Macroeconomic Determinants of Renewable Energy Consumption in Tanzania: A Time Series Analysis from 1990 to 2020

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Abstract

This study examines the macroeconomic determinants of renewable energy consumption in Tanzania using time-series data from 1990 to 2020. The augmented Dickey-Fuller and Zivot Andrews are conducted, along with the autoregressive distributive lag bound test, to assess long-run relationships between the variables, which allows for the use of the error correction model. Moreover, the Granger causality test examines the causal links between the variables. In the long run, economic growth and trade openness positively impact renewable energy consumption while carbon dioxide emissions negatively impact renewable energy consumption. Short-run analysis reveals a negative coefficient for economic growth and a positive coefficient for interest rates. Granger causality testing supports the feedback hypothesis between renewable energy consumption and economic growth. Policy implications include the need for sustained efforts to promote economic growth, increase trade and investments, and enhance accessibility and affordability of renewable energy technologies to foster sustainable energy consumption.

Keywords: Renewable energy consumption, sustainable economic growth, environmental Kuznet curve, feedback hypothesis, autoregressive distributed lagged error correction model.

JEL Classification: O13

1. Background of the Study

Energy is a crucial driver of economic and human development globally. However, the economic, environmental, and societal consequences have called into doubt the usefulness of traditional energies (Basak, 2016). Energy from renewable resources has thus been recognized as a sustainable alternative given their vast distribution, availability, and environmentally friendly nature (Wesseh and Lin, 2016) and affordability (Charfeddine and Kahia, 2021).

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 ◆ *https://doi.org/10.56279/ter.v14i1.174*

The use of renewable energy fosters growth in the economy in a variety of ways. It contributes to the diversification of energy supply, hence energy demand security (Azzuni et al., 2018). It increases both environmental and social gains by lowering CO_2 emissions into the environment and lowering the cost of resolving ecological damage. As Ajayi et al. 2022 noted, renewable energy is eco-friendly and capable of mitigating climate change, producing either no or negligible greenhouse gas emissions. Harnessing renewable energy sources helps economies become self-sufficient and overcome energy shortages, vulnerability to volatile oil prices, and other macroeconomic crises like foreign reserve depletion and balance of payment disequilibria (Basak, 2016). Thus, Renewable Energy Consumption is critical to achieving Sustainable Development Goal 7 (SDG7), aiming to attain access to affordable, reliable, sustainable, and modern energy by 2030.

In general, there has been a substantial rise in renewable energy consumption from 2010 to 2019, owing to global efforts. The proportion of energy consumption from renewable sources in the overall quantity of energy consumed, including biomass usage, in 2020 was 19.1% compared to 16% recorded in 2010 (International Energy Agency (IEA), 2023). Moreover, end-use trends vary, with the highest rise in the proportion of energy from renewable sources remaining in electricity production. In contrast, the heat and transport industries experienced less progress (IEA, 2022). The report on tracking the progress of SDG7 shows that to reach the envisioned goal; there must be strategic global efforts to enhance the share of renewable energies to the total energy consumption by 33 to 38% by 2030. Specifically, the use of renewable energy in the power sector should be between 60-65% and much more in the transport sector through enhancing the use of geothermal, solar, and bioenergy and indirectly by enhancing electrification (IEA, 2023). This calls for research-informed drivers of renewable energy consumption to inform the design and implementation of appropriate policies.

Regionally, Eastern Asia is leading in consuming renewable energy, accounting for almost half of the annual increase in total modern renewable energy (solar PV, wind, and hydropower) consumption (IEA, 2023). On the other hand, Europe accounts for more than a quarter of this year-on-year increase. A substantial share (29%) of modern renewable energy use is recorded in Latin America and the Caribbean due to the dominance of hydro in power generation, bioenergy in industries, and biofuels in the transport sector. Even though Sub-Saharan Africa holds the most significant share of renewable energy in its total energy supply, this is due to the dominance of biomass in cooking and heating. The Africa Energy Report by PWC (2021) shows that Africa's energy mix has remained relatively steady over the past three decades despite successful renewable energy initiatives. The existing power generation balance in the continent is dominated by fossil energy production, with hydropower providing the only significant renewable energy contribution (PwC, 2021).

Tanzania has vast renewable energy resources ranging from wind, geothermal, solar, hydro, biomass, tidal, and waves. Despite these endowments, the country faces significant challenges in harnessing the resources for sustainable development. The country's potential to generate energy from wind, solar, hydro, and other renewable sources remains largely untapped, with current energy production still dominated by natural gas (57.02%), followed by hydro (36.6%), fossil fuel (5.67%), and biomass (0.67%) (United Republic of Tanzania (URT), 2020). At the household level, energy use is dominated by biomass, which forms 85% of the total energy consumption in the country. The use of firewood is more dominant in rural areas (84.8%) than in urban areas (17.4%) (URT, 2019). Only 6.9% of the population can access clean cooking technologies and fuels. Of these, 16.5% are from urban areas, and 1.6% are from rural areas (IEA, 2023). The use of fossil fuels in the household and transport sector is significant, and projections indicate an increasing trend over time. According to the Africa Energy Outlook report, in 2019, the transport sector, which is heavily dependent on imported fossil fuels, consumed 1.8 Mtoe of fossil fuels 2019 (IEA, 2019). The report projects this level to increase to 4.5 Mtoe in 2040. The consumption of these non-renewables at the household level is projected to increase from 0.2 Mtoe to 2.5 Mtoe in 20140. Modern renewables, excluding traditional biomass use for heating and cooking, show a decreasing trend in the final energy consumption in Tanzania. The underutilization and uptake of modern energy impede Tanzania's progress toward achieving Sustainable Development Goal 7 and contribute to ongoing environmental and economic vulnerabilities, including high carbon dioxide emissions, energy insecurity, and dependence on imported fossil fuels. Economic growth, diversification of energy sources, and environmental sustainability in Tanzania could all benefit significantly from increased renewable energy consumption. The need for focused research on the macroeconomic drivers that could enhance renewable energy consumption is thus eminent.

