**Causality between Macroeconomic Determinants and Energy Consumption in Rwanda (1990-2021)**

**Center for Development Policy (CDP)**

**Dr. Edward KADOZI & Leon Moise MINANI**

**Abstract**

Currently, energy access and its use are increasingly becoming development priorities for Africa, and Rwanda in particular, as a stimulus for economic growth. This paper examines causal relationship between energy consumption and the macroeconomic variables in Rwanda for the period from 1990-2021. The analytical framework of this study is embedded in the theoretical framework of the Kuznets curve, endogenous growth model, Putty-Putty Model and Putty-Clay Model. We employ causal estimation techniques to examine the short and long-run causal relationship between total final energy consumption and the macroeconomic variables. The results of cointegration tests reveal cointegration between dependent variables and explanatory variables. The results of Granger causality tests and ECM find strong evidence of a unidirectional relationship both in the short-run and long-run running from economic growth, population growth, urbanization, and trade openness to total final energy consumption. The findings reiterate the indispensable role of energy use in stimulating economic growth and development in Rwanda, and the need to implement energy efficiency policies and technologies that ensure less and clean energy consumption.

1. **Background**

Energy will be one of the world's major challenges in the next century, given the ever-increasing demand for energy consumption in developing countries. The demand for energy consumption is strongly correlated with the national well-being (development) and economic growth, as postulated by Wu and Chen (2017). Developing countries, in particular, Sub-Saharan Africa (SSA) are experiencing an increasing scramble for a different energy sources for consumption, as a means to stimulating growth and development of their economies. Indeed, OECD/IEA (2018) indicates that energy use in Africa as a whole rises by just under 60 percent. With increasing population, urbanization, industrialization, and less technological efficiency in energy consumption, Africa is increasingly taking the lead in global energy consumption trends. This is because energy (renewable and natural gas) is accelerating growth and development in some SSA countries, despite deficiency in energy access. The majority of these countries still rely on the traditional use of biomass. As demand for energy is on arise in Africa, there is an increasing hinted debate among academicians, scholars, and policymakers about the determinants of energy usage in the region. However, little is known about factors influencing energy consumption. Some have postulated the rise of industrialization, economic growth, urbanization, population growth, to mention but a few. We know less about the causal relationship between macroeconomic variables and the overall energy use or consumption in the region.

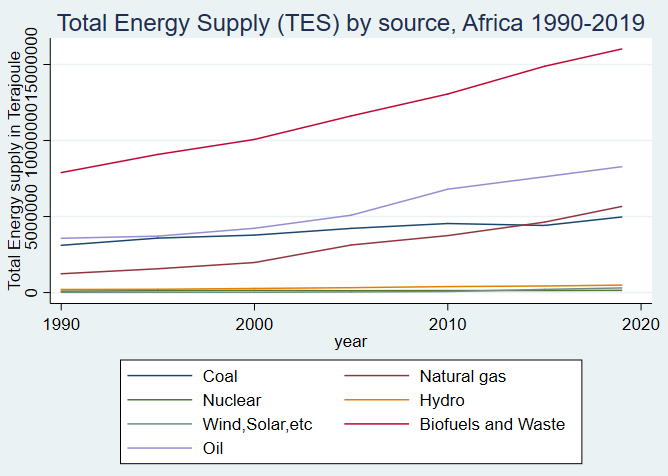
The existing theoretical framework on macroeconomic determinants of energy consumption disagrees with the way different factors influence energy consumption. Human capital development, Industrialization, Population growth, economic growth, trade openness, and financial development, among others, are some of the macroeconomic determinants, which influence energy usage, however, theoretical and empirical narratives related to the causal relationship between the above macroeconomic variables and energy consumption remain scarce and mixed.

Some existing empirical literature attribute energy consumption to overall economic growth. Many empirical studies find a reverse causality between energy usage and economic growth, GDP growth causing energy usage, while energy usage causing GDP growth, a feedback relationship, or no causality[[1]](#footnote-1). Nindi and Odhiambo (2014) claimed that economic growth leads to increased energy usage in a more energy-dependent economy. This is because strong investment in more energy-intensive manufacturing activity helps to sustain economic expansion. While Huang et al. (2008) claim that energy, consumption was negatively impacted by economic growth.

In terms of trade, trade openness stimulate business expansion and production, which increases energy use. Accordingly, Rasiah et al. (2018) argue that trade openness makes it easier for businesses to expand because they can now acquire raw materials and supply completed goods from all over the world. As a result, the amount of energy used to initiate production activities increases. While technological advancement improves efficiency in energy consumption in trade and production process. Indeed, Grossman and Krueger (1991), trade openness allows businesses to be more energy saving because they can now simply obtain energy-saving technology from anywhere in the in the world.

Empirical literature suggests population, economic activity per capita, industrialization, and technology performance as the three most basic drivers of energy demand ( see Tang, 2009; Jumbe, 2004; Narayan and Smyth, 2005; Narayan and Singh, 2007; Tang, 2008;kalid and kalid, 2010). However, the pessimistic school of thoughts claim that GDP per capita reduces energy consumption Ergun et al (2019), while expanded urbanization enhances the consumption for energy-intensive products. If used effectively can reduce energy use (York, 2007; Sadorsky, 2014). The mixed empirical findings seem to be attributed to the various factors such as stage of economic development, estimation methodology, data usage, and sample size, as emphasized by (Khanna & Rao 2009).

In Africa, energy consumption is on arise, accounting for 8 percent increase in oil consumption from 2010 -19 compared to 10 percent increase in global energy consumption. Indeed, similar evidence indicates that, final consumption (i.e. in end‐uses) of modern fuels in Africa rises on average by 5% annually compared with 2% over the previous decade despite a significant energy deficit, which is hampering its growth and development. The Africa energy outlook (2019) finds that,  most Africans do not have access to electricity, and about 80 percent of sub-Saharan African businesses experienced regular power outages, resulting in financial losses. The figure below depicts trends in energy consumption in against different energy sources in Africa with biomass taking the lion share of energy source on the continent.



***Figure 1.0.****-Total Energy Supply (TES) by source, Africa 1990-2019*

*Resource:* [*https://www.iea.org/regions/africa,2022*](https://www.iea.org/regions/africa,2022)

The Government of Rwanda is currently engrossed in intensively developing its economic sectors, such as infrastructure, industry, to mention but a few with a focus on energy as a fundamental driver of economic growth (see National Strategy for Transformation, 2020; Minecofin, 2007). Despite surging investments in energy generation and distribution, little is known about factors influencing energy consumption in Rwanda. This is further compounded by the scarcity of energy data.

The rest of this paper is structured into the Theoretical Framework, empirical discussion, discussion on energy consumption in Rwanda, empirical strategy, results and discussion, conclusion and policy implications.

**2.1. Theoretical Framework**

Scholars and policymakers disagree about the link between energy usage and its macroeconomic determinants. The narratives related to the energy consumption and the energy-growth nexus influence its macroeconomic determinants. (Georgescu- Roegen, 1971) emphasized the relevance of energy in the economic system, arguing that the physical character of economic production required more explicit emphasis in growth theory. The mainstream economists (Stern, 1999; Baptist & Hepburn, 2013; Hulten, 1978) have adopted the concept of primary and intermediate inputs of production so that energy is frequently utilized as an intermediate input because of their indirect importance, the cost of goods and services, the quality of produced items, the growth of the nation, and the availability of jobs are all directly affected by the utilization of energy in the industrial production process. The industry energy consumption is a derived consumption that began during the manufacturing process, according to Berndt and Wood (1975). This means that, like other factors of production, industrial output levels, relative prices, and technical flexibility influence energy consumption from a certain sector. As a result, several analysts have tried to figure out how to combine energy with another factor of production (for instance, Pindych and Rotemberg, 1983; Solow, 1987; Berndt and Wood, 1979; Griffin and Gregory, 1976; Morrison and Berndt, 1981).

The complementarity of capital and energy use in the production process is emphasized by both Putty-Putty Model and Putty-Clay Model created by (Robert S. Pindyck and Julio J. Rotemberg,1983). The main characteristics of putty model are that energy is very complementary to capital, and capital has adjustment costs. The stock of capital responds to changes in energy prices slowly over time because of the adjustment. Energy travels slowly because it is extremely complementary to capital in production. In the long-run, both the capital stock and energy use adjust to unavoidable price fluctuations in energy. While The Putty-Clay Model proposes that, a great number of capital goods are coupled with energy in various fixed magnitudes.

Furthermore, Ayres and van den Bergh (2005) suggest a more differentiated approach to growth drivers. They proposed an economic growth framework based on energy sources and dematerialization with three growth drivers: resource use (fossil fuel), scale cumulative learning growth mechanism and value creation (dematerialization). The authors came to a conclusion that resources input expands approximately linearly with income at sufficiently high growth rates. However, theoretical findings provide inadequate information on future growth trend in connection to resource usage, notably energy use efficiency and dematerialization. Apart from a probable decline in energy consumption through time, simulders and de nooij (2003) believe that the energy consumption is increasing at positive proportion. While energy use and economic growth are influenced by the availability of investment capital whereas energy use is affected by the level of technology as well (Dahl, 2008:56).

