

UNIVERSITY OF RWANDA

COLLEGE OF SCIENCE AND TECHNOLOGY

**AFRICAN CENTER OF EXCELLENCE-ENERGY FOR SUSTAINABLE
DEVELOPMENTDEVELOPMENT**



MSC IN ENERGY ECONOMICS

RESEARCH TOPIC:

**EFFECT OF ENERGY PRICES ON RENEWABLE
ENERGY CONSUMPTION IN RWANDA**

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DECLARATION

I, MUTUYIMANA Gertulde , hereby declare to the best of our knowledge that this work entitled: “EFFECT OF ENERGY PRICES AS A MACROECONOMIC VARIABLE ON RENEWABLE ENERGY CONSUMPTION IN RWANDA” has never been presented in any university or other institution for the award of degree or diploma or other testimonial. It is entirely my work and where people’s ideas are used, it has been indicated in the bibliography.

MUTUYIMANA Gertulde

Signature:

Date...../...../2025

CERTIFICATION

This is to certify that the present research project entitled: “EFFECT OF ENERGY PRICES AS A MACROECONOMIC VARIABLE ON RENEWABLE ENERGY CONSUMPTION IN RWANDA” is conducted by MUTUYIMANA Gelturde under my supervision and is now ready for submission.

Supervisor: Dr. KABANDA Richard

Signature:

Date...../...../2025

DEDICATION

To my God

To my beloved family, my lovely husband NTAKIRUTIMANA Edmond

To my child NGANGI USHINDI ED Hans

To all relatives and friends

To Dr KABANDA Richard for unconditional support to attain postgraduate studies

ACKNOWLEDGEMENT

First of all I would like to appreciate and to thank so much my loving husband, who served as my work advisor and contributed significantly to my study.

I thank also my research's supervisor, Dr. KABANDA Richard, due to he devotes a lot of his time to the work of supervision. His great mentoring was vital in completing this postgraduate program.

In addition let's thank all of the lecturers, classmates, and friends who have helped me advance my knowledge and education.

I want also to thank the World Bank / ACEESD and the UNIVERSITY OF RWANDA, college of science and technology, for their support of this postgraduate study.

ABSTRACT

This study examined the impact of energy prices on renewable energy usage in Rwanda, specifically from 2010 to 2023. Using quarterly data, the study investigated the dynamic relationship between energy prices, renewable energy usage, vital macroeconomic variables such as GDP growth, inflation, urbanization, interest rates, and population growth. The ECM model was used to investigate both the short- and long-term interactions between these factors. The findings showed that energy prices have significant negative effects on renewable energy consumption. Urbanization boosts renewable energy usage by upgrading infrastructure and promoting sustainability programs. Although population growth initially boosts renewable energy use, it has a detrimental long-term impact. Inflation limits renewable energy usage by reducing purchasing power, GDP growth supports renewable energy use over time whereas interest rate showed a positive impact on renewable energy consumption.

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ABBREVIATIONS AND ACRONYMS

ACEESD: African Centre of excellence in energy for sustainable development

ARDL: Autoregressive Distributed Lag

GDP: Gross Domestic Product

CPI: Consumer Price Index

LPG: Liquid petroleum gas

NISR: National Institute of Statistics of Rwanda

ECM: Error Correction Model

ADF: Augmented Dickey Fuller

IEA: International Energy Agency

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CHAPTER ONE: GENERAL INTRODUCTION

1.1. Introduction

As a critical component of the Rwanda's strategy for environmental preservation and sustainable development is the development of renewable energy. The transition towards the use and consumption of renewable energy in Rwanda like hydropower, solar and biogas has the aim to enforce the reduction of the greenhouse gas emissions, sustaining the economic growth at the same time enhancing energy security. This transition aims to meet the increase in energy demand that is driven by the tremendous economic progress of the Rwandan economy through the influence of the macroeconomic factors such as inflation, interest rate, population growth, urbanization, GDP growth and various other factors.

Therefore, this thesis analyses how energy prices as a macroeconomic variable impacts the consumption of renewable energy in Rwanda, it will offer understanding of the challenges and opportunities that are encountered during this transition especially while looking at how energy prices affect the consumption of renewable energy in Rwanda. This thesis also has the aims to guide stakeholders as well as policymakers to advance sustainable energy solutions for long-term economic and environmental benefits in Rwanda.

1.2. Background

Rwanda is one of the few countries which adopted to developed renewable energy sources one of the main components of their natural strategy to achieve energy security and sustainability. For instance, some of the aspirational goals for the country to reduce its dependence on fossil fuels and mitigate the environmental impacts include an increase in the share of renewable energy in the energy mix to 60% by 2030, and ensuring universal electricity access (Ministry of Infrastructure, 2018). Thus macroeconomic variables such as GDP growth, inflation, domestic investment, and energy prices, which are all strong determinants of use and consumption of renewable energy, would be key drivers in this transition. Infrastructure development, public-private partnerships, and international collaboration are some of the key enablers of the Rwanda renewable energy agenda, enabling investment in solar, hydropower, and other clean energy sources to expand access (Rwanda Development Board, 2017).

Renewable energy demand is directly tied to economic growth, as growing incomes raise demand for renewable infrastructure investment. According to research by Sadorsky, (2009) a

1% increase in real per capita income in developing economies leads to 3.5% increase in renewable energy consumption. This finding is in line with the data of Nordic countries that GDP per capita, Human Development Index, and ratios of renewable energy used all increase positively and simultaneously during years 1990-2023 (Suluk, 2024). In a similar manner, income, exchange rates and inflation are macroeconomic variables that play a great role on renewable energy penetration in Nigeria, with income as the most dominating variable (Foye, 2023). These kinds of studies demonstrate the importance of macroeconomic stability in fostering renewable energy adoption.

Higher energy prices (and inflation) play an important role in determining patterns of energy use. Energy price rise leads to reduce in usage of clean energy within unregulated economies (no significant subsidy or main support towards renewables) Sadorsky, (2009) in contrast, government policies to mitigate these impacts, such as the Least Cost Power Development Plan in Rwanda, prefer even economically rational renewable energy options (Rwanda Development Board, 2017). Also, both investment by local actors and financing by foreigners contribute to filling the funding gap of renewable energy projects. Studies from Sub-Saharan Africa also demonstrate how considerably foreign direct investment and concessional funding together have leveraged progress in renewable energy in countries with strong policy frameworks (International Energy Agency, 2023).

Population growth and persistent urbanization is greatly impacting the renewable energy sector in Rwanda, so the demand of energy is increasing. And the demand for renewable energy sources is evident as more households and industries connect themselves to the electrical grid. This trend is consistent with international literature, including the study by Malik, (2014), indicating a positive relationship between urbanization, economic development, and renewable energy use. Moreover, the expansion of off-grid solutions in Rwanda, particularly in rural areas, serves as evidence of the government's commitment to decentralized renewable energy systems as a strategy for increasing energy access and alleviating poverty (Rwanda Energy Group, 2024).

Rwanda's renewable energy development is based on the interplay of macroeconomic variables, government action, and international cooperation. Extracting lessons from other countries and regions is critical and addressing local challenges should happen at the same time as we pursue our energy targets and promote sustainable development goals.

1.3. Problem statement

Rwanda has significantly improved its energy generation mix by diversifying its energy sources and expanding access to electricity, though an increase in energy mix through renewable energy continues to be a challenge. With such an ambitious 60 percent target of renewable energy to be achieved by 2030, it becomes imperative to understand how macroeconomic variables, specifically energy prices, affect the consumption of renewable energy. These parameters are crucial in informing policies that would allow the country to achieve its energy security and sustainability goals while reducing its reliance on fossil fuels (Ministry of Infrastructure, 2018).

In the international literature where these drivers of renewable energy adoption have been studied, much has focused on the role of macroeconomic factors.

Sadorsky, (2009) reported, for example, that in developing countries, the consumption of renewable energy falls by 0.7% when its price increases by 1% and increases by 3.5% with a 1% rise in per capita income. Similarly, Malik et al. (2014) established a direct relationship between the price of energy and renewal energy adoption in Pakistan, with affordability proved vital in incentivizing such use. One cannot directly replicate these lessons from both countries given the differences in their respective socio-economic, geographical, and policy contexts.

Existing literature in Rwanda has mainly focused on improving electricity access and expanding electricity generation with little attention given to the price dynamics between renewable and non-Renewable energy sources.

Technical and infrastructural dimensions of energy development are predominantly outlined in previous reports (e.g. Rwanda Development Board, 2017; Rwanda Energy Group, 2017), creating a broad knowledge gap on how energy price changes influence renewable energy consumption patterns. And the lack of awareness is especially concerning because Rwanda relies heavily on a policy incentive program to facilitate the implementation of renewable energy.

In addition, other studies conducted in different regions, such as that of Foye, (2023), have emphasized the significant importance of macroeconomic variables, including inflation, exchange rates, and income, in relation to the incorporation of renewable energy. Those results

are a springboard for focused research to explore similar dynamics in the context of Rwanda. If the interaction between energy price and renewable energy consumption is not properly examined, the nation may be incorporating ineffective policies that will slow down the achievement of renewables targets for the country.

