# Macroeconomic Determinants of Energy Consumption in Eastern Africa: An Empirical Analysis Using Panel-ARDL Models

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## Abstract

Energy security is crucial for Eastern Africa's economic prosperity and the improvement of living standards. Exploring the drivers of energy consumption is essential for crafting effective energy policy actions that are aligned with focused developmental goals and leveraging available energy resources. Using the Panel Autoregressive Distributed Lag model, this study examines the short and long-run macroeconomic drivers of energy consumption in Eastern Africa from the period 2000-2021. Results reveal that inflation (i.e. consumer price index) exhibits a short-run negative impact on energy consumption. However, in long term, inflation has a positive relationship with energy consumption. The study also show that population size has a negative short-run effect on energy consumption. However, in long term an increase in population size drives energy consumption in EAC. Moreover, trade openness influences short-run consumption and foreign direct investment impacts long-run consumption. The mechanisms influencing these macroeconomics determinants of energy consumption are discussed. We suggest addressing population trends, inflation crisis, and trade-induced fluctuations in the short run, while fostering an environment conducive to attracting foreign direct investment and controlling inflation in the long run. Achieving regional energy security and economic resilience necessitates a balanced approach that considers both internal and external factors across different timeframes.


**Keywords:** Energy Consumption; Macroeconomic Determinants; Panel Analysis
**JEL Classification Codes**: Q4, E1, O55, C23

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## 1. Introduction

Energy consumption is fundamental to global economic growth and improved living standards (Rahman and Alam, 2021). Access to energy powers industries, drives technological advancements, and enhances quality of life across various sectors, ultimately contributing to increased productivity, job creation, and improved healthcare and education. Recognizing its critical role, international frameworks like the Sustainable Development Goals and the African Agenda 2063 have prioritized sustainable energy practices for inclusive economic growth (Garfias *et al.,* 2022; Leal Filho *et al.,* 2021). The SDGs, for example, aim for universal access to affordable and clean energy by 2030, while the African Agenda 2063 envisions a future of sustainable energy use across the continent (Nhamo *et al.,* 2020). These initiatives underscore the transformative potential of energy for collective progress and well-being. Despite these global aspirations, a significant gap exists between goals and reality, particularly in Africa. While developed regions have made progress towards sustainable energy systems, Africa faces unique challenges. Rapid population growth, urbanization, and industrialization, coupled with economic factors like income disparities and energy poverty, place immense pressure on energy resources (Asghar *et al.,* 2024; A. Khan *et al.,* 2020).

Existing research highlights the critical link between energy policy and economic growth in Africa, emphasizing the need for tailored solutions (Ojo *et al*., 2020; Vanegas Cantarero, 2020). Therefore, the policy decisions and actions must address these unique regional factors, including uneven energy consumption and persistent poverty, to ensure equitable access to energy resources and support sustainable economic growth. Energy consumption has profound economic implications at both the macro and micro levels, impacting GDP, employment, trade, and sustainability goals (Nkoa *et al.,* 2023). Policymakers must therefore, consider these wide-ranging effects, including the impacts on households and businesses, when crafting energy policies. This is particularly crucial in Africa, where the population is projected to double by 2050, necessitating a significant increase in energy production to meet future demand (Morris *et al.,* 2023). In the Eastern Africa, experiencing rapid economic growth and urbanization, exemplifies this urgency (Horvat *et al.,* 2021; Namahoro *et al.,* 2021; Sorensen, 2020). Factors like industrial expansion, agricultural intensification, and rising living standards are driving up energy consumption at an unprecedented rate (Sun *et al.,* 2022; Takase *et al.,* 2021; Bishoge *et al.,* 2020), placing immense strain on existing energy infrastructure (Aquilas *et al.,* 2024; Gillespie and Schindler, 2022).

Further, regional collaborations, such as the Eastern African Community, are crucial for creating a supportive environment for effective energy policy actions and fostering innovation (Amir and Khan, 2022; Takase *et al.,* 2021). Thus, understanding the factors driving energy consumption in Eastern Africa offers valuable insights and strategies applicable not only within the region but also in other rapidly developing areas across Africa. This study, therefore establishes two main objectives; to identify the internal and external factors influencing energy consumption in Eastern Africa and ascertain their short-run and long-run impacts. It hypothesize that internal factors, specifically price indices, industrialization, and population growth, have a significant and positive effect on energy consumption in the region. Similarly, it proposes that external factors, including trade openness and foreign direct investment, also positively influence energy consumption growth. Finally, this study seeks to determine the differences between the short-run and long-run effects of these internal and external factors.

Accordingly, this study presents novel contributions to the understanding of energy consumption drivers in Eastern Africa. Unlike previous studies, which have typically focused on either internal or external factors in isolation, and often over limited timeframes, this research examines both internal and external factors over both the short and long run. These findings have significant implications for energy policy, infrastructure development, and investment strategies in Eastern Africa, particularly for promoting inclusive economic growth. By revealing energy use over time, this research informs regulatory frameworks and guide investment decisions towards efficient energy allocation. Ultimately, this study serves as a valuable guide for investors and international stakeholders seeking to enhance energy infrastructure and resource management in the region. Subsequent sections present a literature review, methodology, results and discussion, and conclude with insights for future research areas.