**2.2. Empirical Literature**

This section discusses empirical narratives about determinants of energy usage at the macro level. Energy is so essential to the growth and development process, and macroeconomic determinants of energy usage correlate with the level of development of the economies. However, empirical studies remain inconclusive, attributed to the methodological approaches employed, and inability of tools and methods to determine the causal relationship between macroeconomic factors and energy usage. Specifically, energy use is influenced by certain macro variables and to some vice versa. The link between energy consumption and economic variables has been studied since the oil crises of 1970s , especially economic growth, has been studied, but the empirical evidence is equivocal as to whether energy consumption induces economic growth or vice versa (Ozturk,2010).

For instance, Selim et al (2019) investigated the determinants that impact renewable energy use in Africa for a panel of 21 African countries from 1990 to 2013, using Fixed-effects (FE) and random effects (RE) techniques and found that nations with a larger Human Development Index and income per capita have a smaller extent of renewable energy in their grid. While, increased renewable energy integration has been linked to a rise in foreign direct investment. As a result, foreign direct investment is a factor that influences renewable energy usage, and foreign direct investment (FDI) determine the advancement of renewable energy sources in the African continent. However, Selim et al (2019) found that except for Rwanda, where the relationship is positive, though small, all nations have a negative association between GDP per capita and renewable energy consumption. This can be looked at from two perspectives: first, one of the primary goal of most emerging and underdeveloped nations is to achieve economic development. As energy promotes growth in the economy and fossil fuels are a less expensive choice, their usage will rise to encourage income growth. Second, income growth (GDP) can encourage people to look for more efficient ways of doing things other energy sources and reduce the reliance of established sources of renewable energy. Because of this the capital-intensive nature of the change, the use of renewable energy as a proportion of total energy usage is decreasing. Implying that, there is possible causal link between renewable energy usage and economic growth in Rwanda, but the underlying empirical question, is the direction of causality.

The results of Selim et al. (2019) contrast those of (Sadorsky, 2009a) in the G7 nations and ( Salim and Rafiq,2012) in emerging nations, who found that per capita income is a determinant of green energy use. On other hand ( Attiaoui et al.,2017) used the autoregressive distribution lags-pooled mean community to examine the impact of per capita CO2 emissions, GDP per capita, and per capita non-renewable energy use on renewable energy usage which is calculated using the burnable renewable ratio of total energy in 22 African nations and found that GDP per capita has little effect on renewable energy consumption.

Poumanyvong and Kaneko (2010) evaluate the effect of urbanization, industrialization, income and population on energy consumption in a sample of 99 nations from 1975 to 2005 using panel data methodologies. They found that the influence of urbanization on energy consumption varied by level of income, and that urbanization reduces energy usage in a group of small income. While it raises energy consumption in the high and middle-income categories, and urbanization reduces energy usages in the lower and intermediate socioeconomic groups. The influence of the portion of industrial output on energy usage in the economy is favorable, but only for middle and low-income classes, it is statistically significant.

Admittedly, similar empirical studies (Filippini & Pachauri, 2004) favor the influence of macroeconomic factors on energy use. Accordingly, similar evidence claim that a growing trend in the industry, population expansion, income growth, modernization, and urbanization has increased electricity consumption in the past and will continue to do so in the future. Indeed, Sadorsky (2014) finds that income under the process of rapid Industrialization and Urbanization boosts energy usage both in short-run and long run. Similarly, in terms of FDI, the nature of effects depends on the development stage. Accordingly, empirical evidence suggests a positive effect of FDI on energy usage is prevalent in developing nations, while the effect of FDI on energy usage turns to be negative in developed/industrialized economies where there is clean and new technologies that ensures energy efficiency ( see Polat,2018; Mielnik & Goldemberg, 2002; Bekhet & Othman, 2014).

In brief, urbanization can have both favorable and unfavorable effects on energy usage depending on the context and the income levels of the economies, FDI, industrialization, exports, population growth, and early stage of GDP growth largely influence energy consumption during the early stage of development, and the effect turns out to be negative in developed economies. While the causal relations turn negative in advanced economies with new and efficient technologies and increased per capita income, which reinforces Kuznets curve theoretical framework. However, the direction of causality in terms of determinants of energy usage is mixed for developing countries, attributed methodological approach and the stage of economic development.

**2.3. Contribution to the Scholarship**

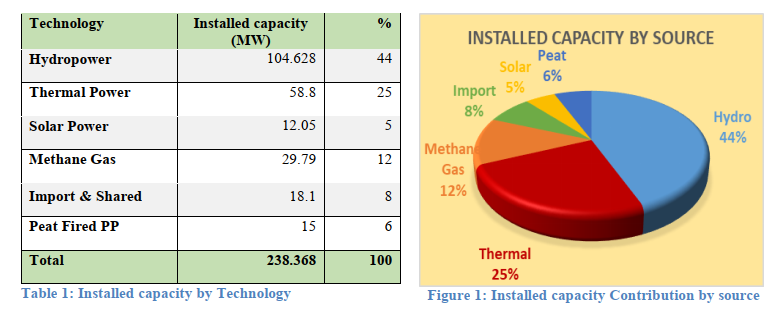
There is a growing tendency to misunderstand the determinants of energy use in developing countries such as SSA countries among empirical scholars and policy practitioners. The point of departure is about the factors driving energy consumption at the macro level, and how to quantify the effects of the same factors on total energy consumption. This question has remained contested among empirical studies and remains inconsistent, with some claiming elastic and others claiming inelastic effects for certain factors. The underlying empirical gap revolves around the causality and direction of causality among identified macroeconomic factors and energy total energy consumption. In terms of causation, empirical findings classify these factors or variables into three categories: unidirectional causality, second bidirectional causality, and finally, no causality (Akinlo, 2009). This inconclusiveness seems to stem from the scope and the context of the study.

Several studies indicate that GDP per capita, population expansion, urbanization, industrialization, trade openness, and FDI determine energy demand, however, the empirical findings are mixed. Technological progress, the level and quality of growth and development are among the contributing factors. In Rwanda, sparse is known about how the above factors contribute to the energy demand. For instance, since the last two decades we see an exponential shift in energy demand and economic growth in Rwanda. Despite the fact that Rwanda's energy situation has improved, little attention has been made to examining the determinants of the country's energy usage. Only a least minimum of researchers, particularly in Africa, have looked at the time-varying behaviour of energy determinants. More so, less attention is paid to the contextual realities of countries. We know from the fact that African countries are at different levels of development with heterogeneity of local policy frameworks. Therefore, the heterogeneity of economic structures influences energy consumption. Indeed, Sari, et al (2008) insert that, the disparity in empirical results could be attributable to the diverse economic structures of the nations under study. Thus, empirical analysis needs to cater for contextual heterogeneity within and across countries. This study seeks to bridge the gap by employing two methodological frameworks to examine the link between energy usage and macroeconomic variables.

We, therefore, situate this study in the context of other similar studies by employing the same variables recommended by the theoretical and empirical literature. The study seeks to examine the causal relationship between energy usage and macroeconomic variables.

**2.4. An Overview of Energy Use in Rwanda**

According to different studies (Safari B. K., 2010; MINENFRA, 2018; business-Sweeden, 2016), Rwanda has different sources of energy including but not limited to photovoltaic, biomass, hydropower, methane gas, and geothermal power however, most these are not yet used to their full potential. For instance, the electricity supply in Rwanda is sourced mainly from hydropower and thermal sources respectively. As of June 2021, the Rwanda Energy Group (REG) annual report 2020-2021 indicates that 64.53 % of households had access to electricity, up from 55.41 % in June 2020 against the country’s target of 100% by 2024 according to the Rwanda Energy Sector Plan (2018). The country targets to reduce biomass use to 42% from the current 83% and increase electricity generation capacity to 556MW in the same period. For instance, as of September 2021, the total installed power generation capacity had increased to 238.37 MW, up from 228.418 MW in June 2020. The independent power producers now have 121.52MW of installed capacity accounting for 50.78 % of total installed capacity largely owned by the Government of Rwanda (99.216 MW), which accounts for 41.62 % of total installed capacity, and imported energy (18.1MW) accounts for 7.59 %. Hydropower and thermal power continue to dominate installed energy sources with the biggest shares of installed generation capacity of 44% (104.628 MW) and 25% (58.8MW), respectively, while solar power provides the least (5%) as per table 1 and graph 1 here below.

**Source:** Rwanda Energy Group (REG) annual report 2020-2021

However, the traditional source of energy, biomass including firewood, charcoal, crop wastes and many others remains the largest source of energy in Rwanda accounting for 85% dominantly used by rural households and contributing about 5% to the GDP.

**2.5 Energy Consumption in Rwanda**

In Rwanda, despite the recent effects of COVID-19, the country experienced exponential economic growth with average annual GDP growth ranging between 7% and 8%. Energy production and consumption have witnessed a continuous increase in recent years. Rwanda’s electricity demand is grouped into two categories; the residential sector comprises the households as consumers and the non-residential sector covers all agricultural, industrial, and service sectors respectively. The electricity demand per house in the base year, as well as the predicted population and GDP, are required inputs in estimating future power demand (Mudaheranwa et al., 2019). Among the determinants of recent economic growth in Rwanda, there has been the emergence of industrialization, public investments and tradable services respectively. The emergence of these sectors is strongly associated with an increase in energy demand and consumption. However, sparse is known to confirm the causal effect. The Government of Rwanda is currently engrossed in intensively developing its sectors, such as infrastructure, with a focus on energy as one of the fundamental mediating drivers of economic growth (Minecofin, 2007).