In essence, this necessitates a detailed exploration of how energy prices respond to consumption of renewable energy in the case of Rwanda. Thus, this research paper will fill a very important research gap in literature and provide policymakers with some evidence-based insights for effective strategy design for the accomplishment of national energy objectives under the strains of changing macroeconomic conditions.

1.4. Objectives

1.4.1. Major objective

The general goal of the research is to investigate the impact of energy prices as a macroeconomic variable, on renewable energy consumption in Rwanda.

1.4.2. Specific Objectives

In order to realize the above-stated broad objective, the following specific objectives are identified:

- Assess the trend and drivers of renewable energy consumption in Rwanda over the last decade.
- Analyze the relationship between energy prices and renewable energy consumption in Rwanda within a macroeconomic context.

1.4.3. Research Questions

The following research questions are made to address major and specific objectives:

- What are the major trends and drivers of renewable energy consumption in Rwanda during the last decade?
- How do energy prices interact with renewable energy consumption within Rwanda's macroeconomic framework?

1.5. Scope of the study

This study looks at the impact of energy prices as a macro variable on renewable energy consumption. Geographically it is limited to Rwanda, looking at development and consumption of renewable energy in the country. Temporally it covers 2010 to 2023, with quarterly data to capture trends and fluctuations in energy prices and their effects over time. Due to time and resource constraints the scope is limited to ensure a thorough analysis within these boundaries.

1.6. The Study's Expected Outcomes and Significance of the study

1.6.1 The Study's Expected Outcome

This study will give a better insight concerning energy prices and how they impact renewable energy consumption in Rwanda. It will offer context-based empirical evidence, on the interplay of energy prices and renewable energy consumption in Rwanda. It will also examine the trends in renewable energy consumption between 2010 to 2023 on a quarterly basis and some critical trends and correlations with macro variables.

Based on this analysis, the study will present policy recommendations to alleviate the effects of energy price fluctuations and to foster the uptake of renewable energy. Findings will also offer a framework for incorporating macro variables into energy policy implementation in Rwanda to contribute to meeting national energy targets.

1.6.2 Significant of the study

The study is in steps with Rwanda's sustainability targets, most notably the goal to reach 60% renewable energy by 2030. It highlights macroeconomic determinants of energy use and thus assists in decreasing our dependency on fossil fuels and fosters environmental sustainability.

The results of this study are also important for economic planning because they help stakeholders, including government and private sector investors, plan their energy portfolios in a cost-effective manner while increasing resilience against energy price volatility. The study adds to the emerging literature on renewable energy uptake on a global scale and could thus have value as a reference for other developing countries which face similar challenges. Additionally, it enhances stakeholder engagement by providing data-backed insights for successful public-private partnerships in renewable energy projects. At last, this work, connects theoretical research with real-world applications in substantive ways in both terms of Rwandan green energy agenda and its overall vision towards a sustainable economy.

CHAPTER 2: LITERATURE REVIEW

2.1. Introduction

This section comprises definitions of key concepts, empirical literature, a theoretical framework, a conceptual framework, and a summarization.

2.2. Conceptual Review

This section provides a theoretical foundation by examining existing literature and frameworks relevant to the study. It establishes the relationship between the research variables and contextualizes them within broader academic and practical discussions.

2.2.1 Definition of Key Concepts

Key terms and concepts central to the study are clearly defined to ensure consistency and understanding. These definitions are drawn from authoritative sources and tailored to the research context.

2.2.1.1. Urbanization Rate

Urbanization rate refers to the percent of a nation's population dwelling in urban areas versus rural areas. It is commonly described as a ratio and measures how fast a population moves from a rural to an urban setting as a result of economic opportunities, infrastructure development, etc. (United Nations, 2018).

2.2.1.2. Renewable Energy

Renewable energy is generally defined as energy coming from natural resources replenished quicker than they are used. The main types include solar, wind, hydro, geothermal, and biomass. This source is considered sustainable and very environmentally friendly since there is very minimal emission related to greenhouse gases (IEA, 2021).

2.2.1.3 Population Growth Rate

It is the rate at which population size increases in a given period, usually measured in percentage terms. It reflects birth rates, death rates, and human migration into an area (The World Bank reports 2020).

2.2.1.4. GDP Growth Rate

It represents the growth rate of GDP-the percentage increase in a country's gross domestic product over time that indicates economic performance. It indicates how fast the economy is growing, and it is a major indicator of the health of the economy. As stated by IMF, (2021).

2.2.1.5. Energy Prices

Energy prices are the prices of such energy resources as electricity, fuel, or natural gas. The price depends on market dynamics, geopolitical relations, production cost, and government policy too (IEA, 2021).

2.2.1.6. Interest Rates

Interest rates are the cost of access to credit or the return on savings and are typically expressed as a percentage. They are determined by central banks to control economic activities, regulate inflation, and affect investment and consumption patterns accordingly (World Bank, 2020).

2.2.1.7. Inflation

Inflation is the continuous rise in the general level of prices of goods and services within the economy over a specific period of time. It decreases the purchasing power of money and is measured by indices such as the Consumer Price Index (CPI) (IMF, 2021).

2.3. Theoretical literature

2.3.1. The Energy Ladder Theory

The energy ladder theory is a conceptual framework that explains the progression of household energy use, particularly in developing countries, as incomes and living standards improve. The theory suggests that households move up a metaphorical "energy ladder," transitioning from traditional energy sources like biomass (e.g., firewood, dung, and crop residues) to more efficient and cleaner options like kerosene, charcoal, liquefied petroleum gas

(LPG), and eventually electricity. Each "rung" on the ladder represents an energy source that is progressively cleaner, more efficient, and more expensive. The Energy Ladder Theory underscores the relationship between economic growth and energy transitions, showing that poverty often traps households at the lower rungs, relying on inefficient and polluting fuels. However, the theory has been critiqued for oversimplifying energy transitions. In practice, households rarely abandon traditional fuels entirely as they adopt modern ones; instead, they "stack" energy sources, using a mix based on availability, cost, and cultural preferences. This limitation led to the development of alternative frameworks, such as the Energy Stacking **Model**, which provides a more nuanced understanding of household energy use and the complex factors shaping energy transitions (Arnold Pacey, 1990).

2.3.2. The Energy Stacking Model

The energy stacking model is an alternative framework to the Energy Ladder Theory, offering a more nuanced understanding of household energy use, particularly in developing countries. Unlike the Energy Ladder, which assumes a linear progression from traditional to modern energy sources as incomes rise, the Energy Stacking Model suggests that households tend to use multiple energy sources simultaneously, or "stack," rather than fully transitioning to a single modern source. For instance, a household might use firewood for cooking traditional meals, kerosene for lighting, and electricity for powering appliances, depending on availability, cost, and preferences. The concept of energy stacking emerged as a critique of the Energy Ladder Theory. The model gained prominence as empirical studies revealed that energy transitions are rarely linear and are influenced by factors such as income fluctuations, cultural norms, infrastructure, and fuel availability. The Energy Stacking Model has been widely embraced for its realistic depiction of energy behavior, which better aligns with the complexities of energy access and use in low- and middle-income contexts. This model has also influenced energy policy by emphasizing the need to support diverse energy options, rather than solely focusing on transitioning households entirely to modern energy systems (Omar R. M & Barbara D.S, 2000).

2.3.3. Energy Substitution Theory

It explores the replacement of one energy source with another due to changes in prices, technological advancements, policy shifts, or resource availability. This theory is essential for understanding how energy markets adapt, particularly as the world transitions from fossil fuels to renewable energy. The elasticity of substitution quantifies the relationship between energy inputs, showing how demand for one energy source responds to price changes in another. Key types of substitution include perfect substitutes (e.g., solar vs. wind electricity), imperfect substitutes (e.g., coal vs. natural gas), and complementary substitutes (e.g., natural gas and electricity in heating). Energy substitution is often analyzed through production functions like Constant Elasticity of Substitution (CES), which help model how energy inputs can replace each other in production processes. The theory is applied to various areas such as the transition to renewable energy, where solar, wind, and hydro power can replace fossil fuels; enhancing energy security by substituting domestic energy sources for imported ones; reducing carbon emissions by substituting fossil fuels with cleaner technologies; and sector-specific substitutions like electric vehicles replacing gasoline-powered cars. Factors that influence substitution include relative prices, technological innovations (e.g., improvements in solar and storage technologies), government policies (e.g., carbon taxes, subsidies), and resource availability. As fossil fuel prices rise or renewable technologies become more cost-competitive, substitution towards cleaner energy sources becomes more viable (Bhattacharyya, 2019).

2.4. Empirical Literature

There are numerous studies performed to analyze the effect of energy price, as a macroeconomic variable, on the renewable energy consumption, providing insights on how changes in the price of energy affect the deployment of renewable energy technologies.

Thus, various papers can be gathered where, regarding empirical testing of the effect of the main macroeconomic variable, its effect could be found on the consumption of renewable energy during the years 2015- onwards. Furthermore, it may also be identified that the amount of findings along with the statistical evidence supports dynamics within the energy market leading to variations in the consumption of renewable energy.