The empirical proof of macroeconomic determinants of renewable energy consumption in low-income countries, especially sub-Saharan Africa, is scant. Studies such as Ergun et al. (2019), Akintande et al. (2020), and Lawal (2023), among others, provide valuable insights. However, as Gershon and Emekalam (2021) argued, more country-specific detailed analyses are crucial for designing and implementing appropriate policies that account for socioeconomic as well as environmental features of these economies. Thus, this study's goal is to use the case of Tanzania to add to the existing body of knowledge in low-income countries. Extending from Lawal 2023[1], this study evaluates the short and long-run effects of economic growth, interest rate, trade openness, and foreign investment factors on renewable energy consumption in Tanzania.

Moreover, it investigates the direction of causality between renewable energy consumption and its determinants in the country. Identifying these drivers is essential. The rich information on renewable energy uptake determinants in this study offers appropriate policy implications and recommendations for more effective policy interventions that could catalyze the transition to a greener economy.

This study adopts time series data analysis techniques. We subject the variables to the individual unit root tests using the Augmented Dickey-Fuller and Zivot Andrews tests. The Autoregressive Distributed Lag (ARDL) bounds test cointegration test is used to test for the presence of a long-run relationship between the variables, which allows the use of the Error Correction Model (ECM) in the analysis. Furthermore, the Granger Causality test assesses the direction of causality between the dependent variable and control variables.

In line with the propositions of the Environmental Kuznet Curve (EKC), economic growth significantly influences renewable energy consumption negatively in the short run and positively in the long run. The effect of interest rates is positive in the short run and negative in the long run. Renewable energy consumption is found to increase from trade openness and decrease from carbon dioxide emissions in the long run. Moreover, the bi-directional causality is observed between the dependent and independent variables, confirming the reverse causality between economic growth and renewable energy consumption, among others. This study recommends continued efforts toward expanding economic growth through increased trade and investments to enhance the availability, accessibility, acceptability, and affordability of renewable energy technologies.

[1] Analyzed the determinants of renewable energy consumption in Africa and provided evidence of selected specific African countries, including Tanzania. However, the study discusses the influence of only environmental and social determinants in the country.

The rest of the paper is organized as follows. An overview of renewable energy consumption in Tanzania is presented in section two. Section three discusses theoretical and empirical literature on determinants of renewable energy consumption. Sections four and five present the methodology and discussion of regression results, while the conclusion, summary, and policy recommendation are discussed in section six.

2. An Overview of Renewable Energy in Tanzania

Tanzania has vast renewable energy sources such as bio energies, hydro, wind, solar, tidal waves, and geothermal, whose capacities are either not utilized at all or partially utilized. The country's hydro potential is 7,491.2 MW**,** but only 573.70 MW have been utilized (URT, 2020). The ongoing Hydropower projects, including Julius Nyerere Hydropower Project (2115 MW), Ruhudji Hydro (358 MW), Rumakali (222 MW), Kikonge (300 MW), Kakono (87 MW), Malagarasi (45 MW) and Rusumo (80 MW) are meant to tap into this potential (URT FYDP III, (2021). There is solar photovoltaic potential, with insulation often higher and more continuous along the coast and in the Lake Victoria basin. As per the URT Ministry of Energy (2020) and the URT FYDP III (2021), the overall installed capacity of the national grid from solar energy sources is projected to be 205 MW and 715 MW by 2026 and 2044, respectively.

Tanzania has abundant wind resources, with speeds ranging from 6-8 m/s, specifically along the coast and on the Rift Valley's escarpment areas (International Renewable Energy Agency, 2013). The country's first large-scale wind power station, with a 100 MW capacity, is being developed in Singida (Kititimo). In addition, there is a 50 MW capacity being developed at Makambako (Njombe Region) and 50 MW at Same (Kilimanjaro region), all to be completed by 2026 (URT FYDP III, (2021). The plan is to install 800 MW in the national grid by 2044 (URT, 2020). Earlier geothermal investigations across the country suggest the potential of over 5,000 MW in geothermal projects, with more than 50 locations found and offered for further examination, primarily in three regions (International Renewable Energy Agency, 2013). These locations are the Southern Zone (Mbeya and Rukwa), the Northern Zone (Arusha, Kilimanjaro, and Mara regions), as well as the eastern coastal belt that is linked to rifting and magma influx (the Rufiji Basin), and the Luhoi Spring location, which has a capacity of 50–100 MW. The overall installed capacity in the national grid from geothermal energy sources is projected to be 995 MW by 2044 (URT, 2020).

2.1 Overall Trend of Renewable Energy Consumption

The country's energy balance shows that biomass consumption in the form of firewood and charcoal dominates and accounts for around 85 percent of total national energy consumption. Petroleum products comprise approximately 9.3 percent of total energy utilized, electricity contributes 4.5 percent, and coal and renewable energies account for 1.2 percent (URT, 2015). Tanzania's renewable energy consumption forms the largest share of its total energy consumption. However, this share is mainly due to the predominance of biomass usage. Modern renewable energy final consumption is overall meager despite its vast availability. For instance, the overall final consumption of renewable electricity (excluding the transport sector) is just 1.1PJ. Moreover, the final consumption of renewable energy (excluding electricity) in the transport sector is only 10PJ (IEA, 2023).

Figure 2.1 shows the trend of Tanzania's overall share of renewable energy in total energy consumption. The observed declining trend and dominance of biomass calls for strategic efforts at all levels to substantially increase modern renewable energy consumption to achieve SDG7 and overall energy security in the country.