## 2. Literature Review

### 2.1 Theoretical Framework

This study integrates dependency theory with an exploration of foreign direct investment (FDI) and trade openness (TRO) to understand the drivers of energy consumption in Eastern Africa. Dependency theory, as discussed by Antunes de Oliveira and Kvangraven, 2023; Jiang and Martek, (2021) and Kang *et al.* (2021), emphasizes how interactions with developed nations shape economic progress in peripheral regions. This study specifically investigates how FDI contributes to increased energy consumption and examines the role of TRO, as discussed by Amoako and Insaidoo, (2021); Cao *et al,* (2020); Wei *et al.* (2020), echoing findings by Alsagr, N., and van Hemmen, Mejia, (2021) on its economic implications.

FDI often leads to improved energy infrastructure and technological advancements, thereby boosting energy consumption (Appiah *et al.*, 2023; Rashed *et al.*, 2022). In Eastern Africa, FDI supports sustainable development goals and the African Union's Agenda 2063, promoting inclusive energy use (Annan-Aggrey *et al.*, 2021; UN, 2018). Similarly, trade openness influences energy consumption; studies by Chen *et al.* (2022); Zhang *et al.* (2021); Aydin and Turan, (2020) show that increased international trade correlates with higher energy demand due to energy-intensive production and transportation activities.

Drawing upon dependency theory, this study also examines internal factors influencing energy consumption in Eastern Africa through systems theory (Chigozie *et al.*, 2024; Ikram *et al.*, 2020). Factors such as price indexes, demographics, and industrialization dynamics interact to shape energy consumption patterns. For example, changes in the Consumer Price Index (CPI) affect industrial production costs and energy use (Celasun *et al.*, 2022; Shahbaz *et al.*, 2021). Industrial growth in Eastern Africa requires substantial energy inputs (Sun *et al.*, 2022; Beyene and Kotosz, 2020), while population growth increases household energy demands, particularly in urban areas (Warsame, 2022; Nathaniel and Adeleye, 2021; Brugger *et al.*, 2021; Ohene-Asare *et al,* 2020). By integrating dependency and systems theories, this study offers a comprehensive analysis of the external and internal factors shaping energy consumption in Eastern Africa.

### 2.2 Empirical Review

This section reviews empirical studies on global and regional energy consumption, providing an in-depth analysis of the diverse factors that influence energy use dynamics. Economic factors, including income levels, industrialization, and overall economic growth, consistently emerge as primary drivers of energy demand across both developed and developing economies. Furthermore, the types of energy sources available and advancements in renewable energy technologies also significantly shape consumption patterns. Demographic and social trends add another layer of complexity. These trends include things like population growth, how fast cities are growing (urbanization), and the human capita; collectively have different effects on energy use in different regions. Critically, policies and institutional frameworks play a big role in shaping how energy is consumed. These include things like how open a country is to trade, foreign direct investment, regulations, and financial development. It's important to note that the impact of these factor change a lot depending on the specific situation and income levels of a region.

**Table 1: Summary of Empirical Works**

| Authors | Countries | Spanning | Methodology | Key Findings |
|---|---|---|---|---|
| Wang *et al.* (2020) | China, USA, India | 1965-2015 | Geographical Detector methods | Coal consumption, GDP per capita, oil consumption with interactions between population changes rates, energy intensity are key determinants of energy consumption growth. |
| Wang *et al.* (2019) | 186 countries in a global spectrum | 1980 - 2015 | Granger causality test to analyze the macroeconomic data in high-income, upper- and lower-middle income groups. | Urbanization's, GDP's, Energy price impact energy consumption and it varies by income groups |
| Ingwen Li *et al.* (2020) | OECD economies | 1990-2017 | Durbin Hausman group mean cointegration, Cross-sectional Autoregressive Distributive Lag, Augmented Mean Group methods | Income, human capital, energy productivity, energy prices, and eco-innovation clarifying renewable energy consumption |
| Dokas *et al.* (2022) | 109 developed & developing countries | 2010 - 2018 | Panel cointegration tests, error correction models | Economic growth, investment, and winter temperature are determinants of energy consumption in developing countries. Whereas, in developed countries are trade openness, corruption, and innovation. |
| Chen *et al.* (2021) | 97 from developed &developing countries | 1995-2015 | Threshold estimation model and democracy score from the Polity IV | Increased trade openness slows down renewable energy growth |
| Papież *et al.* (2018) | 26 EU member states | Mid-1990s - 2014 | Best subset regression, LARS method | The determinants are; energy source distribution, GDP per capita, energy supply concentration, and costs of consumption of energy & Energy consumption per capita |
| J. Li *et al.* (2020) | OECD countries | 1990 - 2021 | CS-ARDL cointegration, Second-generation panel unit root tests | Income, human capital, energy productivity, energy prices, and eco-innovation positively influenced energy consumption |
| Zaharia *et al.* (2019) | 28 EU28 member countries | 1975 - May 2019 | Bibliometric analysis, panel data analysis | Greenhouse gas emissions, GDP, population and labor growth are primary and final energy consumption drivers |
| Fernandes and Reddy, (2021) | China, India, Indonesia, Malaysia, Philippines, Thailand | 1980 - 2018 | OLS Johansen cointegration, Vector Error Correction & Toda Yamamoto test | Industrialization, exchange rate, financial development, and trade openness impact energy consumption and they vary by country |
| Shahbaz *et al.* (2021) | 34 developing countries | 1994 - 2018 | Panel unit root, pedroni & Kao cointegration, FMOLS estimation | Resource availability, technology maturity, and market rules drive renewable energy consumption |