Apergis and Payne, (2015) have estimated panel data for OECD countries for the period 1990 to 2011, observing that when the price level of the fossil fuel increased by 1%, the renewable energy consumption went up by 0.9%. That is to say, the demand becomes more responsive towards renewable energy, at least for the high-priced energy developed economies that eventually must switch to cleaner energies.

Operating from the data of 1995 to 2015, Lin and Ouyang, (2014) found that for an emerging economy, with a rise in the conventional energy price by 10%, renewable energy investment surges upwards by 2.5 percent. They recorded that with higher fossil fuel costs, such a need to transition towards cost-competitive renewable alternatives has been felt in both the private and public sectors.

Dong et al., (2017) analyzed data from 36 countries between the period 1990 and 2014. Their results show that higher energy prices induced by carbon taxes contributed to a growth rate of 3% per annum in renewable energy. The authors estimate that renewable energy consumption was more responsive to changes in the price of renewable energy within countries that have more stringent environmental policies.

Zafar et al., (2019) estimated the impact of energy prices on the use of renewable energy in the South Asian economies. Using panel data for the period 1990-2017, they reported that a 1% increase in energy prices is increasing renewable energy use by 0.7%. Their study further estimated that volatility in energy prices may temporarily impede investments in renewables and hence require stable and predictable pricing mechanisms.

Newer et al., (2020) researched on current leading global renewable energy market - China. Consequently, based on analysis for 1995 -2018, a 15 % increase in coal's price would ensure roughly about a 5 percent yearly growth rate of the installation rates for solar energy. Another interesting deduction they make is that this effect of increasing fossil fuel prices on the rapid development of renewable technologies is enhanced by the government's subsidy or supporting policies.

The panel regression analysis by Nasreen et al., (2021) considered data across 15 Asian economies from the period of 1995 to 2019 to consider how the determinants of energy price and energy policy influence the consumption of renewable energy. In fact, it has been found that energy price positively influences the adoption of renewable energy; a 1% increase in energy price elicits a consumption of renewable energy by 0.8%. Their results have also brought out countries with strict environmental regulations who had a higher responsiveness with regard to change in energy price.

Bhattacharya et al., (2021) comparatively analyzed data for 20 developed and developing economies. They found that with a 5% increase in the price of fossils, renewable energy consumption increased by 2% for the group of developing countries, while for the developed economies, it surged by 1.2%. The authors, therefore, opine that developing economies respond more to energy price shocks because they are more dependent on cost-effective renewable alternatives.

Jiang et al., (2022) studied carbon pricing as a determinant of renewable energy consumption for 20 countries between the year 2000 and 2020. Their results indicated that with each increase of 10 dollars per tonne in carbon price, renewable energy consumption increased by 3.5%. This investigation was based on the prelude that carbon pricing mechanisms raise the price of fossil fuels, with incentives to boost investments in renewable energy.

Kim et al., (2023) analyzed volatility in energy prices and its consequences for investments in renewable energies in G20 economies. Using data from the period 2000 to 2022, they found that with every increase of 10% in the volatility of energy prices, in the short run, the level of investment in renewable energy decreases by 1.8%. If the pricing policy is stable, the growth rate of renewable energy use is 4% annually.

Khan et al., (2023) explored how increase in the prices of energies has driven many to usage of renewable energy in sub-Saharan African regions. Any rise of the energy price about 20% resulted in, they had perceived, 7% use of renewable energies mainly via increased adoptions of solar and biomass technologies. They went ahead to reiterate that such friendly government' policies aimed at cushioning low-income households against adverse effects of increased prices would cause, like subsidies on the renewable.

The authors Malik et al., (2014) investigated the macroeconomic determinants of renewable energy consumption in Pakistan. Results indicate that national income and the adoption of renewable energy are strongly positively related, while a rise in energy prices decreases renewable energy consumption. It therefore implies that a rise in energy prices could be a disincentive to the adoption of renewable energy technologies, especially in low fiscal capacity economies.

Lin & Ouyang, (2014) projected the energy demand in China between renewable and non-renewable energy. They noticed that with the increase in energy prices, there was a considerable substitution towards renewable sources of energy due to the cost-saving effect. In their study, they concluded that the choice between renewable and non-renewable energy is determined by the price of energy, more especially when the fossils become more expensive.

Jiang et al., (2022) factored in carbon pricing to identify how such a method has driven the consumption of renewable energy. They reported that "the expectations over energy price, particularly those of long-term price trends for fossil fuel price increases, drive future investments in renewable energy technologies." They established that carbon pricing mechanisms themselves-a result of the shifts in global energy prices-had something to do with significant higher consumption of renewable energy.

Bashiri & Gholami, (2016) assessed the influence of increased energy prices on the adoption of renewable energy in Iran. They found that increased energy prices acted as a strong driver for the increased adoption of solar energy as consumers sought to look for cheaper alternatives to traditional sources of energy. This also brought to the fore that as the price of energy went up, so did the willingness to invest in renewable energy; however, the cost increased the poor's ability to make such investments.

Liu & Zhang, (2017) study the causalities between energy prices, renewable energy development, and sustainable growth in the context of an emerging economy. Such findings showed that "energy price increases have a saliently positive effect on the adoption of renewable energy technologies, especially for those countries characterized by rapid energy demand growth and supporting policies and measures issued by their governments." As they have noticed, energy prices are key to shaping energy transition in the emerging economies.

On the other hand, Ghosh & Rehman, (2018) did investigate how prices of energy would influence consumption within the renewable energy of South Asian countries. Undeniably, results have suggested that if high energy prices would be the case, then such a huge increase in the intake of renewable energy within the country like India and Bangladesh occurred. Moreover, such policies supporting the subsidizing of renewable technology have hastened this transition.

Krause & Auer, (2019) studied the trends of energy price variation and how promotional policy about renewable energies has influenced the European market. In fact, a rise in energy prices, along with subsidization and government incentives, enabled a very sudden growth in the renewable energy markets across European countries. It was emphasized that this kind of dual policy-market dynamics approach is required in the wide dissemination of renewable energies.

Ali & Yasin,(2020) in their work, focused on reviewing energy price effects on the adoption of renewable energies in developing nations. There, it was deduced that the highly positive effect of increasing energy prices on the adoption of renewable energy made a lot of sense in rural areas where access to relatively cheap resources was lower compared to cities. Again, it depicts how international aid and investment play complementary roles in many such projects.

Ahmad & Hossain, (2021) thus investigated how finally energy price shocks influence investment in renewable energies, especially in the developing economies. Energy price volatility increased the investment in renewable energy largely because such volatile energy prices make both the households, and the business entities try to reduce their vulnerability. Thus, stable energy pricing policy will go a long distance to attract the long-term investment in renewable energy.

Liu & Li, (2021), reviewed the status of renewable energy investment in a world of growing energy prices. The results indicated that increased energy prices attract more investment from the private and public sectors in renewable projects, especially in wind and solar sectors. They reasoned that the higher the price of energy, the greater the financial viability of renewable energy projects, hence the attractiveness to investors.

Carvalho & Pinto, (2022) researched the impact of energy price on the trend of renewable energy diffusion across European nations. The increase in energy price within the region helped develop a full force for renewable energy adoption among those EU countries that had already developed a sound policy framework for renewable energy. The finding from such a study has pointed out that energy prices have been driving, along with policy incentives, the transition toward renewable energies in Europe.

Wu & Zhang, (2022) studied energy price elasticity and renewable energy consumption of the major economies. The results showed that with increased energy prices, a country is likely to shift massively towards renewable energy if it has high energy price elasticity, proving that its consumers are responsive to the changes in the price of energy. For instance, the study found that one of the key drivers of the future pattern of renewable energy consumption was energy price expectations.

Xu & Liu, (2023) targeted the influence of energy price policies on renewable energy consumption in developing countries. Their findings indicated that energy price policy, especially charging a premium for fossil fuel and providing subsidy policies for renewable energy technologies, is effective in promoting the use of renewable energy in developing countries. The research concluded that the government should consider implementing integrated energy pricing policies to promote the transition toward renewable energy.

Gomez and Habimana, (2021) drew on the example of Rwanda and Sub-Saharan Africa to analyze the relationship that exists between the energizing of variable prices and renewable energy consumption. Using data between 2010 and 2019, they indicate that increases in energy price significantly affect renewable energy consumption in urban areas where energy dependence has been high. For instance, a 10% increase in energy prices saw a reduction in renewable energy use by 4%.

However, the study also found that this trend is muted in cases where the Government of Rwanda offered subsidies and incentives for the use of renewable energy. What these findings suggest is that the relationship between energy prices, policy interventions, and the adoption of renewable energy in developing economies is complex.

In addition, Foye, (2023) examined the macroeconomic forces that drive the level of renewable energy penetration in Nigeria, where energy prices have become significant determinants of consumer response. Foye's study focused on income and exchange rate as the key drivers, whereas energy prices were major determinants.

The findings indicated that as energy prices increased, renewable technologies were in higher demand, especially because some of the conventional energy sources, like natural gas, were more expensive. Since the pricing mechanism of energy in a country is sensitive to ups and downs depending on the global market, this study will provide a close look at the immediate and indirect effects of energy prices on renewable energy consumption.