Nevertheless, the overall total energy consumption has increased exponentially over the last three decades, though it is still dominated by the traditional source of energy (biomass). We know that more than 75 percent of people in the country still cook with antiquated, ineffective methods. According to the results of the most recent National Institute of Statistics of Rwanda (NISR) household survey (EICV 6), 77.7% of the population still uses firewood as a source of cooking fuel (see MINIFRA, 2021). Besides biomass, consumption of other sources of energy is still low, but progressively increasing with income levels. Households move from traditional energy to new fuels and technologies partially rather than as full substitutes and as the term leapfrogging implies (Arnold et al., 2006). There is a rapid transition from the traditional source of energy to modern sources like electricity (Murphy, 2001). Accordingly, figure 2 presents the trends of energy consumption by sector in Rwanda. Rwanda’s energy profile shows that Energy consumption increased progressively in different energy sources as illustrated in Figure 2.

**Figure 2.Evolution of Energy Consumption by Source and Sector (%)**

**Source:** (MINIRENA, 2022)

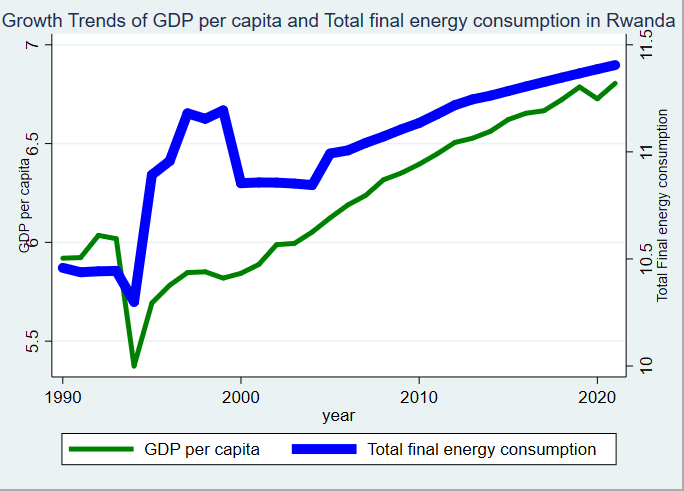
Evidently, figure 2 demonstrates that households are the main source of energy consumption in Rwanda, with traditional sources (biomass) still taking the lion’s share followed by transport and industry. (see Figure 3). However, the transition from traditional to clean energy is still moderate.

**Figure3: Total Energy Consumption by Sub-Sector**

Source :( MINENFRA, 2018)

The energy consumption is dominated by households (82%), which are largely dependent on traditional sources of energy, which is largely consumed by rural households. The socio-economic status of the households determines the consumption and accessibility patterns of energy use in Rwanda. Accordingly, the majority of rural households are under the poverty category, which makes it hard for them to shift to other sources of energy for use, but also the issue of accessibility is playing out. In addition, the quantity and type of energy use depend on the socio-economic characteristics of households and the area of residence (Marathe & Eltrop, 2017). Accordingly, 84% of rural households use traditional sources of energy, against 15% who use modern sources of energy. IOB (2014) note that the distinction in a household's payment ability has an effect on choice, connectivity access, and quantity of energy to consume. This is reinforced by the findings of the Rwanda Poverty Profile Report 2016/17 (EICV5) which shows the impact of the poverty status on energy consumption in Rwanda. Accordingly, 10 percent of poor households use electricity against 76 percent of rich households (NISR, 2018). Despite the observed gap, overall, energy consumption has increased with Rwanda’s economic growth in recent years represented by GDP per capita. The figure 3 depicts trends of GDP per capita and total energy usage in Rwanda.

**Figure 4: Energy Consumption Nexus Economic Growth**



**Source:** Author's estimation based on (June 2022) time-series data from our World in data.

The figure 4 depicts a positive association between energy consumption (Total final consumption) and economic growth (GDP per capita) for the period from 1990 to 2021.

**3.0. Data and Sources**

This study relies on macroeconomic determinants of energy consumption in Rwanda with time series data from 1990 to 2021. The data set of this study is based on secondary data sourced from the World Bank (2022) World Development Indicators. Related theoretical and empirical narratives about energy consumption, respectively informed the selection of control and dependent variables. The data involved in this study include population growth, Industry (including construction), GDP growth (annual % growth), Foreign direct investment as percentage of GDP (FDI % GDP), Trade openness (summation of imports and exports to GDP) (ToT % GDP), Urban population (% of the total population), and Total Energy Consumption (TEFC).

In table 3, 4. I report the summary statistics, the correlation matrix of the studied variables,

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Table 3: Summary Statistics** |  |  |  |  |
|  |  |  |  |  |
|  | Mean | Standard Deviation | Minimum | Maximum |
| TFEC[[2]](#footnote-2) | 6329.2 | 17402.27 | 29724.3 | 89798.7 |
| GDP per capita | 531.6 | 197.17 | 215.75 | 902.61 |
| Industrialization | 7.13 | 17,89 | -65.34 | 48.39 |
| Foreign Direct investment | 1.29 | 1.35 | -0.57 | 3.81 |
| POP | 1.87 | 3.3 | -6.76 | 8.11 |
| Trade openness | 33.19 | 12.19 | 13.94 | 57.11 |
| Urbanization | 14.54 | 3.96 | 5,41 | 17.56 |
| Observations | 32 |  |  |  |

Source: Author's estimation based on (September 2021) time series data from World Bank Dataset.

Total final energy consumption shows the greatest average among all the variables while foreign direct investment shows the smallest mean. All variables shows the highest observations of Thirty two.

Table 4: Pairwise correlations between variables used in the Equation

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Variables | Total FEC | GDP | ToT | POP | Industrialization | FDI%GDP | Urbanization |
| TFEC | 1 |  |  |  |  |  |  |
| GDP pc | 0.750\*\*\* | 1 |  |  |  |  |  |
| ToT | 0.766\*\*\* | 0.875\*\*\* | 1 |  |  |  |  |
| POP | 0.706\*\*\* | 0.201 | 0.306\* | 1 |  |  |  |
| Industrialization | 0.470\*\*\* | 0.173 | -0.009 | 0.476\*\*\* | 1 |  |  |
| FDI%GDP | 0.664\*\*\* | 0.815\*\*\* | 0.558\*\*\* | 0.364\*\* | 0.487\*\*\* | 1 |  |
| Urbanization | 0.816\*\*\* | 0.573\*\*\* | 0.756\*\*\* | 0.645\*\*\* | 0.320\* | 0.497\*\*\* | 1 |

*\*\*\* p<0.01, \*\* p<0.05, \* p<0.1*

**Notes:** The correlation matrix of the dependent and control variables are shown in this table 4. Variables for: Total final energy consumption, GDP per capita, industrial growth as a proxy of industrialization, foreign direct investment percentage to GDP, population growth, and urban population percentage of the total population. Except population growth and industrial growth, other variables expressed in logarithm form. The correlation result of all the control variables are statistically and significantly correlated except the correlation between industrial growth, population growth and GDP per capita.

**3.2. Empirical Strategy**

**3.2.1. Model specification**

To examine the determinants of energy consumption in Rwanda, the study employs time series data and two-stepwise analytical frameworks. The empirical model (1) is based on the assumption that total final energy consumption is determined by foreign direct investment (FDI), industrialization, population growth, GDP per capita, Urbanization, and Trade openness. This empirical model seeks to identify the nature and relevance of the macro determinants in the empirical model. This study follows the following nested stages of analysis:

Firstly, the study employs the ordinary least square (OLS) as the baseline model, however, empirically, OLS is criticized for being subjected to the endogeneity bias. For instance, economic growth might influence energy consumption and energy consumption might influence economic growth (reverse causality) mostly at early phases of economic growth and development. We address the existing empirical the problem of endogeneity bias by employing the causal estimation techniques.

Secondly, the study employs causal estimation techniques, for instance, granger causality to study the short and long-run causality among the total final energy usage- as dependent variable and the control variables. The unit root tests are used to determine whether the time series data of studied variables are stationary before attempting to identify whether the variables are cointegrated. The cointegration technique is used to examine the long-term relationship between the dependent variable and control variables. Thirdly, the granger causality test is employed to examine the direction of causality. The outcomes could be unidirectional, Bi-directional, or there could be no causality at all. Lastly, the Error Correction Model (ECM) is employed to study the short and long-run nature of causality between total final energy demand and the control variables, the direction of causality.

We estimate the baseline as follows:

(1)

The model is stated as Eq.2 after assuming a relationship among the variables.

To capture semi-elasticities, the variables were transformed into logarithmic form, turning Eq (2) into the log-linear specification, empirical model as follows:

*ln*

Where, is the total final energy consumption expressed in terajoule, α is an intercept, β1, β2, β3, β4, β5 and β6 respectively denote the elasticity coefficients of GDP per capita at constant (2015) US$, population growth rate (POP), Urb denotes urban population, a measure of urban population percentage of total population as proxy of urbanization, Indu denotes measures industrial growth as proxy of industrialization , FDI is the measure of foreign direct investment as a percentage of GDP used to represent the impact of external sources on growth, TOT is the measure of openness to trade for Rwandan economy measured as the ratio of the total of exports and imports to GDP which are parameters/coefficients of interest, *t* denotes time period, and Ɛt is an error term.