| | | | | |
|---|---|---|---|---|
| Polcyn *et al.* (2022) | Ten European countries | 2000 - 2018 | Panel fixed effects, random effects, GMM, weighted least squares) | GDP per capita drives renewable energy consumption, whereas labour force, capital formation, and CO2 intensity are inverse related |
| Canh *et al.* (2021) | 115 economies | 1991 - 2014 | Two-step system GMM & estimations, Stochastic | Income level, urbanization, industrialization, trade openness, FDI, and shadow economy influence energy consumption |
| Paramati *et al.* (2018) | African frontier market economies | Q4 1991 to Q4 2012 | Panel Estimations, Econometric Techniques | Stock market indicators, industrialization, trade openness and foreign direct investment inflows influence energy demand |
| Kwakwa and Poku, (2019) | South Africa | 1975 - 2014 | ADF Test, ARDL Cointegration Test, FMOLS | Urbanization has the least impact on energy intensity. Domestic credit and manufacturing play prominent roles in energy |
| Nyiwul, (2018) | 10 African countries | 2000–2011 | Panel Data Model, Panel Unit Root Tests, Cointegration Methods | Economic growth drive energy consumption |
| Da Silva *et al.* (2018) | 17 Sub-Saharan African countries | 1990–2014 | Panel-ARDL methodology | Economic development, fossil fuel prices, imports, population growth, CO2 emissions per capita and ratification of the Kyoto Protocol influence renewable energy adoption |
| Oluoch *et al.* (2021) | 23 Sub-Saharan African countries | 1998 - 2014 | Panel Autoregressive Distributed Lag; Pooled Mean Group (PMG) | GDP per capita influence renewable energy consumption. |
| Akintande *et al.* (2020) | Five selected African countries | 1996 - 2016 | Bayesian Model Averaging (BMA) | Macroeconomic and socio-economic variables, influence renewable energy adoption in African countries |
| Asratie, (2022) | East African countries, MENA region | 1998 - 2019 | Panel Autoregressive Distributed Lag (ARDL) estimation | GDP per capita growth, population growth, energy consumption per capita, and energy imports affect electricity production |
| Bekun & Alola, 2022) | Sub-Saharan African economies | | Correlation analysis, and Pesaran's Pooled Mean Group Auto Regressive Distributed Lag model | Economic growth and urbanization are drivers of renewable energy consumption |

To understand these dynamics better, empirical studies use a wide range of econometric techniques. These include time-series analyses like Granger causality and error correction models, panel data approaches such as Durbin Hausman group mean cointegration and cross-sectional ARDL, as well as techniques like Bayesian model averaging. For instance, Wang *et al.* (2020) emphasize how GDP per capita and energy source intensity influence energy consumption trends in China, the USA, and India. Similarly, Wang *et al.* (2019) use Granger causality tests to demonstrate how urbanization and energy prices affect energy use across different income groups globally. In OECD economies, J. Li *et al.* (2020) find that income levels, human capital, and energy productivity are key drivers of renewable energy consumption. In contrast, Akintande *et al.* (2020a) found that population growth, urbanization, and human capital are crucial for adopting renewable energy in African countries like Ethiopia, South Africa, Nigeria, DR Congo, and Egypt. Whereas, Canh *et al.* (2021) consistently examine the impact of income levels, urbanization, industrialization, trade openness, FDI, and the shadow economy on energy consumption across 115 economies. Building upon the key findings from existing studies on energy drivers summarized in Table 1, this study validates their relevance to Eastern Africa by utilizing panel ARDL model and leveraging regional datasets. In due course, the research intentions are to inform targeted energy policy actions and decisions to facilitate the transition towards reliable energy systems in Eastern Africa.

## 3. Data and Methodology

### 3.1 Data and Study Design

This study utilizes panel data from twelve Eastern African countries: Burundi, Comoros, Djibouti, Ethiopia, Kenya, Madagascar, Mauritius, Mozambique, Rwanda, Sudan, Tanzania, and Uganda. These countries were chosen for their diverse socio-economic characteristics within the region. The study covers the period from 2000 to 2021, capturing significant economic growth marked by the transition from the Millennium Development Goals (MDGs) to the Sustainable Development Goals (SDGs). This timeframe provides insights into how global agendas have influenced energy consumption patterns, fostering inclusive economic growth. The era also witnessed substantial technological innovations and a shift towards sustainable energy practices, which have transformed Eastern Africa's energy sector.

**Table 2: Description of Variables**

| **Variables** | **Units of measurement** | **Source** |
|---|---|---|
| Total energy consumption (TE) | Tera Joule | U.S. Energy Information Administration https://www.eia.gov/international/data/world |
| Trade openness (TOR) | Percentage of GDP | World Development Indicators https://databank.worldbank.org/source/worlddevelopment-indicators |
| Consumer Price Indexes (CIP) | 2010 = 100 | World Development Indicators https://databank.worldbank.org/source/worlddevelopment-indicators |
| Industrialization (IND) | Percentage of GDP | World Development Indicators https://databank.worldbank.org/source/worlddevelopment-indicators |
| Population growth (POP) | Percentage of total population | World Development Indicators https://databank.worldbank.org/source/worlddevelopment-indicators |
| Foreign Direct Investment (FDI) | Percentage of GDP | World Development Indicators https://databank.worldbank.org/source/worlddevelopment-indicators |

Data for this study were sourced from the U.S. Energy Information Administration and the World Development Indicators (WDIs), renowned for their comprehensive and reliable information on key variables. Whereas, the variables of interest include energy consumption as the dependent variable, and independent variables such as foreign direct investment, trade openness, consumer price index, industrialization, and population growth. Detailed descriptions are provided in Table 2. This study employs a longitudinal design, using panel data analysis to explore the determinants of energy consumption in Eastern Africa. Panel data analysis is chosen for its capability to capture temporal variations within the region, offering a comprehensive understanding of energy consumption patterns and their drivers. The panel analysis was chosen due to its ability to control for unobserved differences across countries, addressing potential biases present in cross-sectional studies.