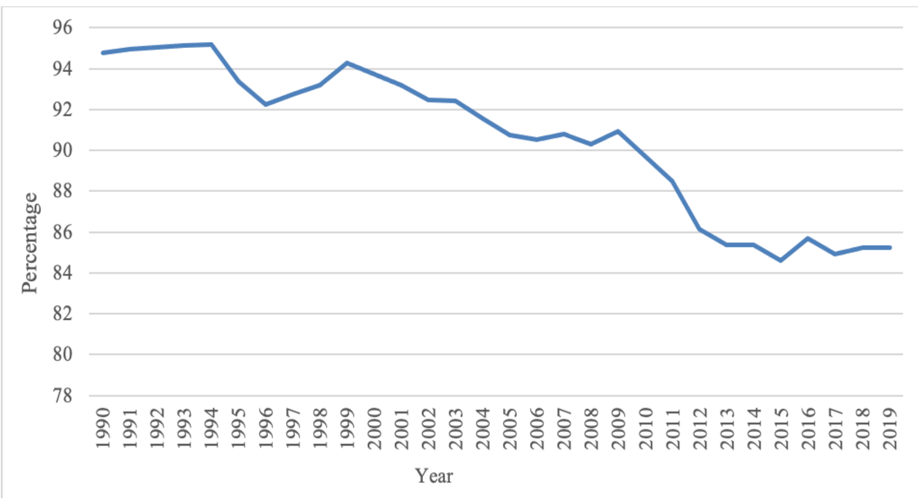

Figure 2.1: Renewable energy consumption trend in Tanzania.
Source: World Bank 2022

2.2 Renewable Energy Consumption by Households, Commercial, and Institutions

Biomass energy is a crucial renewable power source used by Tanzanian families, small and medium-sized businesses, and institutions. It is primarily used to generate heat and as a cooking fuel, with over 90% of biomass demand for domestic use and 10% for institutional, commercial, and industrial purposes (International Renewable Energy Agency, 2013). Charcoal consumption is one million metric tonnes annually, leading to a loss of natural forest and CO_2 emissions. According to the Biomass Energy Strategy study (2013), demand for charcoal will more than double by 2030 due to rapid urbanization and high prices or shortages of energy substitutes. Initiatives to expand access to clean cookstoves or fuels have been disseminated, with various stakeholders spearheaded by the Ministry of Energy coordinating and sustaining initiatives to reduce total firewood and charcoal use. This could have a favourable influence on deforestation and human health and well-being.

2.3 Renewable Energy in Power Generation

Figure 2.2 shows the energy mix in power generation in Tanzania. Currently, there are no non-hydro renewable sources in the process. The primary source of power generation is mainly non-renewable resources, with natural gas forming more than 50% of all the sources. Hydro is the second source, constituting about 37%.

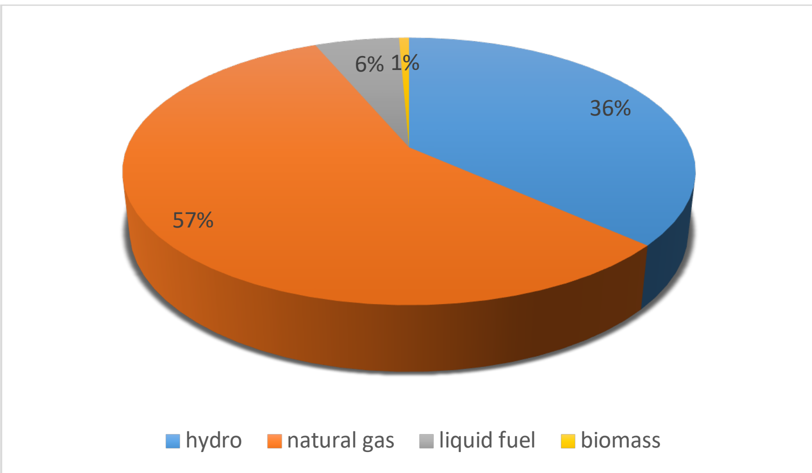

Figure 2.2: Shares of hydro and thermal generation to the total installed capacity.

Source: Power Supply Master Plan, 2020 update.

The role of renewable resources in power generation to enhance energy security, meet the growing electricity demand, and achieve national and international development agenda cannot be overstated. As a result, Tanzania has formulated a proper plan to exploit more of the available renewable resources for power generation. The Power Supply Master Plan projects an installation of 20.200.6MW by 2044 (URT, 2020). 40.6% (8,200.4MW) of this capacity is expected to be generated from renewable resources. Table 2.1 shows the projected proportion of energy resources in power generation by 2044.

Table 2.1: Projected installed capacity (MW) by 2044

Source	Installed capacity (MW) by 2044	Percentage (%)
Hydro	5,690.40	28.15
Natural gas	6,700.00	33.18
Coal	5,300.00	26.24
Wind	800.00	3.96
Solar	715.00	3.54
Geothermal	995.00	4.93
Total	**20,200.40**	**100**

Source: Power System Master Plan, 2020 Update

Despite the efforts to substantially raise renewable energy technologies, their widespread utilization has been delayed worldwide. This delay harms the efforts to transition to an environmentally friendly energy system crucial for enhancing sustainable development. Specifically in Tanzania, consumption of renewable energy technologies is hindered by substantial investment costs, limited human capital, and relevant skills, inadequate research and development, and limited acceptability due to a lack of awareness among the public (Bishoge et al., 2018). Research should thus complement and inform various national, regional, and international strategies that are increasingly implemented to enhance the availability, affordability, accessibility, and acceptability of modern energy resources.

3. Literature Review

3.1 Theoretical Literature Review

Like Bloch et al. (2015) and Lawal (2023), we adopt the neutrality theory, growth hypothesis, conservation hypothesis, and feedback hypothesis to explain the relationship between renewable energy consumption and economic growth.

The *neutrality theory* asserts that renewable energy consumption has insignificant to no correlation with economic growth. Moreover, the two variables are not causally related; hence, any policy implemented to influence the two becomes ineffective. Aïssa et al. (2014) empirical work on Africa's production, renewable energy use, and trade lends credence to this concept. The *growth hypothesis* maintains that growth in the economy is based on energy. Energy demand drives economic growth; thus, conserving the environment will harm the economy. It signifies a unidirectional link from the use of green energy to growth. The significance of the link involving energy utilization with economic expansion is treated within energy economics literature (Raza et al., 2015). Renewable energy is an essential component of growth, which indirectly or directly integrates labor and capital into the production process. In manufacturing, energy supplements labor and capital; hence, it drives economic growth (Payne, 2010). A study by Alper and Oguz (2016) on the contribution of renewable energy usage to economic expansion: Proof from new EU members with asymmetric causality for the years 1990–2009 supports this hypothesis.

On the other hand, the *conservation hypothesis* posits that economic growth does not rely on using renewable energy. The expansion of the economy is what fuels the demand for clean energy. Unlike the growth hypothesis, the causation runs from GDP rise to sustainable energy usage. Programs to conserve energy do not have a detrimental effect on economic expansion (Payne, 2010). A study by Ocal and Aslan (2013) supports this hypothesis. Finally, the *feedback hypothesis* asserts the interdependence in which renewable energy usage and GDP affect each other concurrently (Payne, 2010). This indicates a bi-directional connection between renewable power uses and the economic boom. It shows how the usage of green power and GDP growth are strongly correlated. Studies by Apergis and Payne (2012) and Lawal (2023) confirm this hypothesis.