The model three (3) is transformed into model four (4) captures the interaction between industrialization and trade openness in Rwanda to determine how trade openness moderates energy consumption through industrialization.

*ln)*

Building on the results of model four (4), causal estimation techniques such as such as granger causality and VECM are used to examine the short and long-run relationship between dependent variable and independent variable as well as the direction of causality.

3.2.2**. Unit Root Test**

If the mean, variance, and auto covariance of time series data stay constant across time, they are said to be stationary.

Most of the macroeconomic factors are not stationary and when the regression of two or more variables is non-stationary, spurious regression occurs. As a result, the properties of the time-series data used for a model estimate will be determined to prevent the problem of spurious regression. Hence, the unit root test is used to identify the stationary (Gujarati, 2004).

The integration analysis is the initial phase in the testing procedure. The goal is to assess if the time series variables used in the model are stationary. Engle RF and Granger C (1987) showed that a linear combination of non-stationary series can be stationary, and the series is deemed cointegrated if this stationarity exists. This implies the integration of the series in the same order. To evaluate whether the series is stationary or not, the augmented Dickey-Fuller (ADF) test (Dickey, 1979) is used. Whether the selected research variables' time-series data are stationary at level, first difference, or both.

(4)

Where denotes any variable in the model are, t is the trend . is the different operator.,,,…, is a set of parameters. The null hypothesis implies that there is unit root or is non-stationary ( against the alternative hypothesis.

**3.2.3. Cointegration**

This study uses the autoregressive distributed lag model (ARDL) technique proposed by (Pesaran, 1997; Pesaran and shin,1998; Pesaran et.al,2001) to examine the long-run relationship between energy use and control variables. It was also used to examine the links between time series data variables i.e, TFEC, GDPpc, Ind, Pop, Urb, Open and FDI in the long run.

The traditional ARDL cannot evaluate a series integration of a certain order or difference stationery as a basic postulate. Hence, an alternative estimating approach was developed (see Engle and Granger,1987, Johansen,1991, Phillips and Hansen,1990).

Another problem in evaluating starting long-run relationship is that the cointegration test is ineffective when variables are integrated into different orders. Recent existing literature on re-parameterizing the ARDL model to the Error Correction Model have emerged as a solution for identifying long-term relationship among series with differing integration orders (see Min and Guna, 2017). The significant impact on the results yields both short-run and long-run relationships similar to the ARDL.

There are five main reasons why limits testing is preferred over standard multivariate cointegration techniques (Engle and Granger, 1987; Johansen, 1988; Johansen and Juselius, 1990). First, Once the model lag order has been determined, The ARDL model can be estimated using Ordinary Least Squares (OLS). Second, Both the long-run and short-run parameters of the model can be computed simultaneously. (Pesaran and shin ,1998;pesaran et al.2001). Third, it may be used irrespective of the order in which the underlying variables are integrated (Pesaran and shin,1998). However, to avoid spurious regression or an ARDL procedure crush, verify that none of the variables are I (2). Fourth, the test's efficiency is improved much more when small (limited) sample sizes are used (Haug,2002). Lastly, according to Banerjee et al. (1998), Autoregressive distributed lag does not transform short-run coefficients into residuals.

The ARDL model is expressed as follows Eq,(5)

=+++++++(5)

Where ε is the white noise error term and Δ entitles the difference operator. The error correction dynamics are represented by the summation sign and symbolizes constant.

The long-run relationship is represented by the second part of Eq. (5). The FPE,AIC, SC, and HQC were used to determine the appropriate lag of each series in the model. Accordingly, (Pesaran et.al.2001) affirms the overall relevance of evaluation of the lagged level of the research time-series data using Wald (F statistics). Furthermore, the long-run coefficient is determined if there is a long-run relationship between among variables. Equation (6) for the long-run estimation model is as follows:

=++++++(6)

In addition, if the indication of a long-term association between the research variables is determined, the short-run model that is predicted. Thus, Equation (7) is the short-run model that is used.

=+++ ++++

+ (7)

Where the coefficient of the ECT is represented by η in the estimated model.

**3.2.4. Granger Causality Test**

This testing procedure is used to determine the direction of a causality among two variables using granger causality test. According to the granger (1969) test, if the past values of X make a significant contribution to forecasting the value of another valuable Y, then that X is a granger cause Y, and vice versa.

If the data are not I(1), or even if they are all I(1) but not cointegrated, then there is no long-run relationship between them, according to the Granger causality theories. However, in this scenario, a short-run causal relationship may exists. If they are cointegrated, it means there is a long-run relationship among them, implying causality is at least in one way. Then, the direction of causality is examined using a Vector error correction model (VECM).

++ (8)

+ (9)

Where and are the variables in our model, which are , to be tested.. and are respective error term and t denotes period z and i’s are a number of lags. The null hypothesis for all i’s versus the alternative hypothesis th for at least some i’s if the coefficient are statistically significant but are not, then X causes Y and vice versa, but If both coefficients are significant, causation is present in both directions.

**4. EMPIRICAL RESULTS AND DISCUSSION**

This section presents the results of the econometric analysis and a discussion of the main findings from OLS baseline model. The section further presents the findings of the unit root test, cointegration test, granger causality test, and the Error Correction Model.

**4.1. Results of OLS Estimation**

The table 5 below presents the results of OLS estimation approach examining the effects of control variables (macroeconomic variables) on the final energy consumption in Rwanda.

Table 5: Presents the effects of macroeconomic variables on Total Final Energy Consumption

|  |  |
| --- | --- |
|  |  |
| VARIABLES | Total final energy consumption |
|  |  |
| GDP per capita | 0.572\*\*\* |
|  | (0.174) |
| Population | 0.0468\*\*\* |
|  | (0.00960) |
| FDI%GDP | -0.0214 |
|  | (0.0206) |
| Urbanization | 0.0362 |
|  | (0.102) |
| Industrialization | 0.0362\*\*\* |
|  | (0.0106) |
| Trade openness | 0.145 |
|  | (0.129) |
| ToT\*Indust | -0.00995\*\*\* |
|  | (0.00316) |
| Constant | 6.750\*\*\* |
|  | (0.744) |
|  |  |
| Observations | 31 |
|  |  |

Standard errors in parentheses

\*\*\* p<0.01, \*\* p<0.05, \* p<0.1

The OLS results from table 5 reveal that the GDP per capita statistically and significantly influences total final energy consumption. Evidently, implies that 1% rise in GDP per capita rises total energy demand by 0.572 percentage growth. These findings are reinforced by previous study by (Selim et al, 2019) from similar context. The findings are in line with the stylized trends of GDP per capita with total final energy consumption in Rwanda. Implying that, energy consumption is influenced by the pace of economic growth, or vice versa.

Population growth statistically and significantly influence total energy consumption. Evidently, implies that 1% in population growth increases total final energy consumption by 0.047 percentage increase. These results are reinforced by previous empirical findings by ( Udo et al.2011; Khalid Zaman et al,2012; Chor Foon Tang,2008) who argue that population growth significantly impact energy use. This confirms the traditional view of the energy-population nexus, which argues that energy consumption is determined by population levels. This implies that the larger the population, the more overall energy is required, and that energy consumption is determined exogenously by the population. With increasing population growth, in line with a shift from traditional source of energy to the modern source of energy, population growth influences the overall energy consumption.

Urbanization do not exhibit a significant effect on energy consumption in Rwanda, despite a rapid increase in urbanization mostly in secondary and satellite cities respectively.

Industrialization statistically and significantly increase total energy consumption. This implies that 1% rise on industrialization, increase energy consumption by 0.362 percentage. With less energy efficient technologies and less energy efficient policies, industrialization positively effect energy use mostly at early take-of stage in developing countries like Rwanda. More energy is required when industrial activity grows to boost the gross domestic product. This results is reinforced by the study of Samouilidis & Mitropoulos, 1984 ; Sahoo & sethi,2020; Sadorsky,2014) which affirm a positive link between industrialization and energy usage.

The results indicate an insignificant effect of Trade openness on total energy consumption contrary to the previous empirical findings (Rafindadi& Ozturk, 2017; Rafindadi, 2015; Alkhateeb& Mahmood, 2019). However, we find interactively Trade Openness affecting energy consumption through industrialization. Evidently, the findings indicate no statistically insignificant coefficient of Trade Openness on energy consumption, but the coefficient of interaction term of Trade Openness and Industrialization is positive and statistically significant (0.0262\*\*\*). This provides strong empirical evidence that the conditional marginal effect of Trade Openness on energy consumption moderates through the prevailing industrialization in Rwanda.

The findings indicate no significant effect of on total final energy consumption. Implying that, foreign direct investments are not influencing energy consumption at macroeconomic level. These results are reinforced by previous empirical findings of (Mielnik & Goldemberg, 2002; Polat,2018; Lee ,2013). This seems to be attributed to the quantity and quality of FDI in terms of energy efficiency for FDIs operating in Rwanda at macro level.

In sum, the results of OLS strongly point to the positive and statistically significant effect of GDP per capita, population growth, and industrialization respectively on the total final energy consumption, while FDIs, urbanization, and Trade Openness do not statistically and significantly effect on energy consumption in Rwanda.Nevertheless, Trade Openness affect energy consumption through the increasing levels of industrialization.However, the results of OLS estimation technique is criticized in the empirical analysis for being biased and inconsistent estimates due to the omitted variables (one special form of endogeneity), measurement errors, and heteroscedasticity, which lead to biased and inconsistent OLS causal estimates. We address this problem by employing causal estimation techniques to examine the causal relationship between Total final energy consumption (dependent variable) and the control variables. We examine both short and long-run relationship, as well as the direction of causality.