### 3.2 Model Specification

This study employed the Panel-ARDL model to analyse both the short-run and long-run macroeconomic determinants of energy consumption in Eastern Africa. Specifically, the corresponding pooled mean group (PMG), mean group (MG), and dynamic fixed effects (DFE) models were applied for estimations. These models are particularly useful in clarifying long-run coefficients linked to the lagged levels of independent variables while capturing short-run dynamics through the inclusion of their lagged differences. Therefore, the estimation equation is operationalized through parameters (p,q), where 'p' signifies the lags of the dependent variable and 'q' symbolizes the lags of the independent variables, as presented in Equation 1.

$$\Delta TE_{it} = \alpha_i + \sum_{k=1}^{p} \alpha_{1,ik}\Delta TE_{i,t-k} + \sum_{k=0}^{q1} \alpha_{2,ik}\Delta(POS) + \sum_{k=0}^{q2} \alpha_{3,ik}\Delta(CPI)_{i,t-k} + \sum_{k=0}^{q3} \alpha_{4,ik}\Delta ln(TRO)_{i,t-k} + \sum_{k=0}^{q4} \alpha_{5,ik}\Delta(FDI)_{i,t-k} + \sum_{k=0}^{q5} \alpha_{6,ik}\Delta ln(IND)_{i,t-k} + \beta_{1,ik}(TE)_{i,t-1} + \beta_{2,ik}POS_{i,t-1} + \beta_{3,ik}CPI_{i,t-1} + \beta_{4,ik}ln(TRO)_{i,t-1} + \beta_{5,ik}FDI_{i,t-1} + \beta_{6,ij}ln(IND)_{i,t-1} + \varepsilon_{it} \quad (1)$$

Where, the Variables with coefficients $\alpha_1$ through $\alpha_6$ represent the short-run, while coefficients $\beta_1$ through $\beta_6$ capture the long-run relationships. The regressors and $\varepsilon_{it}$ is the error term which is assumed to be white noise and varies across countries and time. Panel analysis is reported to have the ability to control for unobserved heterogeneity, offering a significant advantage over cross-sectional studies. After presenting the dynamic relationship equation between the variables, short-run disequilibrium is captured by introducing an error correction term (ECT) in Equation 2.

$$\Delta TE_{it} = \alpha_i + \sum_{k=1}^{p} \alpha_{1,ik}\Delta TE_{i,t-k} + \sum_{k=0}^{q1} \alpha_{2,ik}\Delta(POS) + \sum_{k=0}^{q2} \alpha_{3,ik}\Delta(CPI)_{i,t-k} + \sum_{k=0}^{q3} \alpha_{4,ik}\Delta ln(TRO)_{i,t-k} + \sum_{k=0}^{q4} \alpha_{5,ik}\Delta(FDI)_{i,t-k} + \sum_{k=0}^{q5} \alpha_{6,ik}\Delta ln(IND)_{i,t-k} + \beta_{1,ik}(TE)_{i,t-1} + \beta_{2,ik}POS_{i,t-1} + \beta_{3,ik}CPI_{i,t-1} + \beta_{4,ik}ln(TRO)_{i,t-1} + \beta_{5,ik}FDI_{i,t-1} + \beta_{6,ij}ln(IND)_{i,t-1} + \Theta_i ECM_{i,t-1} + \varepsilon_{it} \quad (2)$$

Where $\Theta_i$ is the coefficient of the error correction term, the optimal lag length of the ECM is determined using Akaike's lag selection criteria, with a maximum lag length of two as specified in table 6.

### 3.3 Descriptive statistics

Table 3 presents the descriptive results of the drivers of energy consumption in Eastern Africa. The average total energy consumption is 10.804, with a standard deviation of 1.523, indicating moderate variability. This suggests relatively consistent energy consumption patterns across the region with a range of 7.364 in Comoros and 12.871 units in Sudan. The consumer price index remains stable, with a mean of 4.643 and a standard deviation of 0.676. This stability in inflationary pressures, ranging from 3.541 in Ethiopia to 9.696 in Sudan, holds critical implications for energy pricing and consumption patterns. Furthermore, the average level of industrialization stands at 17.798, exhibiting variation across countries, ranging from 7.37 in Sudan to 28.67 in Tanzania, which correlates with the differing demands in energy.

**Table 3: Descriptive Statistics**

| Variable | Obs | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| TE | 264 | 10.804 | 1.523 | 7.364 | 12.871 |
| TRO | 264 | 89.949 | 150.285 | 4.13 | 980.19 |
| CPI | 264 | 4.643 | .676 | 3.541 | 9.696 |
| IND | 264 | 17.798 | 5.275 | 7.37 | 28.67 |
| POS | 252 | -.718 | 0.87 | -2.67 | 1.12 |
| FDI | 264 | 3.861 | 5.704 | -.6 | 39.46 |

Demographic trends reveal a decline, with an average growth rate of -0.718. Sudan exhibits the highest decline, while Mauritius experiences the lowest, indicating diverse population trends likely influencing energy consumption patterns. Trade openness displays significant diversity, with an average of 89.949 and a substantial standard deviation of 150.285 units. Lastly, FDI presents a varied economic landscape among countries, with an average of 3.861 and a standard deviation of 5.704. The maximum FDI is observed in Mozambique (39.46), while the minimum is in Mauritius (-0.6), which highlighting disparities in economic conditions. These descriptive results, observed with heterogeneity among entities necessitate analysis techniques that account for heterogeneity in capturing the short and long-run influence of the variables.