The Environmental Kuznet Curve (EKC) hypothesis explains the link between environment and economic growth. This hypothesis posits a reverse U-shaped relationship between the two variables and that at the early development phases, countries concentrate more on attaining growth than preserving the environment. However, as economic growth and time progress, there is a massive increase in environmental degradation, and attention starts to switch towards achieving sustainable development (Yao et al., 2019; Jiang et al., 2022). Literature has focused on CO_2 emissions as measures of environmental pollution (Akintande et al., 2020; Jiang et al., 2022).

3.2 Empirical Literature Review

Researchers have studied the macroeconomic drivers of renewable energy consumption using various models for decades, with occasionally divergent results for multiple time frames and areas. However, the empirical proof of macroeconomic determinants of renewable energy consumption in low-income countries, especially sub-Saharan Africa, is scant. This is despite these economies' government's interventions in promoting and developing renewable energy projects and technologies to increase renewable energy consumption. Notably, evidence for specific countries considering their socioeconomic characteristics critical for implementing appropriate policies is limited (Foye, 2022).

The most important drivers of renewable energy consumption reported in the literature include economic growth (GDP), emphasized to be the most relevant driver (Malik et al., 2014; Foye, 2022), trade openness, foreign direct investment (FDI), carbon dioxide emissions, traditional fuel prices/costs, and trade openness. For instance, Sadorsky (2009) finds positive influences of real GDP per capita and carbon dioxide emission on per capita clean energy utilization in the G7 countries from 1980-2005. A large sample study by Omri and Nguyen (2014) reveals that carbon emissions and openness to trade are the main forces behind the utilization of renewable energy. Basak (2016) finds a negative relationship between economic growth and renewable energy consumption in the Balkans, while natural gas rents and openness to trade exhibit a positive influence. Brini et al. (2017) document a bidirectional causality between renewable energy use and global trade in Tunisia from 1980 to 2011. A study in Africa by Ergun et al. (2019) reports low usage of renewable energy in African nations with high economic growth rates and human capital development.

In contrast, African nations with high FDI levels use a significant proportion of renewable energy. On the contrary, economic growth and labor force are found to be favorably correlated with the utilization of renewable energy in ASEAN nations (Yassin, 2021). However, openness to trade, foreign direct investment, urbanization, and inflation negatively influence regenerative energy utilization.

Gershon and Emekalam (2021) find the long-term relationship between CO_2 emissions and real GDP to renewable energy usage in Nigeria. Moreover, a unidirectional causation exists between these determinants and the dependent variable. GDP per capita and trade openness significantly influence Thailand's renewable energy consumption (Hussain et al., 2021). Sadiq et al. (2022) report the positive influence of inflation, foreign direct investment, population growth, and economic boom on sustainable energy consumption in China. At the same time, economic growth and CO_2 emissions are among the drivers documented by Mohamed et al. (2023) and Lawal (2023) in Malaysia and Africa, respectively. Other drivers of renewable energy consumption include financial prosperity (Gershon and Emekalam, 2021), inflation, and population growth (Sadiq et al., 2022; Malik et al., 2014), financial growth (Eren et al., 2019), exchange rate, governance, and human capital (Foye, 2022), electricity consumption (Akintande et al., 2020), and urbanization (Mohamed et al., 2023).¨

A notable observation from the reviewed literature is the underrepresentation of low-income countries, especially sub-Saharan Africa, in analyzing drivers of renewable energy consumption. Deliberate efforts are enacted in these economies to transition to clean and regenerative energy sources. Research to inform these efforts must be balanced. Moreover, the variations of the nature of the influence of drivers, given the area of study and time, signal the importance of countries' unique socioeconomic features in influencing the uptake of renewable energy crucial for designing and implementing appropriate policies. For instance, while economic growth is reported to influence positive renewable energy consumption in G7 countries (Sadorsky, 2009), the influence is negative in Balkan countries (Basak, 2016). African studies report contradicting evidence on how economic growth affects renewable energy consumption. While Ergun et al. (2019) find decreasing renewable uptake from increasing economic growth, a positive relationship is reported by Lawal (2023). This variation in results reflects, among others, the different scope of studies and methodologies employed. Even though these studies provide valuable insights into Africa, more country-specific detailed analyses are crucial for policymakers to design appropriate policies (Gershon and Emekalam, 2021).

Our study, therefore, adds to the existing knowledge of renewable energy consumption in low-income African countries by providing evidence from Tanzania, hence informing the design of various energy policies, plans, and strategies. Lawal 2023 provides evidence from Tanzania; however, the results only cover environmental factors. Informed by the reviewed literature, we extend the analysis by assessing other macroeconomic factors such as economic growth, interest rates, trade openness, and foreign direct investment. Gershom and Emekalam (2021), Hussain et al. (2021), Foye (2022), and Mohamed et al. (2023) use the ARDL method to analyze the macroeconomic determinants of renewable energy consumption in Tanzania.

4. Methodology

4.1 Data Sources and Variables Description

This paper uses annual time series data on renewable energy consumption, economic growth, real interest rate, trade openness, carbon dioxide emissions, and foreign direct investment. The data spans from 1990 to 2020 and are sourced from the World Development Indicator, World Bank. Table 4.1 describes the variables used in the analysis and their sources.

Table 4.1: Variable description, sources, and anticipated sign

Variable	Description	Measurement	Expected Sign
REC	Renewable energy consumption	percentage of total final energy consumption	
EG	Economic growth	Annual percentage of GDP growth	Positive
IR	Real interest rate	Real interest rate (percentage)	Negative
TO	Trade Openness	$\frac{Imports + Exports}{GDP}$	Positive
COE	emissions of carbon dioxide	emissions of CO_2 in tonnes per person	Positive
FDI	Foreign Direct Investment	Foreign direct investment, net inflows (percentage of GDP)	Positive

4.2 Empirical Model Specification

This study uses the following specified econometric model formulated from Equation (1):

$$REC_t = \beta_0 + \beta_1 EG_t + \beta_2 IR_t + \beta_3 TO_t + \beta_4 COE_t + \beta_5 FDI_t + \varepsilon_t \quad (1)$$

Where REC is "renewable energy consumption", t is time, EG is "economic growth", IR is interest rates, TO is trade openness, COE is Carbon dioxide emissions, FDI is foreign direct investment, β_0 is the intercept, β^s are parameters and ε_t is the error term.