While the empirical literature that underpins this study offers useful insight into the effects of energy prices on the use of renewables, it is also incomplete in some ways. However, only a few studies have examined energy price expectations and how they affect consumer behavior in respect to renewable energy use in Rwanda. Second, while several studies have investigated the effect of energy prices on consumption, most of them do not take into consideration the behavioral dimensions of renewable energy adoption, such as consumer preference for energy-efficient technologies.

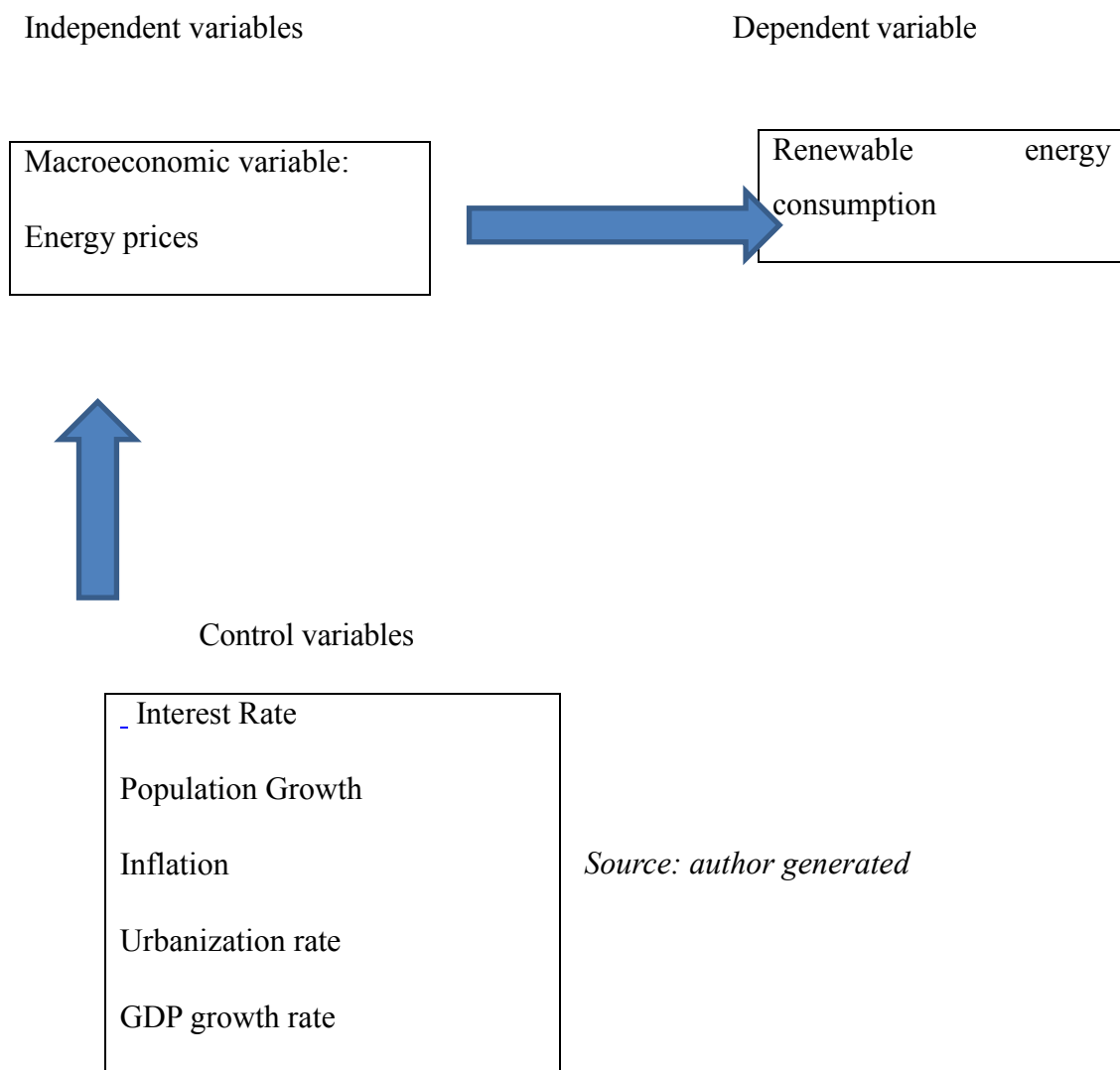
Additionally, previous empirical analysis has not well explored the influence of changes in energy prices on renewable energy adoption and the interaction of energy prices with other macroeconomic drivers, including inflation and exchange rates, within Rwanda. Addressing

these will provide a clearer understanding of the existing relationship between energy prices and renewable energy consumption in Rwanda.

2.5. The conceptual framework

A conceptual framework is characterized as an interlinked system of concepts that, when integrated, offer a holistic comprehension of phenomena. It encapsulates the theories derived from the literature review, aligning with your topic and contributing to a cohesive understanding.

Figure 2. 1 conceptual framework



2.6. Literature gap

There is abundant literature on the effect of energy prices on household spending, but the literature gap for the impact of energy prices on renewable energy consumption, particularly in developing countries such as Rwanda, is prominent. Theories like the Energy Price-Expense Sensitivity Model which indicate the responsive of elasticity of the household expenditures arising due to alterations in energy costs and Energy-Dependency Hypothesis which refers a high degree of dependency on energy with growing susceptibility toward its cost changes apply chiefly to the consumption of the non-renewables. However, less thought has been given to how such a framework would adapt to consumptive activity in renewable energy sources—as is particularly relevant for developing markets and particularly relevant in an African context.

A few other areas would benefit from more nuanced analyses as identified by the literature are those regarding factors that affect energy prices in Rwanda like the Energy Pricing Mechanism the Domestic Resource Mobilization Model and the Inclusivity Paradigm. While these models emphasize the overall economic and policy ramifications of energy pricing, they do not effectively illustrate the interaction between energy prices and the uptake of renewable energy sources in Rwanda. However, although international studies have quantitatively assessed the impact of energy prices changes on household expenditure, there are comparatively few studies specifically on how such changes could affect demand for renewable energy sources (particularly solar, hydro, and biomass) since much of the attention is focused on electricity demand while little is known in the context of Rwanda.

In the case of Rwanda, the current empirical studies do no more than assessing short-run and long-run price shocks spill-over into changes in CPI and total household expenditures, with a conspicuous gap made toward analysis on its consumption pattern with regards to renewable energy. Income levels, energy dependency, and government policy interact with the prices of renewables, yet no research to date has explored how, a set of relationships fundamental to any understanding of how one can design effective policy interventions that can hasten the transition toward renewables. In addition, the literature has underreported socioeconomic differences in energy use and the efficiency of policy interventions for encouraging renewable energy use among different population subgroups.

Although the theoretical and empirical existing literature provides quite an extensive framework on how changes in energy prices affect economic indicators have, e.g. the CPI and household expenditure, the literature on how consumers react to changes in the prices of renewables is still somewhat limited. And analysis of such dynamics in energy pricing unique to Rwanda will need to be investigated further, this investigation will focus on consumption behavior in terms of renewables, the consumer behavior in response to new policies and the policy agenda that enabled this transition.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1. Introduction

In this chapter, the research methodology employed to investigate the study objectives is detailed. This chapter describes the role of data collection methods and tools used to fit the research subject matter. Moreover, it outlines the intended methods of data analysis and establishes the structure of the model that will be adopted to ensure that meaningful and relevant insights are obtained from this dissertation.

3.2. Data collection method and tools

This study uses secondary sources to collect data. We have obtained the key datasets from the National Institute of Statistics of Rwanda and World Bank. Data on inflation, GDP growth, energy prices, population growth, urbanization rates, and interest rates were retrieved from NISR and information on renewable energy consumption and interest rates were extracted from World Bank.

These datasets provide an indispensable basis for the relative analysis considering energy prices as a macroeconomic variable influencing the uptake of renewable energy in Rwanda. The review and extraction techniques employed in the study, will ensure the retrieval of relevant and reliable data from such publications in an accurate manner, and serve as a sound basis of the analysis of the research work.

3.3. Analysis and Data processing

The data used in this analysis is secondary and spans the period between 2010Q1 and 2023Q4. It contains such variables that would best explain the determinants of inflation, GDP growth, energy prices, population growth, urbanization rates, and interest rates.

Inflation: Monthly Consumer Price Index data were obtained from the National Institute of Statistics of Rwanda. From the CPI indices, the inflation rate was computed, and the series were transformed from monthly to quarterly frequency by using extrapolation in order to fit the frequency of the analytical framework.

GDP Growth Rate: Quarterly growth in GDP directly obtained from NISR did not call for any frequency transformations.

Energy Prices: Energy price at a monthly frequency was obtained from NISR. These were extrapolated from monthly to quarterly frequency for consistency with the other variables.

Population Growth Rate and Urbanization Rate: Data was taken on a yearly basis from the World Bank database. It was then transformed using interpolation to quarterly frequency to make it temporal with the quarterly analysis framework.

Interest Rate: Annual interest rate data from the World Bank database and interpolated to a quarterly frequency, accordingly.