4.2. **Unit root test**

The empirical results of Augmented Dickey-Fuller (ADF) unit root tests were employed to estimate the stationarity of the variables of interest, as recommended by  Dickey and Fuller (1979) test. Table 6 presents the findings of the unit root with maximum lags specified.

Table 6: The Summary Results of Augmented Dickey-Fuller (ADF) Unit Root Tests

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Variables | Order of integration | P-value | Test-statistic | 5% Critical value | |
| TFEC | I(1) | 0 | -6.001 | | -3.58 |
| GDP | I(1) | 0 | -5.546 | | -3.584 |
| Industrialization | I(0) | 0 | -6.293 | | -3.576 |
| FDI%GDP | I(0) | 0.0086 | -3.939 | | -3.592 |
| ToT | I(0) | 0.0008 | -4.352 | | -3.588 |
| Population | I(0) | 0 | -7.729 | | -3.592 |
| Urbanization | I(0) | 0.0086 | -4.008 | | -3.592 |

**Source**: Authors’ Estimation using Stata 15

The results in Table 6 show that FDI, industrialization, population growth, trade openness, industrialization, and urbanization are all integrated at the order zero, *I*(0) and their corresponding P-values are under critic values at level (at 5% significance level). On either hand, Total final energy consumption, and GDP per capita are integrated of the order one, *I*(1). Hence, the data are non-stationary time-series integrated at the order of one I(0) and I(1).

4.3.**Lag Selection**

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Sample: 1994 - 2020, but with a gap** | | | |  | | |  | |  | **Number of obs = 27** | | |
| **No of lags** | | **LL** | **LR** | | **df** | **P** | | **FPE** | | **AIC** | **HQIC** | **SBIC** |
| 0 | -119.27 | |  | |  |  | | 0.00002 | | 9.35347 | 9.45337 | 9.68943 |
| 1 | 116.889 | | 472.32 | | 49 | 0 | | 2.9e-11 | | -4.51026 | -3.71108 | -1.8226 |
| 2 | 280.347 | | 326.92 | | 49 | 0 | | 1.5e-14 | | -12.9887 | -11.4902 | -7.94934 |
| 3 | 139.95 | | 2231.2 | | 49 | 0 | | 2.5e-47\* | | -91.9965 | -89.7987 | -84.6054 |
| 4 | 5247.7 | | 7703.5\* | | 49 | 0 | | - | | -374.718\* | -372.02\* | -365.648\* |

Table 7: The Number of Lags Selected

**Notes:** Endogenous: Total final energy Consumption. Exogenous: foreign direct investment (FDI%GDP), industrial growth, population growth, GDP per capita, Urbanization, and Trade openness. LL = The log likelihood, LR = Likelihood-ratio, df = degree of freedom, P = probability, FPE = The final prediction error, AIC = Aikaike Information Criterion, HQIC=Hannan criterion, SBIC: Bayesian Information Criteria. \* indicates significant at the 1% level.

To address the sample's limitation, this study uses the FPE criteria to determine the best appropriate lag for the model as suggested by Venus Khim−Sen (2004) for small samples (i.e 60 observations and below), Akaike's information criterion (AIC) and final prediction error (FPE) perform better than the other criteria being considered. Accordingly, the results in table 7 show that the optimal lag selected is three (3) based on FPE Tests. This indicates that macroeconomics variables and total final energy consumption are explained in three lags.

**4.4. ARDL bound test *Cointegration Results***

The ARDL bound test of cointegration is used to analyze the long-run relationship between the variables in Equations (6) and (7) after validating the unit root properties of the variables. More so, the study uses FPE criteria to locate the optimal fitting lag for ARDL model to solve the sample’s limitation and the optimal lag selected is three based on FPE Tests. Enders (2004) claims that for yearly data analysis, the system’s dynamics can be captured with an optimum lag order of three years. Therefore, The ARDL –bound testing approach is used to describe the cointegration relationship between total final energy consumption and the control variables. (Persan et al. 2001) recognize the value of critical bounds for both small and big samples.   
**Table 9: Showing the Results of ARDL the bounds test of cointegration**

|  |  |  |
| --- | --- | --- |
| Model | TFEC=∫(GDPPC,INDUS, ,FDI,POP,URB,TOT) | |
| Optimum lag structure | 3 3 2 3 3 1 3 |  |
| F statistics | 337.092 |  |
| Critical Values | 1% |  |
| Lower Bounds I(0) | 3.15 |  |
| Upper Bounds I(1) | 4.43 |  |
|  |  |  |

Building on the work of (Pesaran et al.2001), the computed F-statistic is 337.092 in the ARDL bound test greater than the upper critical bound value of 4.43 at the 1% significance level. Thus, the null hypothesis of no cointegration is rejected. Implying that, in Rwanda, the final energy consumption, GDP per capita, industrialization, urbanization, and population growth, trade openness are all cointegrated. These findings are reinforced by previous empirical studies (Mavikela& Khobai, 2018; Soytas &Sari, 2003; Sadorsky, 20144.5).

**4.5. Granger causality Wald tests**

We examine the long-run relationship between final energy consumption with explanatory variables using Granger Causality Test. Table 10 presents the results of Granger Causality. Accordingly, the results of the granger causality tests confirm short-run bidirectional causality traced between population growth, urbanization and energy usage, the unidirectional causality runs from trade openness to total final energy usage. Furthermore, the results reveal no evidence of causal effect between GDP per capita, industrial growth, foreign direct investment and total final energy consumption.

**Table10: Granger causality Test Results**

|  |  |  |
| --- | --- | --- |
| Null Hypothesis | Chi square (F-statistic) | p-value |
| Total final energy consumption did not granger cause GDP per capita | 0.27691 | 0.926 |
| GDP per capita did not granger cause Total final energy consumption | 0.26593 | 0.606 |
| Total final energy consumption did not granger cause Trade openness % GDP | 0 .12507 | 0.724 |
| Trade openness do not granger cause Total final energy consumption | 5.5232 | 0.136 |
| Total final energy consumption did not granger cause Population Growth | 42.528 | 0.000\*\*\* |
| Population growth did not granger cause Total final energy consumption | 121.35 | 0.000\*\*\* |
| Total final energy consumption did not granger cause industrial growth | 0.61351 | 0.433 |
| industrial growth did not granger cause Total final energy consumption | 0.07091 | 0.790 |
| Total final energy consumption did not granger cause FDI%GDP | 1.028 | 0.311 |
| FDI%GDP did not granger cause Total final energy consumption | 0.00092 | 0.799 |
| Total final energy consumption did not granger cause Urbanization | 12.25 | 0.000\*\*\* |
| urbanization did not granger cause Total final energy consumption | 13.333 | 0.000\*\*\* |

**Note:** \*\*\*, \*\*, and \* indicates the rejection of the Null hypothesis at 1%, 5% and 10% significant level, respectively.

Overall, the results validate different causal relationships for different variables. The H0 is rejected on trade openness and urbanization respectively. Accordingly, the results reveal unidirectional long-run causality from trade openness to total final energy consumption. This implies that increasing trade openness through international trade decreases energy consumption in the long-run through adoption of energy-efficient technologies, and hence energy intensity significantly decreases in the long-run. Similarly, a unidirectional causality running from urbanization and population growth to the total final energy consumption is detected. Implying that, the existing increase in the rate of urbanization and population growth, with no efficient energy policies have a short-run significant effect on total final energy consumption in Rwanda. While for other variables, the results indicate no causal relationship between total final energy consumption and GDP per capita, FDI and industrialization respectively.

**4.6. Error Correction Model (ECM)**

We examine the short and long-run causality between total final energy consumption and other control variables using a vector error correction model. Table 11 presents the results for ECM. The results reveal the short and long-run relationship between total energy consumption and explanatory variables.