### 3.4 Diagnostic Tests

Prior to estimating the Panel ARDL model, a series of diagnostic tests were conducted to ensure the robustness and reliability of the analysis. This involved examining the data for potential multicollinearity among the independent variables and addressing the unique characteristics of panel data, specifically cross-sectional dependence and stationarity. Additionally, the Hausman test was employed to guide the selection between estimators, specifically comparing Pooled Mean Group (PMG) against Dynamic Fixed Effects (DFE) and Mean Group (MG) against DFE, ensuring the appropriate specification for the analysis.

#### 3.4.1 Pairwise Correlations and Multicollinearity Results

Table 4 presents pairwise correlations between macroeconomic variables and energy consumption in Eastern Africa, ranging from weak to moderate. No correlation exceeds 0.8, indicating a satisfactory level of distinction between variables and minimal risk of multicollinearity. Variance Inflation Factors, ranging from 1.06 to 1.3, further confirm low to moderate multicollinearity (Tasnova, 2022; Nathaniel and Adeleye, 2021). All VIF values fall below the threshold of concern, with reciprocal VIFs (0.76682 to 0.942163) and an average VIF of 1.16 further supporting absence of significant multicollinearity. These findings suggest that each predictor contributes independently to the model, enabling confident interpretation of regression coefficients and reinforcing the reliability of identified relationships.

**Table 4: Correlations and Multicollinearity**

| Variables | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| (1) TE | 1.000 | | | | | |
| (2) TRO | -0.203* | 1.000 | | | | |
| (3) CPI | 0.308* | -0.098 | 1.000 | | | |
| (4) IND | 0.554* | -0.351* | 0.156* | 1.000 | | |
| (5) POS | -0.159* | 0.244* | -0.164* | 0.020 | 1.000 | |
| (6) FDI | 0.235* | 0.204* | 0.078 | 0.076 | 0.150* | 1.000 |
| VIF | | 1.3 | 1.06 | 1.2 | 1.12 | 1.1 |
| 1/VIF | | 0.767 | 0.942 | 0.833 | 0.897 | 0.908 |
| Mean VIF | | 1.16 | | | | |

#### 3.4.2 Cross Sectional Dependency and Panel Unit Root Tests

Table 5 presents the cross-section dependency and panel unit root test results using the Breusch-Pagan LM, Pesaran CD, and Friedman's tests, following Voumik, Hossain, *et al.* (2023); Voumik, Mimi, *et al.* (2023); Hongxing *et al.* (2021); Arshad *et al.* (2020). The null hypothesis of no cross-sectional dependence is rejected for all variables, suggesting economic linkages among Eastern African countries, potentially due to spillover or un- observed common factors. Consequently, shocks affecting one country's energy use and economic growth may have spillover effects on others. Given this dependence, second-generation panel unit root tests are employed to examine stationarity, as first-generation tests may yield spurious results.

**Table 5: Cross-Section Dependency and Panel Unit Root Tests**

| Tests | Cross-Section Dependency | | | CIPS Panel Unit Root | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | Level | | First Difference | | |
| Variables | Breusch-Pagan LM | Pesaran CD | Friedman's | Constant | Constant and trend | Constant | Constant and trend | 0rder |
| TE | 996.861*** | 26.686*** | 183.227*** | -1.104 | -1.876 | -2.698*** | -2.781** | I(1) |
| TRO | 433.652*** | 3.122** | 41.101*** | -2.045 | -1.503 | -4.27*** | -4.441*** | I(1) |
| CPI | 1146.377*** | 31.59*** | 216.474*** | 0.193 | 0.252 | -2.056 | -2.726* | I(1) |
| IND | 562.009*** | 0.374 | 16.984 | -1.22 | -2.156 | -3.611*** | -3.802*** | I(1) |
| POS | 212.907*** | -1.943* | 11.506 | -1.973 | -2.229 | -4.368*** | -4.427*** | I(1) |
| FDI | 190.304*** | 3.13** | 48.959*** | -2.842*** | -3.142*** | | | I(0) |

*Note*: Significance levels: *** p<0.001, ** p<0.05, * p<0.1

Given the confirmed cross-sectional dependence, the stationarity properties of the variables were examined using the cross-sectionally augmented IPS panel unit root test, which accounts for cross-sectional dependence by combining the Augmented Dickey-Fuller and Im-Pesaran-Shin tests. Table 5 shows that FDI is stationary at level (I (0)), as indicated by significant negative test statistics at both level and trend. The remaining variables are non-stationary at level but achieve stationarity after first differencing, implying they are integrated of order one (I (1)). The robustness of the CIPS test to cross-sectional dependence enhances the reliability of the subsequent Panel ARDL model, known for its effectiveness with mixed order of variables as supported by Sheikh and Hassan, (2023); Schneider *et al. (*2022); Ahmad *et al.* (2020) and Le, (2020).