All transformations and extrapolations were done in Eviews 10 to ensure methodological coherence, since this software allows very accurate changes in data frequency while preserving the integrity of the original dataset. These quarterly time-series data have then been used in the investigation of relationships among the variables over the period under consideration, hence allowing an analysis that embeds dynamic trends and interactions.

3.4. Model specification

This study has adopted the ARDL model in the analysis of the long-run relationship and short-run dynamics between, energy prices, renewable energy consumption, and Interest Rate, Population Growth, Inflation, Urbanization rate, GDP growth rate in Rwanda. The ARDL approach was used because of its flexibility in handling variables integrated at different orders, that is, $I(0)$ and $I(1)$, but not at the second difference, that is, $I(2)$. In other words, this provides the best guarantee that the analysis is able to appropriate the dynamic interaction among the series involved without imposing a restriction of integration order on the series studied; this again tallies with characteristics observed in the data set of the current study (Pesaran et al., 2001).

The ARDL model further offers robustness to analyze such macroeconomic variables that are usually very vulnerable to external shocks. In the Rwandan context, these would be majorly energy prices and consumption of renewable energies. The nature of the model has thus enabled us to assess the way in which short-term oscillations within these variables impact on their long-run equilibrium-that is, how interest rate and Population Growth, Inflation, Urbanization rate, GDP growth rate variables interlink with the energy-related variables in determining renewable energy use.

The ARDL bounds testing approach is an indispensable step in this framework, as this will identify the cointegration relations. This includes the short-run dynamics in a conditional ECM and thus has all the aspects of both a short- and long-run relationship in one analysis, as in Pesaran et al. (2001).

In respect to the variables that are used in this paper, the theoretical model specification for this study is:

$$RE = f(URBR, POPGR, IR, INFL, GDPGR, EI)$$

Where;

RE: Renewable Energy consumption

URBR: Urbanization Rate

POPGR: Population Growth Rate

IR: Interest rate

INFL: Inflation

GDPGR: Gross Domestic Product Growth Rate

EI: Energy prices

Thus, from the above equation Renewable energy consumption depends on interest rates, energy prices, and Population Growth, Inflation, Urbanization rate and GDP growth rate therefore the empirical model is specified as follows;

$$RE = \beta_1 + B_2URBR + B_3POPGR + B_4IR + B_5INFL + \beta_6GDPGR + \beta_3EI + Er \text{ Where;}$$

RE: Renewable Energy consumption

URBR: Urbanization Rate

POPGR: Population Growth Rate

IR: Interest rate

INFL: Inflation

GDPGR: Gross Domestic Product Growth Rate

EI: Energy prices

Er: error term

3.5. Bounds Test for Cointegration

The present study conducted the Bounds Test in testing for the existence of long-run relationships among the variables in the model. The test is appropriate in cases of models with mixed integration orders, that is integrated at levels $I(0)$ and first differences $I(1)$, excluding variables integrated at $I(2)$. The reliability of the test also derives from flexibility in accommodating small sample sizes, a key consideration in this study. This test was pioneered by the work of Pesaran et al., (2001), while other studies have affirmed the performance ability of this test in the econometrics in dynamic relationship applications such as Nkoro & Uko, (2016).

The bounds test decision rule involved an assessment of whether the calculated F-statistic as compared with critical value bounds at the 5% significant level. If the F-statistic were to be larger than the upper bound, this should lead to the rejection of the null hypothesis of no cointegration, confirming the presence of a long-run equilibrium relationship. Because this test sounded in mixed integration orders of the variables, it was a good starting point for doing further econometric modeling.

3.6. Stationarity test

In this respect, stationarity of the variables was checked by using the Augmented Dickey-Fuller test, which is generally considered quite reliable to find unit roots in time series data. It is reliable because it embeds the lagged differences of the dependent variable, hence it helps address some issues of autocorrelation, thereby making the test more accurate (Said & Dickey, 1984; Nkoro & Uko, 2016).

Against alternatives such as the Phillips-Perron test, the ADF test was preferred because of its robustness in small samples and the ability to directly control for higher-order correlation by incorporating lagged terms (Nkoro & Uko, 2016). The rationale behind using an ADF test ensures that the outcome presents a better foundation to decide on whether the variables were stationary or need to be different, therefore avoiding any spurious regression.

Then, using EViews 10 software,, automatic lag selection was carried out with the help of SIC, which is a means of model selection that well-balances the goodness-of-fit with the complexity of a parsimonious model according to Greene, (2018). The maximum lag length was chosen to be 10 so as not to over fit the model but to make it flexible enough for the dynamics of each variable.

3.7. Diagnostic tests

The Diagnostic tests should be carried out on this study to ensure that the statistical methods employed in the research are accurate and fitted. The Diagnostic tests check whether the instruments and procedures used measure the variables that they say they are, and thus that the research is going towards its intended targets.

In contrast, tests of reliability are directed toward the evaluation of consistency and replicability of the result in repeated applications. On aggregate such tests will ensure that the methodology is sound, the findings are powerful, and the conclusion drawn therein is well supported by data.

3.7.1. Normality test

Most econometric models are based on the assumption of normality, as it is this assumption that allows valid statistical inference to be made from the model. Normality tests are typically employed in order to assess if a set of data is normally distributed (Jarque, 1987). Commonly employed measures that assess these properties of the data include the Shapiro-Wilk test, the Jarque-Bera test and others. In order to identify the degree of normality of the variable, these tests provide the degree of asymmetry and kurtosis.

A significance level (often set at 5%) is used to interpret results. If the derived p-value from the test is more than the threshold, the null hypothesis of normality is accepted and this means that data is normally distributed. While we reject the null, which is an indication of non-normality, when it turned out that p-value is less than 5%. Normality is a very important assumption, because the valid hypothesis testing and a reliable estimation of the model may not be held if its assumption is violated.

3.7.2. Serial correlation LM test

The Lagrange Multiplier test is a diagnostic test for autocorrelation of the residuals from a regression model. In regression, autocorrelation is when error terms can be correlated through time. This can in turn bias time series estimates and generate inefficiencies in the model. LM stands for Lagrange multiplier test, which tests for independence of the residuals. Once serial correlation is determined, the model is changed to correct for it. This test will also be very helpful in obtaining accuracy and reliability in the results in the time series (Breusch, 1980).

3.7.3. Heteroskedasticity Test

Heteroskedasticity refers to the fact that the variances of the residuals in a regression model are not constantly violating homoscedasticity. This potentially leads to cultishly and biased parameter estimates that weakens the model. Common tests for heteroskedasticity include the Breusch-Pagan Test and White Test. If the p-value of these tests is smaller than the critical value i.e. 0.05, then the homoscedasticity null hypothesis is rejected and heteroskedasticity is shown in the model. This is frequently adjusted for using robust standard errors or transforming the data (White 1980).

3.7.4. CUSUM Test

The CUSUM test is a statistical procedure to determine whether a time series of coefficients in a regression model is stable or not over time. It plots the cumulative sum of recursive residuals versus critical boundaries. The model coefficients have the right stability if the plots lie within these limits. Deviations outside the limits indicate structural changes and are thus indicative that the parameters of the model are different in the current time than they had been in the previous time period. Because this test helps to ensure that the regression results are robust against temporal instabilities (Brown et al., 1975), this has a number of applications, most notably in time series analyses.

3.7.5 CUSUM of Squares Test

CUSUMSQ A test of regression model variance constancy over time (CUSUMSQ) In contrast to the CUSUM test above, which tests for coefficients, the CUSUMSQ test tests whether the residual variance is stable. You can draw a cumulative sum of square residuals against critical boundaries. If the plot remains between these boundaries, we say the variance is stable. While, a crossing of the bounds indicates variance instability, and the model should be adjusted. In

order to improve the robustness and reliability of the model, the test is performed alongside the CUSUM test (Brown et al., 1975).

CHAPTER FOUR: FINDINGS AND DISCUSSION

4.1. Introduction

This chapter presents the key findings of the study and addresses the research questions outlined in Chapter One. Through the analysis of results derived from the data, it provides a comprehensive discussion linking the findings to the research objectives and theoretical framework; it also looks at implications in the context of the focus of the study, giving insights and interpretation that add to the understanding of the topic.

4.2. Test for stationarity

Table 4. 1 Results of the ADF test

Variable	Test at	ADF at level	ADF at first difference
RE	Intercept	0.0040	0.0000
	Trend and Intercept	0.0007	0.0000
	None	0.2415	0.0000
URBR	Intercept	0.0000	0.0000
	Trend and Intercept	0.0000	0.0011
	None	0.7716	0.0000
POPGR	Intercept	0.2665	0.0000
	Trend and Intercept	0.0027	0.0000
	None	0.4524	0.0000
IR	Intercept	0.0120	0.0000
	Trend and Intercept	0.0157	0.0000
	None	0.0970	0.0000
INFL	Intercept	0.9710	0.0000
	Trend and Intercept	0.9572	0.0000
	None	0.8697	0.0000
GDPGR	Intercept	0.0013	0.0000
	Trend and Intercept	0.0079	0.0000
	None	0.4031	0.0000
EI	Intercept	0.0000	-
	Trend and Intercept	0.0000	-
	None	0.0000	-

The following table presents the Augmented Dickey-Fuller test results for each of the variables under different levels of significance-intercept, trend and intercept, none-for both level and first difference.