**Table 11: Showing Results of Vector Error Correction Model (ECM)**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | (Model 1) | (Model 2) | (Model 3) | (Model 4) | (Model 5) | (Model 6) | (Model 7) | |
| VARIABLES | D\_LTFEC | D\_LGDP | D\_LToT | D\_POP | D\_Indus | D\_LFDI | D\_LUrban | |
|  |  |  |  |  |  |  |  | |
| ECT(L.\_ce1) | -0.0446\* | -0.186\*\*\* | 0.333\*\*\* | 0.00779\*\*\* | -2.357\*\*\* | -18.83\*\*\* | 0.134\*\* | |
|  | -0.0251 | -0.0392 | -0.0371 | -0.00281 | -0.651 | -5.086 | -0.0543 | |
| LD.LTFEC | -0.876\*\*\* | -0.00231 | -1.028\*\* | -0.0397 | 2.319 | 35.63 | 0.662 | |
|  | -0.318 | -0.498 | -0.47 | -0.0357 | -8.261 | -64.53 | -0.689 | |
| L2D.LTFEC | -0.123 | 0.0687 | -1.359\*\*\* | -0.0608\* | 5.141 | 83.23 | 0.763 | |
|  | -0.282 | -0.442 | -0.418 | -0.0317 | -7.338 | -57.32 | -0.612 | |
| LD.LGDP | -0.0709 | -0.213 | -1.866\*\*\* | -0.150\*\*\* | 2.658 | -108.9\*\* | -0.408 | |
|  | -0.225 | -0.351 | -0.332 | -0.0252 | -5.832 | -45.56 | -0.487 | |
| L2D.LGDP | 0.302 | 0.386 | -1.170\*\* | 0.0327 | 4.062 | -1.612 | 0.202 | |
|  | -0.311 | -0.487 | -0.46 | -0.0349 | -8.078 | -63.1 | -0.674 | |
| LD.LToT | 0.242\*\*\* | 0.258\*\*\* | 1.093\*\*\* | -0.00754\* | 3.071\*\*\* | 25.44\*\*\* | -0.288\*\*\* | |
|  | -0.0365 | -0.0571 | -0.054 | -0.00409 | -0.948 | -7.404 | -0.0791 | |
| L2D.LToT | -0.158\*\*\* | -0.256\*\*\* | -0.290\*\*\* | 0.0136\*\*\* | -3.163\*\*\* | -29.17\*\*\* | 0.199\*\* | |
|  | -0.0393 | -0.0615 | -0.0581 | -0.00441 | -1.021 | -7.979 | -0.0852 | |
| LD.PoP | 0.99 | 1.086 | 2.683\*\* | 1.137\*\*\* | 20.84 | 26.67 | -2.338 | |
|  | -0.714 | -1.117 | -1.055 | -0.08 | -18.54 | -144.8 | -1.547 | |
| L2D.PoP | -2.040\*\* | -4.487\*\*\* | 3.065\*\* | -0.212\*\* | -59.16\*\*\* | -352.6\*\* | 4.853\*\*\* | |
|  | -0.856 | -1.34 | -1.266 | -0.096 | -22.24 | -173.8 | -1.856 | |
| LD.Indust | 0.000908 | 0.0199 | 0.0141 | 0.00537\*\*\* | -0.414 | 3.42 | 0.0327 | |
|  | -0.014 | -0.0219 | -0.0207 | -0.00157 | -0.363 | -2.836 | -0.0303 |
| L2D.Indust | -0.000749 | -0.0134 | -0.0146 | -0.000816 | -0.748\* | -0.367 | 0.023 |
|  | -0.0158 | -0.0248 | -0.0234 | -0.00178 | -0.412 | -3.215 | -0.0343 |
| LD.LFDI | 0.000262 | 0.00215 | 0.000925 | 0.000338\*\* | 0.0251 | -0.573\* | 0.000586 |
|  | -0.00153 | -0.0024 | -0.00226 | -0.000172 | -0.0398 | -0.311 | -0.00332 |
| L2D.LFDI | -0.00196\* | -0.00223 | 0.00494\*\*\* | 0.000234\* | -0.0183 | -0.562\*\* | 0.00199 |
|  | -0.00112 | -0.00176 | -0.00166 | -0.000126 | -0.0291 | -0.228 | -0.00243 |
| LD.LUrban | -0.219 | -0.29 | 0.592\*\*\* | 0.0108 | 0.224 | -56.69\*\* | 0.0944 |
|  | -0.137 | -0.214 | -0.203 | -0.0154 | -3.56 | -27.81 | -0.297 |
| L2D.LUrban | 0.0181 | -0.328 | 0.0431 | 0.0309\* | -3.946 | -16.39 | 0.367 |
|  | -0.148 | -0.232 | -0.219 | -0.0166 | -3.844 | -30.03 | -0.321 |
| Constant | 0.0462 | 0.0206 | 0.247\*\*\* | 0.00860\*\* | -0.585 | 0.0773 | 0.00659 |
|  | -0.0327 | -0.0512 | -0.0484 | -0.00367 | -0.85 | -6.64 | -0.0709 |
|  |  |  |  |  |  |  |  |
| Observations | 28 | 28 | 28 | 28 | 28 | 28 | 28 |

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

The coefficients of the total energy consumption and control variables detect short-run causality running from GDP per capita, trade openness, population growth, industrialization, FDI, and urbanization to total final energy consumption. Accordingly, the value of on model 2 is -0.186\*\*\* and it is significant at 1%, on model 3 is 0.333\*\*\* and it is significant at 1%; significant at 1% on model 4 is 0.007\*\*\*,. On model 5 is -2.357\*\*\*, on model 6 is –18.8\*\*\*, significant at 5% on on model 7 is 0.134\*\*. These values represent the short-run coefficients and short-run equilibrium. For long-run equilibrium relationship, the adjustment term (-0.0446\*) is statistically significant at 10 % level with negative sign, implying that the previous year deviation from long-run equilibrium is corrected within the current year with an adjustment speed of 4.4%.

**Table 12.Diagonistic test showing results of serial correlation and Normality tests.**

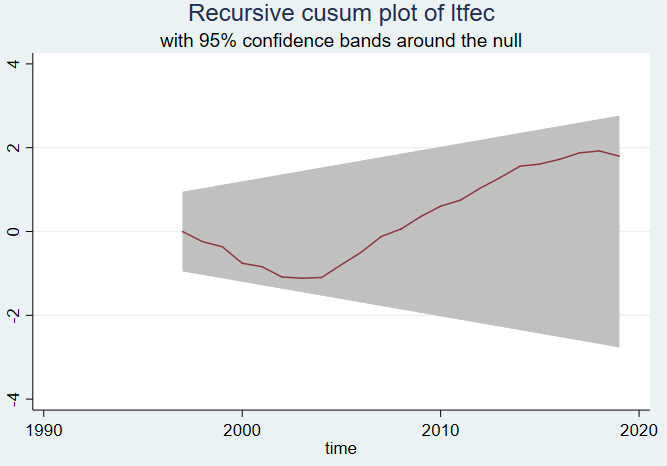
|  |  |  |
| --- | --- | --- |
| Diagonistic tests | Statistics | Results |
| R squared | 0.9531 | Good fitted |
| Adj R-squared | 0.9995 | Good fitted |
| Breusch-Godfrey LM | 0.9026 | No evidence of serial correlation |
| White’s Test | 0.4154 | No evidence of heteroscedasticity |
| Ramsey RESET test | 0.0000 | Model specified correctly |
| Jarque-Bera test | 0.451 | Residuals are normally estimated |
|  |  |  |

Several diagnostic tests were conducted and are reported in table 11 such as Breusch–Godfrey serial correlation LM test, White’s Test, Ramsey RESET test, Ramsey RESET test and jarque bera test. Accordingly, the results of serial correlation (in Table 11) on the long-run causality indicate no autocorrelation among explanatory variables and total final energy consumption (the null hypothesis). For results of the normality test for distribution of residuals using jarque bera test indicate that the p-value of the dependent values and for the overall model is greater than 0.05 significance level. Therefore, the null hypothesis is rejected, confirming that the residuals of the model are normally distributed. The most of the errors are both skewed and kurtotic.

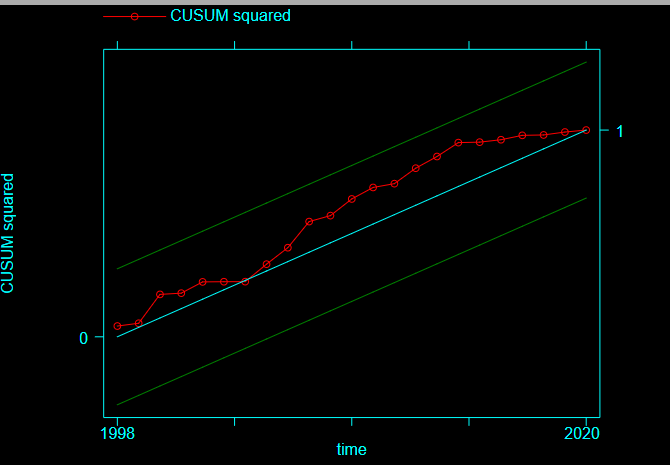
**Stability Tests**

To assess the model’s robustness and stability, we employ the cumulative sum (CUSUM) and the cumulative sum of recursive residual squares of residuals (CUSUMSQ) tests as suggested by (Pesaran et al, 1997). The results of CUSUM and CUSUMSQ tests are indicated in figure 5 and figure 6.

**Figure 5.CUSUM and CUSUM square**



**Figure 6: Showing Stability tests for Total Final Energy Consumption and the Macroeconomic Variables**



The CUSUM and CUSUM of squares graphs are used to determine whether or not the coefficients are stable (Fig. 6). The blue lines, which indicate that coefficients are constant at the 5% level of significance lie in the middle lower and upper boundaries in the above graphs so that the models used in this study are reliable and suitable for policy making.

**CONCLUSION**

Today, energy access and its use are compelling development priorities for Africa, and Rwanda in particular, as a stimulus for economic growth and development in the region. However, there is existing scarcity of empirical evidence about determinants of energy use in driving economic development. This is coupled with the mixed theoretical and empirical evidence on the relationship between macroeconomic variable and energy consumption. This study bridges the gap by examining causal relationship between energy consumption and the macroeconomic variables in Rwanda over the period 1990-2021. The analytical framework of this study is embedded in the theoretical framework of Kuznets curve, endogenous growth model, Putty-Putty Model and Putty-Clay Model. We employ a nested analytical framework, starting with the OLS as a baseline model. We further conduct causal estimation techniques to examine the short and long-run causal relationship between total final energy consumption and the macroeconomic variables. The results of OLS reveal strong evidence of positive and statistically significant effect of GDP per capita, population growth, urbanization, and industrialization respectively on the total final energy consumption, while FDI adversely affect energy consumption in Rwanda. Further, results of cointegration tests confirm cointegrating relationship between total final energy consumption and the macroeconomic variables. The results of granger causality tests confirm short-run bidirectional causality between population growth, urbanization, and energy usage, and causality runs from trade openness to total final energy usage. However, the results reveal more no evidence of a causal effect between GDP per capita, industrial growth, foreign direct investment and total final energy consumption in the short-run.