### 3.4.3 Hausman Test

The selection of the best model for the panel ARDL analysis was informed by the Akaike information criterion (2 2 2 2 2 2), that dictated the maximum number of lags for each entity. Likewise, to verify the robustness and credibility of the results the study employed Hausman test. When comparing the PMG against DFE estimators, a chi-square statistic of 6.72 with a p-value of 0.243 was obtained. As the p-value surpassed the conventional significance threshold of 0.05, the null hypothesis, which supports the use of PMG over DFE due to lack of correspondence between country-specific effects and the independent variables, was not rejected. This indicates that the PMG estimator is more appropriate for this analysis compared to the DFE. In a similar comparative test between MG and DFE, the chi-square statistic was shown with 0.00 with a p-value of 1.00. Once again, there was no statistical basis to reject the null hypothesis, providing further support for the reliability of panel estimators used in the study and the homogeneity assumption for long-run estimators. These consistent results from the Hausman test support the stability of long-run coefficients across entities. Moreover, the PMG estimator is adept at accommodating entity variations, thus enhancing the reliability of both long-run and short-run estimates. These estimations serve as the cornerstone of the study's conclusions and policy recommendations.

## 4. Results

### 4.1 Error Correction Term

Table 6 presents the results of PMG, MG, and DFE. The ECT coefficients for PMG, MG, and DFE are -0.311, -0.669, and -0.219, respectively, all of which are statistically significant at the 1% level. The negative sign of the ECT coefficients indicates convergence towards long-run equilibrium, suggesting that short-run fluctuations in energy consumption correct themselves over time. The significant ECT coefficients highlight the importance of energy policies that consider the dynamic interplay between short-term shocks and long-term stability in energy consumption. Policymakers should account for the temporary effects of policy measures and develop strategies to maintain balanced energy usage over time.

### 4.2 Short-Run Results

The PMG estimation reveals a statistically significant positive coefficient of 0.00287 at the 10% significance level between trade openness and total energy consumption. This indicates that a one-unit increase in trade openness is associated with a 0.00287 unit increase in energy consumption in the short run. Similarly, the MG estimator shows a statistically significant positive association between industrialization and energy consumption at a 1% significance level, with a coefficient of 0.358. This suggests that a one-unit increase in industrialization is associated with a 0.358 unit increase in energy consumption, implying that industrial expansion is a significant driver of energy consumption in the region. However, it is important to note that the MG model, unlike the PMG model, does not account for country-specific factors that might be influencing both industrialization and energy consumption. These unobserved factors, which could vary significantly from country to country, might explain the variation in results between these models.

**Table 6: ARDL Results Model (2 2 2 2 2 2)**

| | Pooled Mean Group | | Mean Group | | Dynamic Fixed Effect | |
|---|---|---|---|---|---|---|
| Variables | Long Run | Short Run | Long Run | Short Run | Long Run | Short Run |
| Error Correction Term | | | | | | |
| (ECT) | | -0.311*** | | -0.669*** | | -0.219*** |
| | | -0.0417 | | -0.137 | | -0.0382 |
| D.TRO | | 0.00287* | | 0.0016 | | -0.00035 |
| | | -0.00156 | | -0.00193 | | -0.00049 |
| D.CPI | | -0.537*** | | -0.548*** | | -0.449*** |
| | | -0.162 | | -0.209 | | -0.0975 |
| D.IND | | 0.0148 | | 0.0358*** | | 0.00444 |
| | | -0.0103 | | -0.0134 | | -0.00464 |
| D.POS | | -0.0635* | | 0.00224 | | -0.02 |
| | | -0.0367 | | -0.0575 | | -0.0256 |
| D.FDI | | -0.00743 | | 0.00117 | | -0.00126 |
| | | -0.00569 | | -0.00805 | | -0.00252 |
| TRO | 0.000529 | | 0.0676 | | 0.000461 | |
| | -0.00047 | | -0.0651 | | -0.00049 | |
| CPI | 0.642*** | | 1.91 | | 0.521*** | |
| | -0.0398 | | -1.59 | | -0.0628 | |
| IND | -0.00778 | | -0.304 | | -0.0113 | |
| | -0.00631 | | -0.268 | | -0.012 | |
| POS | 0.312*** | | 0.895 | | 0.286*** | |
| | -0.0592 | | -0.917 | | -0.1 | |
| FDI | 0.0117** | | -0.1 | | 0.00786 | |
| | -0.00502 | | -0.117 | | -0.00801 | |
| Constant | | 2.537*** | | 6.145*** | | 1.980*** |
| | | -0.355 | | -1.567 | | -0.322 |
| Number of countries | | 12 | | 12 | | 12 |
| Observations | | 228 | | 228 | | 228 |
| Hausman Test | | 6.72(0.243) | | | | 0.0 (1.000) |

*Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1*

Further, the energy price indexes reveal a statistically significant inverse relationship with energy consumption at a 1% significance level. A one-unit increase in energy prices is associated with a decrease in energy consumption by 0.537%, 0.548%, and 0.449% as estimated by the PMG, MG, and DFE models, respectively. This highlights the influential role of energy prices in shaping consumption patterns in Eastern Africa. Additionally, the analysis reveals an inverse influence between population size and energy consumption at a 10% significance level, with a coefficient of -0.0635. This indicates that a one-unit increase in population size is associated with a 0.0635-unit decrease in per capita energy consumption in the short run. This suggests that rapid population growth might, at least temporarily, lead to a decrease in the average energy consumption per person. This could be attributed to a higher proportion of younger individuals who generally have lower energy consumption patterns, or to short-term constraints in energy infrastructure development that cannot keep pace with the rising population.