RE (Renewable Energy) , at a level, the series is not stationary under all conditions: Intercept = 0.0040, Trend and Intercept = 0.0007, None = 0.2415. First difference, RE is stationary at all conditions: all p-values = 0.0000.

URBR (Urbanization), at the level, URBR is stationary under the conditions of Intercept and Trend and Intercept: p-values = 0.0000. Under the "None" condition, it is non-stationary: p-value = 0.7716. At first difference, URBR is stationary under all conditions: p-values = 0.0000 except for Trend and Intercept at 0.0011.

POPGR (Population Growth), at the level, POPGR is not stationary under any condition: p-values > 0.05. At the first difference, POPGR becomes stationary (all p-values = 0.0000).

IR (Interest Rates), at the level, IR is stationary under Intercept and Trend and Intercept (p-values = 0.0120 and 0.0157). Under the "None" condition, IR is non-stationary (p-value = 0.0970). At the first difference, IR is stationary (p-value = 0.0000).

INFL (Inflation), at the level, INFL is non-stationary (p-values > 0.05). At the first difference, INFL is stationary (all p-values = 0.0000).

GDPGR (GDP Growth Rate), at the level, GDPGR is non-stationary under all conditions (p-values > 0.05). At the first difference, GDPGR becomes stationary (all p-values = 0.0000).

EI (Energy Prices), at the level, EI is stationary under all conditions (p-values = 0.0000).

4.3. Bound test.

As observed from the above unit root testing the variables employed are either integrated at level or at first difference. We can now proceed to the ADRL bound test to see if there is a long-term relationship between the explained and the explanatory variables after testing for the unit root and finding that none of the variables is integrated at I (2). The results of the ADRL bound test are displayed on the table below:

Table 4. 2 Bound test cointegration results

F-Bounds Test		Null Hypothesis: No levels relationship		
Test Statistic	Value	Signif.	I(0)	I(1)
			Asymptotic: n=1000	
F-statistic	8.178404	10%	1.75	2.87
k	6	5%	2.04	3.24
		2.5%	2.32	3.59
		1%	2.66	4.05
Actual Sample Size	50		Finite Sample: n=50	
		10%	-1	-1
		5%	-1	-1
		1%	-1	-1

F-statistic values are significantly higher than values at the upper bound at 1% and the 5% critical value

Therefore, this indicates that the explained and the explanatory variables have a long-run relationship consequently; we can categorically reject the null hypothesis that the dependent and independent variables do not have a long-run relationship.

Henceforth, the bound test shows that we can use the ECM approach to compute short run and the long-run coefficients since it is established that the explained and explanatory variables have a long-run relationship.

Table 4. 3 Short run error correction model results

ARDL Error Correction Regression
 Dependent Variable: D(RE)
 Selected Model: ARDL(3, 6, 6, 6, 4, 6, 6)
 Case 1: No Constant and No Trend
 Date: 01/21/25 Time: 04:59
 Sample: 2010Q1 2023Q4
 Included observations: 50

ECM Regression				
Case 1: No Constant and No Trend				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(RE(-1))	1.580969	0.240132	6.583746	0.0003
D(RE(-2))	0.524301	0.128158	4.091068	0.0046
D(URBR)	1.167165	0.372213	3.135740	0.0165
D(URBR(-1))	-10.79736	1.509426	-7.153289	0.0002
D(URBR(-2))	-5.655802	1.149161	-4.921680	0.0017
D(URBR(-3))	0.009882	0.914576	0.010805	0.9917
D(URBR(-4))	1.931932	0.710948	2.717405	0.0299
D(URBR(-5))	1.350991	0.400873	3.370120	0.0119
D(POPGR)	1.243249	1.417400	0.877134	0.4095
D(POPGR(-1))	9.856359	1.895966	5.198594	0.0013
D(POPGR(-2))	2.740971	2.167241	1.264728	0.2464
D(POPGR(-3))	-8.243420	2.374768	-3.471253	0.0104
D(POPGR(-4))	-5.369057	2.034104	-2.639520	0.0334
D(POPGR(-5))	-6.578585	1.500274	-4.384922	0.0032
D(IR)	1.519397	0.320925	4.734428	0.0021
D(IR(-1))	1.678175	0.359045	4.674003	0.0023
D(IR(-2))	1.585821	0.328875	4.821948	0.0019
D(IR(-3))	1.215762	0.242377	5.015997	0.0015
D(IR(-4))	0.055607	0.447047	0.124387	0.9045
D(IR(-5))	-0.827892	0.472126	-1.753539	0.1230
D(INFL)	-0.972791	0.214446	-4.536303	0.0027
D(INFL(-1))	-0.100546	0.109417	-0.918922	0.3887
D(INFL(-2))	-0.751844	0.090614	-8.297241	0.0001
D(INFL(-3))	-1.075020	0.121518	-8.846576	0.0000
D(GDPGR)	-9.597911	6.600455	-1.454129	0.1892
D(GDPGR(-1))	-88.71851	8.930459	-9.934372	0.0000
D(GDPGR(-2))	-74.89244	8.263576	-9.062957	0.0000
D(GDPGR(-3))	-77.63170	7.636718	-10.16558	0.0000
D(GDPGR(-4))	-30.95349	9.427600	-3.283284	0.0134
D(GDPGR(-5))	-17.08319	7.191489	-2.375474	0.0492
D(EI)	-0.118289	0.038031	-3.110321	0.0171
D(EI(-1))	0.534554	0.049340	10.83413	0.0000
D(EI(-2))	0.431071	0.041515	10.38349	0.0000
D(EI(-3))	0.271654	0.045388	5.985218	0.0006
D(EI(-4))	0.117794	0.029635	3.974891	0.0054
D(EI(-5))	0.061276	0.024871	2.463707	0.0432
CointEq(-1)*	-3.152540	0.305742	-10.31112	0.0000
R-squared	0.988074	Mean dependent var	-0.361600	
Adjusted R-squared	0.955046	S.D. dependent var	4.532149	
S.E. of regression	0.960919	Akaike info criterion	2.891074	
Sum squared resid	12.00376	Schwarz criterion	4.305971	
Log likelihood	-35.27685	Hannan-Quinn criter.	3.429875	
Durbin-Watson stat	1.775659			

* p-value incompatible with t-Bounds distribution.

Table 4. 4 Long run error correction model results

Levels Equation				
Case 1: No Constant and No Trend				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
URBR	5.386587	0.632133	8.521290	0.0001
POPGR	-3.327110	5.872852	-0.566524	0.5887
IR	0.014349	0.341890	0.041971	0.9677
INFL	-0.390604	0.202814	-1.925919	0.0955
GDPGR	23.25841	8.474676	2.744460	0.0287
EI	-0.246130	0.023274	-10.57509	0.0000

$$EC = RE - (5.3866*URBR - 3.3271*POPGR + 0.0143*IR - 0.3906*INFL + 23.2584*GDPGR - 0.2461*EI)$$

4.4. Overall Interpretation

From the above output, the ECM model for renewable energy consumption, RE, explained by set of regressors are: the urbanization rate, URBR; population growth rate, POPGR; interest rate, IR; inflation, INFL; GDP growth rate, GDPGR; and energy prices, EI.

4.4.1. Highlights of findings

Error Correction Term (CointEq(-1)):

The Error Correction Term (ECT) in cointegration models measures how quickly the dependent variable returns to equilibrium after a deviation. With an ECT value of **-3.152540**, the system adjusts by approximately 3.15 units for every unit deviation from equilibrium, indicating a rapid correction process. The negative sign suggests the system actively moves towards balance. The statistical significance of 0.0000 confirms that this relationship is not due to random chance, but reflects a genuine and reliable adjustment mechanism. Overall, the negative ECT value and high significance indicate a swift and decisive return to long-term equilibrium.

4.4.2. Long run and short-run dynamics

4.4.2.1. Renewable energy consumption

The model's inclusion of lagged values of Renewable Energy (RE) consumption, denoted as (-1) and (-2), underscores the positive influence of past RE consumption on current trends. The statistical significance of these lagged terms suggests that previous increases in RE consumption contribute to higher current consumption levels. This indicates a positive, time-dependent relationship where past consumption patterns continue to drive future consumption. Such findings highlight the importance of historical RE consumption in shaping current trends, allowing for a better understanding of short-run dynamics and offering more reliable forecasting of future RE consumption.

4.4.2.2. Urbanization

From the ECM regression, the results show that urbanization has a significant positive impact on renewable energy consumption in short run and long run. According to the coefficient, a 1% increase in urbanization result in 1.16%, 5.38% respectively rise in renewable energy consumption at 5%, 1% level of significance respectively. The significant positive impact of urbanization on renewable energy consumption can be attributed to several factors. As urban areas grow, there tends to be greater access to infrastructure, including renewable energy sources such as solar, wind, and hydropower. Additionally, urbanization often leads to increased awareness of environmental issues and a higher demand for cleaner energy options. Cities also tend to have more policies and investments focused on sustainability, which can drive the adoption of renewable energy technologies. As a result, urbanization promotes both the availability and demand for renewable energy, leading to increased consumption.