We then linearize the model using a logarithmic transformation in equation 2. Logarithmic transformations yield coefficients with appealing interpretations. Moreover, logarithm models often obey Classical Linear Model (CLM) suppositions, alleviate skewed or heteroskedastic conditional distributions, and reduce value range (Wooldridge, 2012).

The transformed model is shown in Equation 2.

$$\ln(REC_t) = \beta_0 + \beta_1 EG_t + \beta_2 IR_t + \beta_3 TO_t + \beta_4 COE_t + \beta_5 FDI_t + \varepsilon_t \quad (2)$$

Where;
REC is Renewable Energy Consumption widely used in the literature (Basak, 2016; Brini et al., 2017; Ergun et al., 2019; Sadiq et al., 2022) to proxy the consumption of renewable energy in the economy. EG is economic growth expected to influence renewable energy consumption positively in the long run. This expectation conforms to the postulation of the Environmental Kuznet Curve (EKC) hypothesis that the economy's growth allows substantial investment and advancement in environmentally friendly energy, which usually requires high investment costs. This expectation aligns with the findings of Hussain et al. (2021), Mohamed et al. (2023), and Lawal (2023). IR is the real interest rate proxying the investment cost and is anticipated to affect the dependent variable negatively. Since financing becomes costlier as the interest rate increases, firms undertake fewer renewable energy investments (Foye, 2022). TO is trade openness expected to affect renewable energy consumption favorably through enhancing economic growth and technology transfers (Omri et al., 2015; Basak, 2016). Carbon dioxide emission, COE, is anticipated to have a positive sign on the model since the nations tend to adopt environmentally as climate change worsens (Sadorsky, 2009; Omri and Nguyen, 2014). Foreign Direct Investment, FDI is anticipated to affect renewable energy consumption positively through technological transfer, which increases the uptake of renewable power (Ergun et al., 2019; Sadiq et al., 2022).

4.3 Estimation Technique

This study employs time-series-based econometric methods for assessing macroeconomic determinants of REC in Tanzania. The study uses augmented-dickey fuller alongside Zivot-Andrews tests for unit roots to determine stationarity for variables employed. Since the interest rate is stationary at the level and the remaining variables stationary at the first difference, we use the ARDL bounds cointegration test to check for a long-term relationship between them. The existence of cointegration allows us to formulate and use the Error Correction Model (ECM). Moreover, this study uses Granger causation analysis to determine the existence of any causal connection regarding the use of renewable energy along with the macroeconomic determinants used.

The Autoregressive Distributed Lag (ARDL) model

ARDL specification of the renewable energy consumption model is as follows:

$$\Delta(lnREC_t) = \alpha_O + \delta_1 ln(REC_{t-1}) + \delta_2(EG_{t-1}) + \delta_3(IR_{t-1}) + \delta_4(TO_{t-1}) + \delta_5(COE_{t-1}) + \delta_6(FDI_{t-1}) + \sum_{i=1}^{p} \beta_1 \Delta(lnREC_{t-i}) + \sum_{i=1}^{q} \beta_2 \Delta(EG_{t-i}) + \sum_{i=1}^{q} \beta_3 \Delta(IR_{t-i}) + \sum_{i=1}^{q} \beta_4 \Delta(TO_{t-i}) + \sum_{i=1}^{q} \beta_5 \Delta(COE_{t-i}) + \sum_{i=1}^{q} \beta_6 \Delta(FDI_{t-i}) + \varepsilon_{1t} \quad (3)$$

Whereby q is lag length, Δ is the difference operator, ε_{1t} is an error term assumed to be serially uncorrelated, and the variables are as defined in Table 4.1.

The null (H_0) and alternative (H_1) hypotheses under the specified model are:

$$H_0 = \delta_1 = \delta_2 = \delta_3 = \delta_4 = \delta_5 = \delta_6 = 0 \ (No\ cointegration) \quad (4)$$

$$H_1 \neq \delta_1 \neq \delta_2 \neq \delta_3 \neq \delta_4 \neq \delta_5 \neq \delta_6 \neq 0 \ (There\ is\ cointegration) \quad (5)$$

We use the OLS approach in Equation (5) and then test hypotheses with the Wald test. Given the decision criteria, we fail to reject the null hypothesis if the F statistic value is below critical I (0), reject the null if it exceeds the I (1) critical value bound, and be indecisive if it falls within lower and higher bounds (Pesaran et al., 2001; Narayan, 2005).

Error Correction Mechanism

Since the variables are cointegrated, we formulated the Error Correction Model (ECM) in equation 6 and employed it in the analysis.

$$\Delta(lnREC_t) = \alpha_O + \sum_{i=1}^{p} \beta_1 \Delta(lnREC_{t-i}) + \sum_{i=1}^{q} \beta_2 \Delta(EG_{t-i}) + \sum_{i=1}^{q} \beta_3 \Delta(IR_{t-i}) + \sum_{i=1}^{q} \beta_4 \Delta(TO_{t-i}) + \sum_{i=1}^{q} \beta_5 \Delta(COE_{t-i}) + \sum_{i=1}^{q} \beta_6 \Delta(FDI_{t-i}) + \gamma ECT_{t-1} + \varepsilon_{1t} \quad (6)$$

Variables having a different sign βs denote short-term predicts; (ECT) is the error correction term representing the long-term predictions. It's estimated γ

measure adjustment speed and should be negative to indicate long-term convergence.