### 4.3 Long-Run Results

In the long run, the CPI indicates a statistically significant positive influence on energy consumption at the 1% significance level, across PMG and DFE models, respectively. This relationship suggests that a one-unit increase in CPI leads to a 0.642 and 0.521 rise in energy usage over time, implying the region's energy consumption is sensitive to price changes. This sensitivity potentially highlights the influence of macroeconomic factors such as economic growth, industrial development, or shifts in energy-intensive industries, contributing to a consistent upward trend in energy consumption as the overall price level rises. Similarly, both the PMG and DFE models reveal a statistically significant positive relationship between population size and energy consumption at the 1% significance level. The PMG model indicates that a one-unit increase in population size is associated with a 0.312 unit increase in energy consumption, while the DFE model estimates a 0.286 unit increase. These findings emphasize that population growth in this region is a significant driver of increased energy consumption.

Additionally, the PMG model demonstrates a statistically significant positive relationship between foreign direct investment and energy consumption in Eastern Africa at a 5% significance level. The model estimates that a one-unit increase in FDI is associated with a 0.0117 unit increase in energy consumption. This positive and statistically significant association suggests that FDI plays a role in driving energy consumption trends within the region over the studied period. Lastly, the empirical analysis reveals no statistically significant relationship between industrialization and energy consumption in Eastern Africa, both in the short and long run. However it is better to note that, the variation of significance in these estimations models point to deviations in short-run dynamics across countries, emphasizing the PMG model's strength in capturing long-run equilibrium relationships.

## 5. Discussion

### 5.1 Trade Openness and Energy Consumption

This study found that more trade openness leads to higher energy consumption in the short run. This supports the idea of dependency theory, which suggests that a country's economic growth and development are influenced by its relationships with other countries. When trade increases, it likely boosts energy-intensive activities like transportation and manufacturing, leading to higher energy use. In Eastern Africa, this means increased trade lead to more trucks on the roads, more ships in the ports, and more factories operating; all requiring energy. This finding has important implications for policymakers in Eastern Africa's energy sector. They should prioritize energy efficiency, which could involve updating regulations to promote fuel-efficient vehicles and energy-saving technologies in factories, as well as providing incentives for businesses to adopt these practices.

Similarly, strategic investments in energy infrastructure are crucial. This includes upgrading power grids to handle increased demand and investing in energy storage solutions, such as batteries and pumped hydro, to improve reliability and incorporate renewable energy sources. Our findings align with Ibrahiem and Hanafy, (2021) which found that trade openness promotes renewable energy consumption in North African countries. This connection might exist because increased trade lead to investments in renewable energy infrastructure and technology transfer. However, our results differ from those of Chen *et al.* (2021) who found increased trade openness linked to slower renewable energy growth in less democratic countries. This difference highlights that the relationship between trade and energy is complex and might be influenced by political systems, geographic factors, and a country's institutions.

**5.2 Industrialization and Energy Consumption**

This study reveals that industrialization is a significant driver of short-run energy consumption in Eastern Africa, a finding supported by the MG model. This aligns with global trends observed by Fernandes and Reddy, (2021) and Paramati et al. (2018) highlighting the consistent influence of industrial activity on energy use. Several region-specific mechanisms underpin this short-run relationship. Expanding industrial sectors like manufacturing and mining directly increase energy demand through production processes, machinery operation, and logistics. Furthermore, industrialization necessitates energy-intensive infrastructure development, including factories, industrial parks, and transportation networks. Lastly, the adoption of advanced technologies, while potentially boosting productivity, often increases consumption. However, this study surprisingly finds no significant long-run relationship between industrialization and energy use. This suggests that factors beyond industrialization, such as economic structure and resource availability, are crucial in shaping Eastern Africa's future energy landscape and, consequently, in developing energy policies (Fernandes and Reddy, 2021; Canh *et al.*, 2021). While the MG model is informative for short-run trends, it may not fully capture these country-specific factors influencing industrialization and energy consumption. Therefore, policymakers must balance short-run energy consumption with long-run sustainability goals. This requires integrating energy-efficient practices and technologies into industrial development and promoting a transition away from fossil fuels towards renewable energy sources.

**5.3 Consumer Price Indexes and Energy Consumption**

The revealed findings of an inverse relationship between consumer price indexes and energy consumption in Eastern Africa align with typical market behavior, where higher prices generally lead to reduced consumption. This finding resonates with Wang *et al.* (2019), who demonstrated that energy prices negatively impact energy use in lower-middle-income countries. However, a contrasting trend emerges in upper-middle-income countries, where energy prices positively influence consumption. This deviation might stem from distinct economic dynamics, such as higher income levels enabling consumers to absorb price increases, or energy subsidies that artificially lower costs and weaken price signals (Nyiwul, 2018). In the context of Eastern Africa, the observed inverse relationship between consumer price indexes and energy consumption may be influenced by several mechanisms. Firstly, as Eastern African countries continue to experience economic growth and development, higher consumer prices for energy may lead to increased awareness and adoption of energy-saving practices and technologies among households and businesses.