For the long-run, the results of granger causality tests the results reveal unidirectional long-run causality from trade openness to total final energy consumption. This implies that increasing trade openness through international trade decreases energy consumption through adoption of energy-efficient technologies and hence energy intensity significantly decrease in the long-run. Similarly, a unidirectional causality running from urbanization to the total final energy consumption is detected. Implying that, the existing increasing rate of urbanization with no efficient energy policies have positive and significant effect on total final energy consumption. While for other variables, the results indicate no causal relationship between total final energy consumption and GDP per capita, population growth and industrialization respectively for the period of the study in Rwanda. Similarly, ECM results reveal plausible evidence of short and long-run relationship between total final energy consumption and explanatory variables running from GDP per capita, trade openness, population growth, industrialization, FDI, and urbanization to Total final energy consumption in the short-run. Thus, we conclude based on our findings reiterating indispensable role of energy use in stimulating economic growth and development in Rwanda. However, in its policy strategies of increasing energy access, Rwanda, concurrently and progressively should consider implementing energy efficiency policies and technologies for less and clean energy consumption. Second, a favorable and coordinated institutional framework should strengthened to ensure equity and policy continuity with energy efficiency targets, mostly in the strive for economic growth and increasing urbanization.

REFERANCES

Akinlo, A. E. (2009). Electricity consumption and economic growth in Nigeria: Evidence from

cointegration and co-feature analysis. *Journal of Policy Modeling*, *31*(5), 681-693.

Alkhateeb, T. T. Y., & Mahmood, H. (2019). Energy consumption and trade openness nexus in

Egypt: Asymmetry analysis. *Energies*, *12*(10), 2018.

ANNUAL ECONOMIC REPORT FISCAL YEAR 2017/2018 Retrieved on 10 august 2022

<https://www.minecofin.gov.rw/index.php?eID=dumpFile&t=f&f=12446&token=61d7171de98c6fb6b8369166a481556db66930ad>

Arnold, J.E.M., Kohlin, G. & Persson, R. (2006). Woodfuels, livelihoods and policy

interventions: Changing perspectives. World Development, 34 (3), 596-611

Attiaoui, I., Toumi, H., Ammouri, B., & Gargouri, I. (2017). Causality links among renewable

energy consumption, CO2 emissions, and economic growth in Africa: evidence from a panel ARDL-PMG approach. *Environmental science and pollution research*, *24*(14), 13036-13048.

Ayres, R. U., & Van Den Bergh, J. C. (2005). A theory of economic growth with material/energy

resources and dematerialization: Interaction of three growth mechanisms. *Ecological Economics*, *55*(1), 96-118.

Balaguer, J., & Cantavella, M. (2018). The role of education in the Environmental Kuznets Curve.

Evidence from Australian data. *Energy Economics*, *70*, 289-296.

Banerjee, A., Dolado, J., & Mestre, R. (1998). Error‐correction mechanism tests for cointegration

in a single‐equation framework. *Journal of time series analysis*, *19*(3), 267-283.

Baptist S, Hepburn C. 2013 Intermediate inputs and economic productivity. Phil. Trans. R. Soc. A

371, 20110565. (doi:10.1098/rsta.2011.0565)

Bekhet, H. A., & bt Othman, N. S. (2014). Long-Run Elasticities of Electricity Consumption, FDI,

Export and GDP in Malaysia. *International Journal of Economics and Finance*, *6*(8).

Bekhet, H. A., & Othman, N. S. (2014). Long-run elasticities of electricity consumption, FDI,

export and GDP in Malaysia. *International Journal of Economics and Finance*, *6*(8), 78-90.

Berndt, E. R., & Morrison, C. J. (1981). Capacity utilization measures: underlying economic

theory and an alternative approach. *The American Economic Review*, *71*(2), 48-52.

Berndt, E. R., & Wood, D. O. (1979). Engineering and econometric interpretations of energy-

capital complementarity. *The American Economic Review*, *69*(3), 342-354.

Burrough-Boenisch, J. (2014). Access to energy in Rwanda: impact evaluation of activities

supported by the Dutch Promoting Renewable Energy Programme

business-sweeden.(2016). Opportunities Within the Energy Sector in Rwanda. Nairobi: The

Sweden Trade and Invest Council .Business Sweden in Kenya. 1–9.

Churchill, S. A., Inekwe, J., Ivanovski, K., & Smyth, R. (2019). Dynamics of oil price, precious

metal prices and the exchange rate in the long-run. *Energy Economics*, *84*, 104508.

Dahl, C.A. (2008), Međunarodna tržišta energije: Cijene, politike i profiti, Kigen d.o.o., Zagreb.

Dickey, D. A., & Fuller, W. A. (1979). Distribution of the estimators for autoregressive time series

with a unit root. *Journal of the American statistical association*, *74*(366a), 427-431.

Enders, J. (2004). Higher education, internationalisation, and the nation-state: Recent

developments and challenges to governance theory. *Higher education*, *47*(3), 361-382.

Engle, R. F., & Granger, C. W. (1987). Co-integration and error correction: representation,

estimation, and testing. *Econometrica: journal of the Econometric Society*, 251-276.

Ergun, S. J.,Owusu, P. A., & Rivas, M. F. (2019).Determinants of renewable energy consumption

in Africa. Environmental Science and Pollution Research, 26(15), 15390-15405

Filippini, M., & Pachauri, S. (2004). Elasticities of electricity demand in urban Indian

households. *Energy Policy*, *32*(3), 429 -436. <https://doi.org/10.1016/S0301-4215(02)00314-2>.

Griffin, J. M., & Gregory, P. R. (1976). An intercountry translog model of energy substitution

responses. *The American economic review*, *66*(5), 845-857.

Grossman, G. M., & Krueger, A. B. (1991). Environmental impacts of a North American free trade

agreement.

Gujarati, D. N., Bernier, B., & Bernier, B. (2004). *Econométrie* (pp. 17-5). Brussels: De Boeck.

Haug, A. A. (2002). Temporal aggregation and the power of cointegration tests: A Monte Carlo

study. *Available at SSRN 334965*.

Huang, B. N., Hwang, M. J., & Yang, C. W. (2008). Causal relationship between energy

consumption and GDP growth revisited: a dynamic panel data approach. *Ecological economics*, *67*(1), 41-54.

Hulten, C. R. (1978). Growth accounting with intermediate inputs. *The Review of Economic*

*Studies*, *45*(3), 511-518.

IEA, O. (2018). Update on Recent Progress in Reform of Inefficient Fossil Fuel Subsidies That

Encourages Wasteful Consumption. *G20 Energy Minist. Meet*, *23*.

IEA. (2019). Africa Energy Outlook 2019(World Energy Outlook Special Report). paris:

international energy Agency retrived on 10th jan 2021 from https://www.iea.org/reports/africa-energy-outlook-2019

IRENA (International Renewable Energy Agency)(2022).Energy profile Rwanda. Retrieved on 10

July 2022 from <https://www.irena.org//media/Files/IRENA/Agency/Statistics/Statistical_Profiles/Africa/Rwanda_Africa_RE_SP.pdf>

Johansen, S. (1988). Statistical analysis of cointegration vectors. *Journal of economic dynamics*

*and control*, *12*(2-3), 231-254.

Johansen, S. (1991). Estimation and hypothesis testing of cointegration vectors in Gaussian vector

autoregressive models. *Econometrica: journal of the Econometric Society*, 1551-1580.

Johansen, S., & Juselius, K. (1990). Maximum likelihood estimation and inference on

cointegration—with appucations to the demand for money. *Oxford Bulletin of Economics and statistics*, *52*(2), 169-210.

Jones, D. W. (1991). How urbanization affects energy-use in developing countries. *Energy*

*policy*, *19*(7), 621-630.

Jumbe, C. B. (2004). Cointegration and causality between electricity consumption and GDP:

empirical evidence from Malawi. *Energy economics*, *26*(1), 61-68.

Khalid, I., & Khalid, B. (2010). The Determinant of Demand for electricity. *The Case of Jordan*

*(1979-2008). Retrieved on*, *14*(06), 2012.

Khan, M. I., Teng, J. Z., & Khan, M. K. (2020). The impact of macroeconomic and financial

development on carbon dioxide emissions in Pakistan: evidence with a novel dynamic simulated ARDL approach. *Environmental Science and Pollution Research*, *27*(31), 39560-39571.

Khanna, M., & Rao, N. D. (2009). Supply and demand of electricity in the developing

world. *Annual review of resource economics*, *1*(1), 567-596.

Khim-Sen, L. V. (2004). On Autoregressive Order Selection Criteria. *Faculty of Economics and*

*Management, Universiti Putra Malaysia, 43400 UPM, Serdang, Malaysia*.