Granger causality test
The Granger causality test is employed to determine a causative connection between alternative energy usage and its determining variables (Granger, 1969). If a variable's past and present values predict the latter, it is said that Granger causes it.

$$\Delta Y_t = \sum_{i=1}^{n} \alpha_i \, \Delta Y_{t-i} + \sum_{j=1}^{n} \beta_j \, \Delta X_{t-j} + \mu_{1t} \qquad (7)$$

$$\Delta X_t = \sum_{i=1}^{n} \lambda_i \, \Delta X_{t-i} + \sum_{j=1}^{n} \delta_j \, \Delta Y_{t-j} + \mu_{2t} \qquad (8)$$

In this study, our interest is centred, among others, on the causation between renewable utilization and its determinants. If the variables are cointegrated, then any of the three linkages can exist: a) renewable energy consumption causes the determinants, b) the determinants cause the renewable energy consumption, or c) renewable energy consumption and determinants cause each other.

4.4 Post-estimation Analysis
We perform diagnostic tests, including stability as measured by the CUSUM and CUSUMSQ stability tests, normality by Sktest under the null hypothesis of residual normality, and Breusch-Pagan-Godfrey test for heteroscedasticity under the null hypothesis of homoscedasticity. Moreover, the Ramsey RESET model misspecification test and Breusch-Pagan serial correlation test under the null hypotheses of correctly specified and no serial correlation, respectively.

5. Results and Discussion
5.1 Descriptive Statistics
Table 5.1 shows the descriptive statistics of the variables in the analysis. It represents each variable's maximum and minimum values and measures the central tendencies, means, and standard deviations. Moreover, the table provides the Jacque-Bera test statistic for normality under the null hypothesis that the variable is normally distributed. Given the p-value, all the variables in our analysis are normally distributed.

Table 5.1: Descriptive statistics for raw data

Variable	Observations	Mean	Minimum	Maximum	Standard deviation	Jarque-B	(Probability)
Renewable energy Consumption (REC)	31	90.43	84.62	95.18	3.73	3.003	0.22
Economic growth (EG)	31	5.20	0.58	7.67	2.03	3.89	0.14
Interest rates (IR)	31	6.31	-26.50	16.28	7.69	2.01	0.37
Trade Openness (TO)	31	0.43	0.25	0.65	0.11	1.22	0.54
Carbon Dioxide Emission (COE)	31	0.14	0.07	0.23	0.06	2.99	0.23
Foreign Direct Investment (FDI)	31	2.57	0.0002	5.66	1.51	0.71	0.70

5.2 Correlation Analysis Result

A negative correlation between renewable energy consumption and economic growth, interest rates, carbon emissions, and FDI is depicted in Table 5.2. the dependent variable correlates positively to trade openness. Most variables have an acceptable level of correlation except for CO_2 emissions, which may signal a multicollinearity problem. However, using the VIF test, we discovered no significant multicollinearity concern, as the mean VIF is less than 10 (Gujarat, 2004). Therefore, we continue with this variable because it is essential in explaining the changes in renewable energy consumption, and removing it could result in an omitted variable bias.

Table 5.2: Correlation coefficient matrix

Variable	REC	EG	IR	TO	COE	FDI
REC	1					
EG	-0.4207	1				
IR	-0.3702	0.2442	1			
TO	0.1588	-0.2617	-0.1645	1		
COE	-0.9824	0.5031	0.3489	-0.0871	1	
FDI	-0.2741	0.5184	0.1553	-0.0513	0.3408	1

5.3 Unit Root Test Result

Table 5.3 presents the Augmented-Dickey Fuller (ADF) and Zivot Andrews unit root test results. Except for the interest rate, which is stationary at level, all the remaining variables are integrated into order one, I (1). This result is consistent under the two tests, which shows that the ADF test is robust.

Table 5.3: Unit root and stationarity test results

Variable	ADF		Zivot Andrews	
	I(0)	I(1)	I(0)	I(1)
	t-statistic	t-statistic	t-statistic	t-statistic
REC	-0.22	-4.41*	-4.38	-4.86**
EG	-2.12	-6.11 *	-4.04	-6.25*
IR	-4.13*		-5.13**	
TO	-1.35	-3.87 *	-3.46	-4.85**
COE	-0.94	-3.54**	-3.11	-4.87**
FDI	-2.93	-8.79*	-3.27	-6.56*
5% critical value test statistic	-2.97	-2.99	-4.80	-4.80

* Stationary at 1% and 5% critical values; ** Stationary at 5% critical value

5.4 Optimal Lag Selection Criteria Results

It is crucial to establish an acceptable lag order for variables before running the ARDL bounds test to examine if there is cointegration. Table 5.4 shows the lag selection criterion for using the ARDL bound test, indicating that the model outperforms at lag two, relying on all criteria.

Table 5.4: Maximum lag selection results

Sample:1992-2020						Number of obs = 29		
lag	**LL**	**LR**	**df**	**p**	**FPE**	**AIC**	**HQIC**	**SBIC**
0	-133.16				0.001	10.31	10.39	10.59
1	-34.82	196.68	36	0.00	0.00001	5.69	6.29	7.71
2	0.23	70.09*	36	0.001	0.000022*	5.76*	6.87*	9.50*
3	68.53	136.6	36	0.00	9.1e-06	3.37	4.99	8.84
4	2171	4205	36	0.00	1.8e-69	-149.71	-147.57	-142.51

* the value with the maximum lag

5.5 Cointegration Results

Table 5.5 illustrates cointegration test results, which check an equilibrium link of the variables. The estimated F-statistic (22.3) exceeds the higher critical bounds (3.79) at a 5% significance level. Therefore, we reject the null hypothesis of no cointegration.

Table 5.5: ARDL bounds test cointegration results

F-statistic	Pesaran 5% Critical value		Decision
	I(0)	I(1)	
22.3	2.62	3.79	Reject null

After determining the equilibrium relationship, we execute the ARDL model with error correction to provide long-run results alongside short-run estimates. Table 5.6 illustrates the outcomes based on AIC. The ARDL lag is (1, 2, 2, 0, 0, 0).

5.6 Estimation Results

Objective 1: Assess short and long-run effects of economic growth, interest rate, trade openness, and foreign investment factors on renewable energy consumption in Tanzania.

The ARDL-ECM method is used to assess the first objective of this study. Table 5.6 depicts the short-run and long-run estimated results in our analysis. The reader should note that since our model is log-level, we have transformed estimated long-run and short-run coefficients by multiplying them by 100 to their appropriate approximate percentage changes for convenience and consistency in interpretation. Moreover, the table represents only the significant results.

