.148
Normality	
Normality on e	0.372
Normality on u	0.507

Note(s): All the *p*-values are insignificant, implying the absence of heteroskedasticity, serial correlation and that the variables are normally distributed
Source(s): Authors' computation

Table A2. Diagnostics tests

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