Secondly, fluctuations in consumer prices may influence investment decisions in the energy sector, with higher prices incentivizing the development and adoption of renewable energy sources and energy-efficient technologies. Additionally, government policies and regulations aimed at managing consumer prices for energy, such as subsidies or tax incentives, can also impact energy consumption patterns in the region. Similar trends are observed in the long run, reflecting the adaptive nature of economic systems in growing economies. Over time, economic agents in the region may adapt to higher prices through investments in energy-efficient technologies or by shifting towards more energy-intensive sectors amidst overall economic growth, leading to increased energy demand. Nyiwul's, assertion that price increases can incentivize consumers to adopt more efficient energy practices holds relevance in this context. These findings underscore the adaptive nature of economic systems, as posited by systems theory. Consequently, policymakers in Eastern Africa should craft energy strategies that consider price alongside energy efficiency and the availability of alternative energy sources to effectively manage energy consumption patterns in this region.

### 5.4 Population Growth and Energy Consumption

The study reveals an interesting contrast in the relationship between population size and energy consumption between the short and long run. In the short run, demographic factors such as a youthful population and limited energy access contribute to a surprising inverse relationship, reducing per capita energy consumption despite overall population growth. This inverse relationship can be explained by several mechanisms. Firstly, a larger proportion of younger individuals typically have lower energy requirements compared to older demographics, which can temporarily dampen per capita energy consumption. Secondly, outdate infrastructure and traditional energy practices prevalent in the region may constrain energy use efficiency, further influencing this relationship. Contrary findings from studies like Zaharia *et al.* (2019) and da Silva *et al.* (2018), which show a positive association between population growth and energy consumption in other contexts, underscore the complexity of these relationships. While contextual factors like income levels and subsidies can influence the relationship, Eastern Africa's rapid population growth demonstrably drives up energy demand over the long run. This increase stems from industrial expansion, urbanization (which often leads to higher per capita energy consumption), and infrastructure development. These findings underscore the critical importance of integrating demographic projections into energy planning and policy formulation in Eastern Africa to ensure reliable energy allocation and development.

### 5.5 Foreign Direct Investment and Energy Consumption

The study unveils a positive relationship between FDI and energy consumption in Eastern Africa, particularly over the long run. This finding suggests that FDI plays a pivotal role in driving growth and modernization within the energy sector, thereby stimulating industrial activities and leading to increased energy consumption. FDI influences energy consumption through various mechanisms unique to the Eastern African context. Firstly, FDI inflows often entail substantial investments in energy infrastructure. This includes the construction and enhancement of power plants, transmission lines, and distribution networks, which not only expand energy capacity but also improve efficiency. These investments are critical for meeting rising energy demands driven by economic growth and industrialization. Secondly, FDI fosters industrialization by facilitating the establishment and expansion of industries. Manufacturing processes, machinery operations, and the transportation of goods all integral to industrial activities require significant energy inputs. As FDI inflows contribute to the expansion of these sectors, they concurrently drive up energy consumption levels. The observed positive relationship between FDI and energy consumption aligns with Canh *et al.* (2021), who found a significant impact, particularly in developing economies. However, as Paramati *et al.* (2018) highlight, contextual factors, particularly in Africa, can moderate this relationship. Therefore, policymakers must recognize that leveraging FDI for sustainable energy-driven growth requires carefully tailored policies that consider these contextual nuances and broader financial and trade dynamics.

## 6 Conclusion and policy implications

### 6.1 Conclusion

This study, using Panel ARDL analysis, identifies key drivers of energy consumption in Eastern Africa, revealing distinct short- and long-run effects. While trade openness positively influences energy consumption in the short run, opportunities exist to mitigate the negative impacts observed from population size and consumer price index. Conversely, in the long run, CPI and population size positively correlate with energy consumption, highlighting the need to address demographic and inflationary pressures. The positive contribution of foreign direct investment underscores the importance of attracting and directing these investments towards viable energy development. Ultimately, Eastern Africa requires comprehensive energy policies that account for the evolving dynamics of these drivers to ensure energy security and inclusive economic growth.

### 6.2 Policy Implications

The study findings indicate that Eastern Africa needs proactive energy strategies and a policy framework to accommodate growing demands from increased trade, expanding industrial activities, and a rising population. Policymakers should prioritize energy efficiency initiatives, particularly within trade and industry sectors, while also undertaking strategic investments in energy infrastructure. Integrating demographic projections into energy planning is essential to ensure the long-run sustainability of the energy sector. Given the short-run negative association between CPI and energy consumption, policymakers should explore opportunities to maximize this relationship's potential for implementing conservation measures. Additionally, recognizing that this impact reverses in the long run, addressing inflationary pressures through appropriate monetary and fiscal policies is crucial. The central banks in the EAC should aim to control inflation below single digits, stabilizing energy costs and reducing price fluctuations, which could drive greater energy consumption within the EA. This dual approach will help manage energy demand both in the present and future. Furthermore, attracting FDI through targeted policies is essential for enhancing energy infrastructure. Such investment can, in turn, encourage the adoption of energy-efficient technologies, a crucial step towards achieving SDG 7's goal of accessible, affordable, and reliable modern energy for all.

### 6.3 Areas for Further Research

One potential area is to investigate the influence of technological advancements on energy consumption patterns. Another area of further study could be the impact of policy interventions on energy efficiency and conservation. Additionally, it would be beneficial to investigate the social and cultural factors that influence energy usage behaviors. Furthermore, further research could explore the potential synergies between energy policies and other development objectives, such as poverty alleviation and environmental sustainability. This would help in developing more integrated and holistic approaches to energy management in the Eastern African region.

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