The adjustment coefficient, ECT (-0.8670), is statistically significant at one percent, signifying departures from long-run equilibrium are corrected at an 86.7 percent convergence rate in the current year. According to theory, this adjustment coefficient must fall between 0 and -1. The Adjusted R-squared shows that the macroeconomic determinants account for 84% of the variations in renewable energy consumption.

Economic growth

This variable is found to significantly affect renewable energy consumption positively in the long run, but the effect is negative in the short run. Specifically, a one-percent increase in economic growth results in a 0.6% increase in renewable energy consumption in the long run while reducing the dependent variable by 0.2% in the short run. The long-run effect aligns with the findings of Brini et al. (2017), Yassin (2021), and Gershon & Emekalam (2021), and the short-run aligns with the results of Basak (2016) and Ergun et al. (2019). The finding of how economic growth influences renewable energy consumption in Tanzania conforms to the Environment Kuznets Curve Hypothesis proposition. This hypothesis holds that economies are more concerned with attaining economic growth than preserving the environment in the early development phases; however, as economic growth and time progresses, there is a massive increase in environmental degradation, and attention starts to switch toward achieving renewable energy. In the short run, the developing economy cares about economic growth, usually driven by the fossil energy sector; however, in the long term, environmental concerns kick in, and the focus shifts to investment in clean and efficient energy technologies (Ergun et al., 2019).

Interest rates

The estimated results indicate that the interest rate is statistically significant at one percent and negatively influences renewable energy consumption in the long run. However, the effect is positive in the short run. Specifically, a one-percent increase in interest rates results in a 0.07 percent decline in long-run renewable energy consumption while increasing the use of renewable energy by 0.06% in the short run. The estimated coefficients bear the expected sign and align with the findings of Foye (2022). Generally, the observed relationship between renewable energy consumption and interest rate conforms to the conclusion of Keynesian theory, among others, that real interest rate drives savings and investment. In the short run, an increase in interest rate increases households' deposits, which increases loanable funds to investors (Lugo, 2003; McKinnon, 1973; Shaw, 1973). In our context, the available loanable funds increase investment in renewable energy projects in the short run. However, as the demand for investment increases, interest rates rise, making investment expensive, hence a decline in the overall investment (Foye, 2022).

The policy reforms in Tanzania led to interest rate deregulation and overall financial liberalizations, which started in 1990 (Bank of Tanzania, 2011). Interest rate liberalization allowed the interest rate to be determined by loanable funds demand and supply forces to reflect the real market interest rate. The variations in deposit and lending interest rates translated into variations in savings and investment have thus been experienced over time. For instance, the highest recorded lending rate (34% of GDP) in the country witnessed the lowest monetary sector lending to the private sector (3% of

GDP) in 1996 (World Development Indicators, World Bank, respective years). In 2020, the financial sector credit to the private sector reached 16.7% of GDP at a lending rate of 12% of GDP. The high borrowing cost (interest rate) has adversely affected global investment in clean energy technologies (IEA, 2023).

Trade openness

The estimated coefficient shows that trade openness is statistically significant at one percent and positively impacts renewable energy consumption in the long run. This finding aligns with that of Omri et al. (2015) and Lawal (2023). Specifically, a one-percent trade openness boost results in a 0.043 percent rise in renewable energy use in the long run. This means that Tanzania's trade liberalization initiatives will enhance trade openness while improving the uptake of renewable energy. The impact of trade openness on renewable energy consumption is through the expansion of economic growth from trade openness (Omri et al., 2015). The resulting economic growth makes the investment and development of more clean and efficient technologies affordable. In addition, foreign trading fosters the exchange of green technologies in deploying and using renewable energy through technical transfer.

Carbon dioxide emissions

The long-run estimated Carbon Dioxide Emissions coefficient is statistically significant and negatively related to renewable energy consumption. Specifically, a one-percent rise in per capita CO_2 emissions results in a 0.804 percent decline in renewable energy consumption in the long run. This finding is different from what is expected. It contradicts the findings of Sadorsky (2009), Omri and Nguyen (2014), and Lawal (2023), who assert that rising CO_2 emissions are the primary motivator for increased renewable energy uptake. However, it suggests that environmental damage does not result in a transition to renewable energy in Tanzania. Constraints to transition include the country's overdependence on fossil fuels and traditional use of biomass, which are relatively available and affordable. For instance, given the massive natural gas discovery, it is increasingly becoming cheaper to generate power using natural gas than conventional hydro and non-hydro renewable resources, whose technology is costly (URT, 2020). Plans are underway to increase the use of natural gas by households, firms, industries, and the transport sector by 2045 (URT, 2016). Moreover, biomass, especially charcoal and firewood, dominated household energy use, given their easy availability, affordability, and inadequate awareness of modern cooking technologies, which shapes people's negative perceptions and attitudes. As

Foye (2022) notes, the public's unresponsiveness to climate change issues reflects a knowledge gap that should be addressed to increase the uptake of environmentally friendly technologies.

Table 5.6: Estimates of the long-run and short-run coefficients – ARDL ECM

			Sample	**1992-2020**
			Observations	**29**
			R-Squared	**0.8985**
			Adj R-squared	**0.8422**
Dependent variable: Renewable energy consumption	**Coeff.**	**Std. Err**	**T**	**P>|t|**
ECT	-0.867***	0.09	-8.71	0.000
Long run				
Economic growth	0.60***	0.0008	7.13	0.00
Interest rate	-0.07***	0.0002	-3.28	0.00
Trade openness	0.04***	0.0089	4.83	0.00
Carbon dioxide emissions	-0.80***	0.0214	-37.59	0.00
Short run				
D1 Economic growth	-0.22***	0.0008	-2.92	0.00
LD Economic growth	-0.23***	0.0005	-4.24	0.00
D1 Interest rate	0.06***	0.0001	3.69	0.00
LD Interest rates	0.03***	0.0001	2.92	0.00
Constant	3.48***	0.4531	8.75	0.00

(significant at 10 percent level, **significant at 5 percent level, *** significant at 1 percent level)*

Diagnostic Test Results

The results in Table 5.7 and Figures 5.1 and 5.2 show the post-estimation results of our analysis. The model is correctly specified, does not suffer from heteroskedasticity and serial correlation problems, and is stable.