Furthermore, the lagged values of URBR produce mixed results; some, though positive, are significant and, therefore, show that the series of urbanization positively affect the current consumption of renewable energy, while some are negative and significant, showing probably that past urbanization has negatively affected current RE consumption.

4.4.2.3. Population growth

From the ECM regression, the results show that population growth has a positive impact on renewable energy consumption in short run although it is not significant. According to the coefficient, a 1% increase in population growth result in 1.24% increase in renewable energy consumption. Population growth positively impacts renewable energy consumption by increasing energy demand and encouraging investment in renewable technologies. However, the short-run insignificance suggests that the effects take time to materialize, as factors like slow adoption and infrastructure development may delay the observable impact on renewable energy consumption. Even though population growth showed an insignificant positive impact in short run, in the long run population growth showed an insignificant negative impact on renewable energy consumption. From the coefficient, a 1% increase in population growth reduces renewable energy consumption by 3.32%. The insignificant negative impact of population growth on renewable energy consumption in the long run could be due to several factors. As population grows, there may be a higher overall energy demand, but this demand might not prioritize renewable energy. In some cases, increased population growth could lead to greater reliance on non-renewable energy sources due to lower initial investment in renewable infrastructure or technological challenges in meeting the growing energy needs with renewables.

Additionally Lags in POPGR demonstrate conflicting signals with the appearance of positive and negative coefficients, whose theoretical meaning is thus more complicated and can depend on time perspective as well.

4.4.2.4. Interest rate

From the ECM regression, the results show that interest rate has a positive impact on renewable energy consumption in short run and significant. According to the coefficient, a 1% increase in interest rate result in 1.51% increase in renewable energy consumption. The positive short-run relationship between interest rates and renewable energy consumption can arise due to shifting investment dynamics and policy incentives. the Higher interest rates may reduce fossil fuel investments, making renewables more attractive due to lower operational costs and also Governments and financial institutions often introduce green financing schemes to support renewable projects, mitigating the impact of higher borrowing costs ,in the long run

interest rate showed a positive but insignificant impact on renewable energy consumption, the coefficient indicates a 1% increase in interest rates results in 0.01% increase in renewable energy consumption. The interest rate has overall positive and significant lag values pointing towards the fact that historical rises in the rate of interest result in greater current consumption of real estate.

4.4.2.5. Inflation

The result showed that in short run, inflation has a significant negative impact on renewable energy consumption which means a 1% increase in inflation result in a 0.97% decrease in renewable energy consumption, and this effect is statistically significant due to Inflation reduces purchasing power and increases borrowing costs, raises input prices, and shifts demand to cheaper energy and in the long run, inflation has a significant negative impact on renewable energy consumption. a 1% increase in inflation results in a 0.39% decrease in renewable energy consumption.

Furthermore the lagged values of inflation are negative and significant, showing that the rise in past inflation depresses the current RE consumption.

4.4.2.6. GDP growth rate

From the ECM regression, the results show that GDP growth rate has a positive significant impact on renewable energy consumption in long run .a 1% increase in GDP growth rate (GDPGR) leads to a 23.25% increase in renewable energy consumption. Economic growth facilitates investments in renewable energy technologies, infrastructure, and research, encouraging cleaner and more sustainable energy consumption and in short run GDP growth rate has negative impact on renewable energy consumption a 1% increase in GDP growth is associated with a 9.59% decrease in renewable energy consumption. In the short run, GDP growth may lead to higher energy demand, primarily from non-renewable sources, as industries and sectors expand. This increased demand for cheaper, conventional energy sources could outpace the adoption of renewable energy, resulting in a decrease in renewable energy consumption despite GDP growth.

Additional the lagged values of GDPGR are negative and significant, showing that the increase in economic growth in the past has depressed current RE consumption. This is a little

surprising but could be for various reasons, including the initial high energy intensity of economic growth.

4.4.2.7. Energy Prices

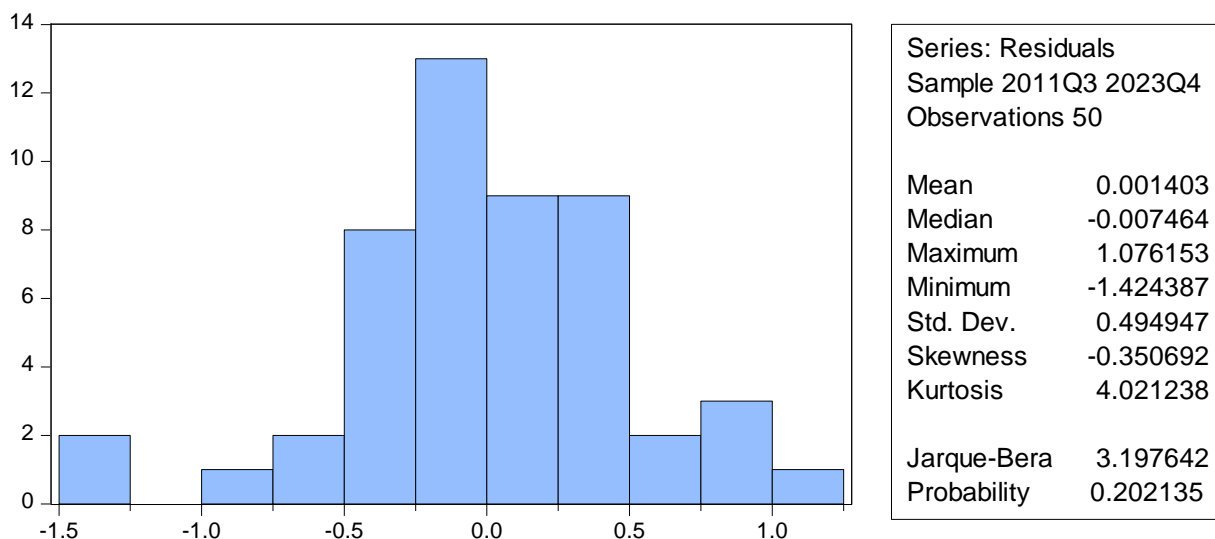
The results show that energy price has negative relationship with renewable energy consumption indicate that a 1% increase in energy prices reduces renewable energy consumption by 0.118% in the short run and 0.246% in the long run and both are statistically significant. The negative relationship between energy prices and renewable energy consumption can be attributed to the increased cost of energy, which may lead consumers to reduce their demand for renewable energy. Higher energy prices often result in a preference for cheaper, non-renewable energy sources, especially in the short term when renewable energy infrastructure may not be fully developed or affordable. Over time, as prices rise, it could also deter investment in renewable energy technologies, further limiting consumption.

Furthermore, the lagged values of EI are positive and significant, showing that higher energy prices in the past positively contribute to current RE consumption. This justifies that, with increased energy prices, renewable energy sources need to be embraced.

4.5. Model Validity and reliability tests

4.5.1. Normality test

Figure 4. 1 Normality test results



The Jarque-Bera test for normality indicates that the residuals are normally distributed as the probability is 20% far above the 5% significance level.

4.5.2. Autocorrelation

Figure 4. 2Serial correlation LM test

Breusch-Godfrey Serial Correlation LM Test:

F-statistic	0.092354	Prob. F(2,5)	0.9133
Obs*R-squared	1.781268	Prob. Chi-Square(2)	0.4104

The Breusch-Godfrey serial correlation LM test indicates that there is no serial correlation in the residuals as the probability of both the F-statistic and Obs*R-squared is 91% and 41% respectively far above the 5% significance level

4.5.3. Heteroskedasticity

Figure 4. 3 Breusch pagan test

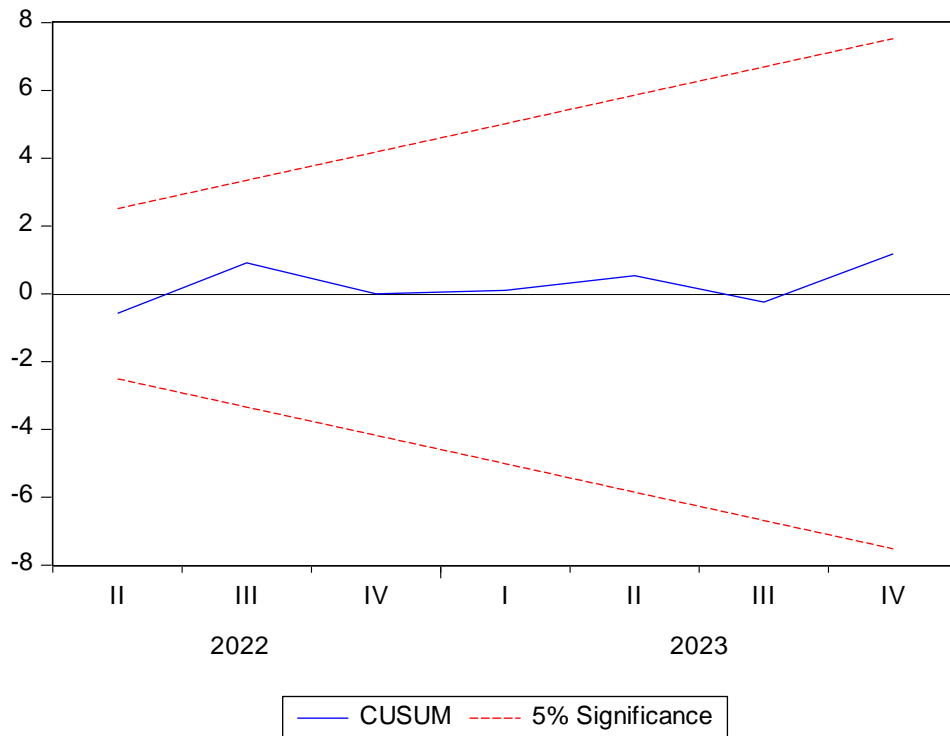
Heteroskedasticity Test: Breusch-Pagan-Godfrey