Koondhar, M. A., Li, H., Wang, H., Bold, S., & Kong, R. (2020). Looking back over the past two

decades on the nexus between air pollution, energy consumption, and agricultural productivity in China: a qualitative analysis based on the ARDL bounds testing model. *Environmental Science and Pollution Research*, *27*(12), 13575-13589.

Lee, J. W. (2013). The contribution of foreign direct investment to clean energy use, carbon

emissions and economic growth. *Energy policy*, *55*, 483-489.

Liu, X., & Bae, J. (2018). Urbanization and industrialization impact of CO2 emissions in

China. *Journal of cleaner production*, *172*, 178-186.

Mavikela N, Khobai H (2018) Investigating the link between foreign direct investment, energy

consumption and economic growth in Argentina. Munich Personal RePEC Archive (MPRA) Paper No 83960

Mielnik, O., & Goldemberg, J. (2002). Foreign direct investment and decoupling between energy

and gross domestic product in developing countries. *Energy policy*, *30*(2), 87-89.

MINECOFIN, J. (2007). The Economic Development and Poverty Reduction Strategy

(EDPRS). *Final Draft. Kigali*.

Minenfra.(2018).Energy Sector Strategic Plan(2018/19 to 2023/24.Kigali:Rwanda

MININFRA. (2021). WWW.MININFRA.GOV.RW. Retrieved june 16, 2021, from

<https://www.mininfra.gov.rw/digital-transformation-1-1>

Mudaheranwa, E., Udoakah, Y. O., & Cipcigan, L. (2019, August). Rwanda’s energy profile and

potential renewable energy resources mapping toward sustainable development goals. In *2019 IEEE PES/IAS PowerAfrica* (pp. 533-538). IEEE.

Murphy, J. T. (2001). Making the energy transition in rural East Africa: Is leapfrogging an

alternative?. *Technological Forecasting and Social Change*, *68*(2), 173-193.

Narayan, P. K. (2005). The saving and investment nexus for China: evidence from cointegration

tests. *Applied economics*, *37*(17), 1979-1990.

Narayan, P. K., & Singh, B. (2007). The electricity consumption and GDP nexus for the Fiji

Islands. *Energy Economics*, *29*(6), 1141-1150.

Narayan, P. K., & Smyth, R. (2005). Electricity consumption, employment and real income in

Australia evidence from multivariate Granger causality tests. *Energy policy*, *33*(9), 1109-1116.

Nindi, A. G., & Odhiambo, N. M. (2014). Energy consumption and economic growth in

Mozambique: an empirical investigation. *Economics*, *5*(4).

Ohlan, R. (2017). The relationship between tourism, financial development and economic growth

in India. *Future Business Journal*, *3*(1), 9-22.

Ozturk, I. (2010). A literature survey on energy–growth nexus. *Energy policy*, *38*(1), 340-349.

Parikh, J., & Shukla, V. (1995). Urbanization, energy use and greenhouse effects in economic

development: Results from a cross-national study of developing countries. *Global environmental change*, *5*(2), 87-103.

Pesaran, H. H., & Shin, Y. (1998). Generalized impulse response analysis in linear multivariate

models. *Economics letters*, *58*(1), 17-29.

Pesaran, M. H. (1997). The role of economic theory in modelling the long run. *The economic*

*journal*, *107*(440), 178-191.

Pesaran, M. H., Shin, Y., & Smith, R. J. (2001). Bounds testing approaches to the analysis of level

relationships. *Journal of applied econometrics*, *16*(3), 289-326.

Pesaran, M.H., Pesaran, B., 1997. Working with Microfit 4.0: Interactive Econometric Analysis.

Oxford, Oxford University Press

Phillips, P. C., & Hansen, B. E. (1990). Statistical inference in instrumental variables regression

with I (1) processes. *The Review of Economic Studies*, *57*(1), 99-125.

Pindyck, R. S., & Rotemberg, J. J. (1983). Dynamic factor demands and the effects of energy price

shocks. *The American Economic Review*, *73*(5), 1066-1079.

Polat, B. (2018). The Influence of FDI on Energy Consumption in Developing and Developed

Countries: A Dynamic Panel Data Approach. *Journal of Yasar University*, *13*(49).

Poumanyvong, P., & Kaneko, S. (2010). Does urbanization lead to less energy use and lower CO2

emissions? A cross-country analysis. *Ecological economics*, *70*(2), 434-444.

Rafindadi, A. A. (2015). Could the expanding economic growth and trade openness of the United

Kingdom pose a threat to its existing energy predicaments. *International Journal of Energy economics and policy*, *5*(1), 121-137.

Rafindadi, A. A., & Ozturk, I. (2017). Dynamic effects of financial development, trade openness

and economic growth on energy consumption: Evidence from South Africa. *International Journal of Energy Economics and Policy*, *7*(3), 74-85.

Rasiah, R., Guptan, V., & Habibullah, M. S. (2018). Evaluating the impact of financial and

economic factors on environmental degradation: A panel estimation study of selected Asean countries. *International Journal of Energy Economics and Policy*, *8*(6), 209.

Rehman, A., Ozturk, I., & Zhang, D. (2019). The causal connection between CO2 emissions and

agricultural productivity in Pakistan: empirical evidence from an autoregressive distributed lag bounds testing approach. *Applied Sciences*, *9*(8), 1692.

Republic of Rwanda. (2020). 7 Years Government Programme: National Strategy for

Transformation (NST1) 2017–2024.

Rwanda Energy group (REG) annual report 2020-2021.(2022) retrieved on 10 june,2022 from

<https://www.reg.rw/fileadmin/user_upload/REG_Annual_report_2021-2022.pdf>

Sadorsky, P. (2010). The impact of financial development on energy consumption in emerging

economies. *Energy policy*, *38*(5), 2528-2535.

Sadorsky, P. (2014). The effect of urbanization and industrialization on energy use in emerging

economies: implications for sustainable development. *American Journal of Economics and Sociology*, *73*(2), 392-409.

Sadorsky, P. (2014). The effect of urbanization and industrialization on energy use in emerging

economies: implications for su

Sadorsky, P. (2014). The effect of urbanization on CO2 emissions in emerging economies. *Energy*

*economics*, *41*, 147-153.

SadorskyP(2009a)Renewable energy consumption, CO2 emissions and oil prices in the G7

countries. Energy Econ 31:456–462

Safari, B. (2010). A review of energy in Rwanda. *Renewable and Sustainable Energy*

*Reviews*, *14*(1), 524-529.

Sahoo, M., & Sethi, N. (2020). Impact of industrialization, urbanization, and financial

development on energy consumption: Empirical evidence from India. *Journal of public affairs*, *20*(3), e2089.

Samouilidis, J. E., & Mitropoulos, C. S. (1984). Energy and economic growth in industrializing

countries: the case of Greece. *Energy Economics*, *6*(3), 191-201.

Sari, R., Ewing, B. T., & Soytas, U. (2008). The relationship between disaggregate energy

consumption and industrial production in the United States: An ARDL approach. *Energy Economics*, *30*(5), 2302-2313.

Selim et al (2019) Determinants of renewable energy consumption in Africa, Springer-Verlag

GmbH Germany, part of Springer Nature 2019

Shahbaz, M., Van Hoang, T. H., Mahalik, M. K., & Roubaud, D. (2017). Energy consumption,

financial development and economic growth in India: New evidence from a nonlinear and asymmetric analysis. *Energy Economics*, *63*, 199-212.

Smulders, S., & De Nooij, M. (2003). The impact of energy conservation on technology and

economic growth. *Resource and Energy Economics*, *25*(1), 59-79.

Solow, J. L. (1987). The capital-energy complementarity debate revisited. *The American*

*Economic Review*, 605-614.

Soytas, U., & Sari, R. (2003). Energy consumption and GDP: causality relationship in G-7

countries and emerging markets. *Energy economics*, *25*(1), 33-37.

stainable development. *American Journal of Economics and Sociology*, *73*(2), 392-409.

Stern, P. C. (1999). Information, incentives, and proenvironmental consumer behavior. *Journal of*

*consumer Policy*, *22*(4), 461-478.

Tang, C. F. (2008). A re-examination of the relationship between electricity consumption and

economic growth in Malaysia. *Energy Policy*, *36*(8), 3077-3085.

Tang, C. F. (2009). Electricity consumption, income, foreign direct investment, and population in

Malaysia: New evidence from multivariate framework analysis. *Journal of Economic Studies*.

World Bank.( 2022)outsourced from world Bank Dataset, Retrieved from

:https://databank.worldbank.org/source/world-development-indicators assessed on 08th august 2022.

Wu, X. F., & Chen, G. Q. (2017). Global primary energy use associated with production,

consumption and international trade. Energy Policy, 111, 85-94.

York, R. (2007). Demographic trends and energy consumption in European Union Nations, 1960–

2025. Social science research, 36(3), 855-872.

Zaman, K., Khan, M. M., Ahmad, M., & Rustam, R. (2012). Determinants of electricity

consumption function in Pakistan: Old wine in a new bottle. *Energy Policy*, *50*, 623-634.

1. Gulasekaran Rajaguru and Safdar Ullah Khan (2021), Causality between Energy Consumption and Economic Growth in the Presence of Growth Volatility: Multi-Country Evidence [↑](#footnote-ref-1)
2. Total final Energy Consumption [↑](#footnote-ref-2)