Table 5.7: post estimation test results

Test	**F-Statistic/ chi**	**P value**	**Null hypothesis**	**Decision**
Ramsey Reset Test	1.42	0.26	Ho: The Model has no omitted variables	Fail to reject the null hypothesis
Breusch Pagan	0.28	0.59	Ho: **Homoscedasticity**	Fail to reject the null hypothesis.
Breusch-Godfrey LM test	3.146	0.21	Ho: no serial correlation	Fail to reject the null hypothesis.

The Cumulative Sum (CUSUM) and Cumulative Sum Squared (CUSUMSQ) test results are depicted in Figures 5.1 and 5.2, showing no structural instability for estimated parameters that arose over the sample period.

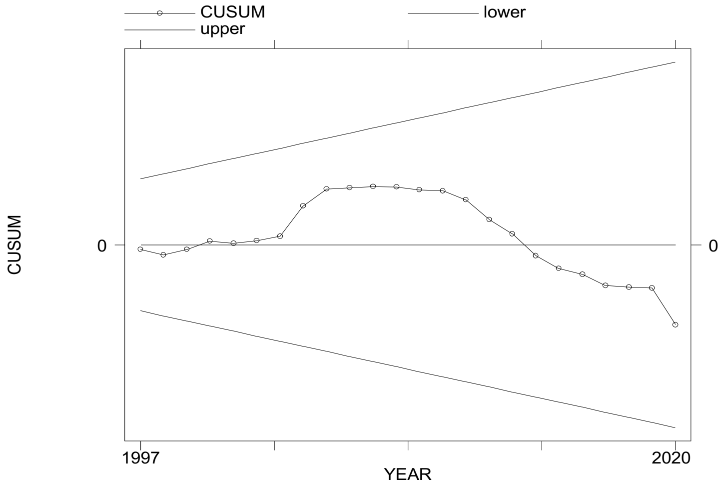

Figure 5.1: Plot of cumulative sum (CUSUM) test for Equation of renewable energy consumption

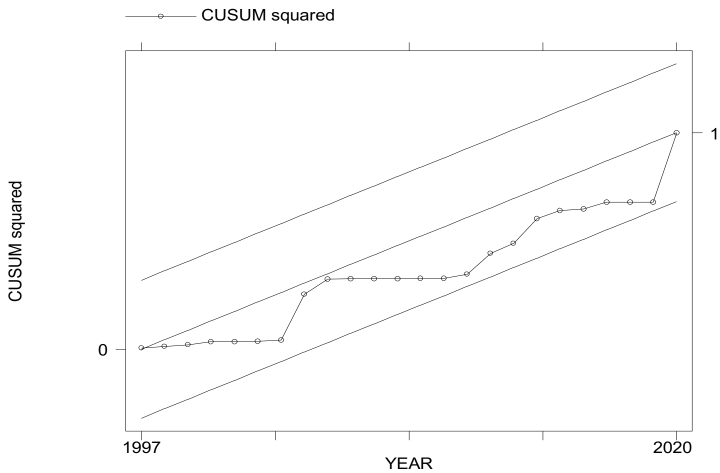

Figure 5.2: Plot of CUSUM of squares test for the Equation of renewable energy consumption

Granger Causality Test Results

Objective 2: Assessment of the direction of causality between renewable energy consumption and its determinants.

Table 5.12 indicates a bi-directional causality between renewable energy consumption and all the control variables. The established causation between the dependent variable and economic growth confirms the feedback hypothesis. Other studies that confirmed the feedback hypothesis include Payne (2010), Apergis and Payne (2012), and Lawal (2023).

Table 5.8: Granger causality Wald tests

Null hypothesis	**chi2**	**Prob> chi2**	**Decision**
Economic growth doesn't Granger cause RE consumption	20.89	0.000	reject the null
Interest rates do not guarantee cause RE consumption	11.24	0.024	reject the null
Trade openness doesn't Granger cause RE consumption	31.37	0.000	reject the null
COE doesn't Granger cause RE consumption	87.80	0.000	reject the null
FDI doesn't Granger cause RE consumption	35.03	0.000	reject the null
RE consumption doesn't Granger cause economic growth	13.99	0.007	reject the null
RE consumption doesn't Granger cause interest rates	39.4	0.000	reject the null
RE consumption doesn't Granger cause trade openness	378.79	0.000	reject the null
RE consumption doesn't Granger cause COE	149.34	0.000	reject the null
RE consumption doesn't Granger cause FDI	561.83	0.000	reject the null

6. Conclusion and Policy Implication

This study examines the macroeconomic determinants of renewable energy consumption in Tanzania using time-series data from 1990 to 2020. Utilizing the ARDL bounds test for cointegration and the Granger causality test, we found a positive and significant long-run effect of economic growth and trade openness on renewable energy consumption. Conversely, interest rates and carbon dioxide emissions negatively impact renewable energy consumption. In the short run, economic growth negatively affects renewable energy consumption, while interest rates have a positive effect. We also found bi-directional causation between renewable energy consumption and its determinants, confirming the feedback hypothesis that renewable energy consumption is related to economic growth.

The empirical findings have crucial policy implications for Tanzanian policymakers; they should keep pursuing prudent policies to ensure robust economic growth, expand international trade, and curb the cost of investments to boost the investment and consumption of renewable energy. The confirmation of the feedback hypothesis indicates that increasing economic growth enhances renewable energy consumption by improving its availability, accessibility, and affordability. Extensive use of renewable energy in power generation, households, and industries boosts economic growth by increasing output and productivity, thereby promoting sustainable development. Furthermore, policymakers should enhance existing strategies to improve the availability, accessibility, and affordability of renewable energy at all levels—from households and firms to heavy industries and power generation—to reduce the dominance of traditional energy sources. There should be deliberate efforts to enhance research and development of cheaper renewable energy technologies, hence improving their availability and affordability, and deliberate awareness campaigns on environmentally friendly technology to enhance their acceptance among the public.

As an area for future research, we recommend studies on the determinants of uptake of specific renewable energy. Much as the current assessment provides valuable insights into macroeconomic determinants of renewable energy consumption, this evidence is at the aggregate level. Studies on specific renewable energies will provide detailed information on enhancing the consumption of respective renewables.

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