F-statistic	0.973934	Prob. F(43,6)	0.5788
Obs*R-squared	43.73423	Prob. Chi-Square(43)	0.4401
Scaled explained SS	1.293160	Prob. Chi-Square(43)	1.0000

The Breusch-Godfrey heteroskedasticity test indicates that there is no heteroskedasticity in the residuals as the probability of both the F-statistic, Obs*R-squared and scaled explained SS is 57, 44, and 100% respectively far above the 5% significance level.

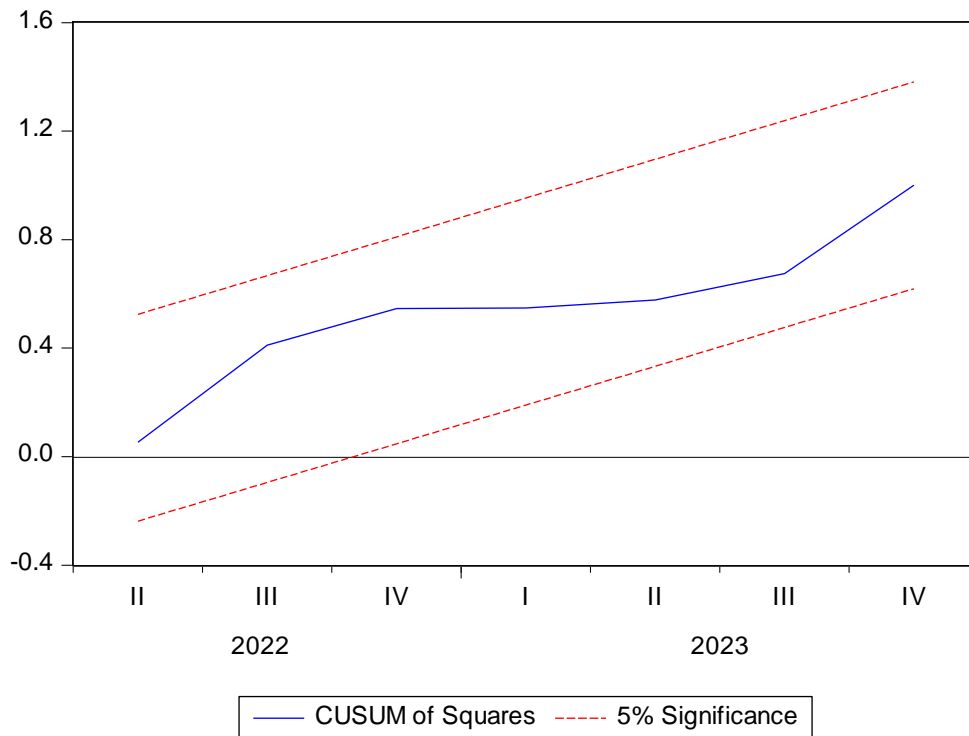
4.5.4. Model stability

Figure 4. 4CUSUM test



The CUSUM test for stability shows that the model is stable at a 5% significance level as the CUSUM line doesn't cross the 5% significance level boundaries in red lying between them as shown on the graph.

Figure 4. 5. CUSUM sum of squares test



The CUSUM of squares test for stability shows that the model is stable at a 5% significance level as the CUSUM of squares line doesn't cross the 5% significance level boundaries in red lying between them as shown on the graph.

CHAPTER 5. CONCLUSION AND RECOMMENDATIONS

This study has explored the impact of energy prices on renewable energy consumption in Rwanda, with a focus on the period between 2010 and 2023. Through the use of the ARDL model and ECM model, the analysis of key macroeconomic variables such as interest rates, population growth, urbanization, inflation, GDP growth, and energy prices has provided valuable insights into the dynamics of renewable energy consumption.

The findings indicated that higher energy prices negatively affect renewable energy consumption; both in the short and long term, but past energy price increases may have boosted renewable energy adoption. Urbanization positively influences renewable energy consumption both in short run and long run due to better infrastructure and sustainability initiatives. Population growth showed an insignificant positive impact on renewable energy consumption in short run and it also has insignificant negative long-term effect. Inflation significantly reduces renewable energy consumption both in the long and short run by lowering purchasing power, while GDP growth promotes long-term renewable energy consumption significantly yet it decrease renewable energy consumption in the short run but insignificantly. Interest rate showed significant positive effect on renewable energy consumption in short run and a positive but insignificant effect in the long run.

To foster renewable energy adoption in Rwanda, the government should implement policies such as subsidies, tax incentives, and green financing, along with investing in urban and rural renewable energy infrastructure. Managing inflation and prioritizing renewable energy in areas with growing populations is crucial. Long-term investment should focus on innovation, diversification, and sustainability, with balanced energy pricing and interest rate management supporting green initiatives.

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APPENDIX

A: UNIT ROOT TESTS.

A.1. ADF at level for RE

Null Hypothesis: RE has a unit root
Exogenous: Constant
Lag Length: 0 (Automatic - based on AIC, maxlag=10)

	t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic	-3.883008	0.0040
Test critical values: 1% level	-3.555023	
5% level	-2.915522	
10% level	-2.595565	

*MacKinnon (1996) one-sided p-values.

Null Hypothesis: RE has a unit root
Exogenous: Constant, Linear Trend
Lag Length: 0 (Automatic - based on AIC, maxlag=10)

	t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic	-5.051664	0.0007
Test critical values: 1% level	-4.133838	
5% level	-3.493692	
10% level	-3.175693	

*MacKinnon (1996) one-sided p-values.

Null Hypothesis: RE has a unit root
Exogenous: None
Lag Length: 3 (Automatic - based on AIC, maxlag=10)

	t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic	-1.103163	0.2415
Test critical values: 1% level	-2.610192	
5% level	-1.947248	
10% level	-1.612797	

*MacKinnon (1996) one-sided p-values.

A.2. ADF at First difference for RE

Null Hypothesis: D(RE) has a unit root
 Exogenous: Constant
 Lag Length: 2 (Automatic - based on AIC, maxlag=10)

	t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic	-7.403129	0.0000
Test critical values: 1% level	-3.562669	
5% level	-2.918778	
10% level	-2.597285	

*Mackinnon (1996) one-sided p-values.

Null Hypothesis: D(RE) has a unit root
 Exogenous: None
 Lag Length: 2 (Automatic - based on AIC, maxlag=10)

	t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic	-7.305738	0.0000
Test critical values: 1% level	-2.610192	
5% level	-1.947248	
10% level	-1.612797	

*Mackinnon (1996) one-sided p-values.

Null Hypothesis: D(RE) has a unit root
 Exogenous: Constant, Linear Trend
 Lag Length: 2 (Automatic - based on AIC, maxlag=10)

	t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic	-7.619533	0.0000
Test critical values: 1% level	-4.144584	
5% level	-3.498692	
10% level	-3.178578	

*Mackinnon (1996) one-sided p-values.

[A.3. ADF at level for URBR](#)

Null Hypothesis: URBR has a unit root
 Exogenous: Constant
 Lag Length: 0 (Automatic - based on AIC, maxlag=10)

	t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic	-10.37798	0.0000
Test critical values: 1% level	-3.555023	
5% level	-2.915522	
10% level	-2.595565	

*Mackinnon (1996) one-sided p-values.

Null Hypothesis: URBR has a unit root
 Exogenous: Constant, Linear Trend
 Lag Length: 2 (Automatic - based on AIC, maxlag=10)

	t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic	-7.289673	0.0000
Test critical values: 1% level	-4.140858	
5% level	-3.496960	
10% level	-3.177579	

Null Hypothesis: URBR has a unit root
 Exogenous: None
 Lag Length: 9 (Automatic - based on AIC, maxlag=10)

	t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic	0.311810	0.7716
Test critical values: 1% level	-2.616203	
5% level	-1.948140	
10% level	-1.612320	

*Mackinnon (1996) one-sided p-values.

A.4. ADF at First difference for URBR

Null Hypothesis: D(URBR) has a unit root
 Exogenous: Constant
 Lag Length: 6 (Automatic - based on AIC, maxlag=10)

	t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic	-5.871897	0.0000
Test critical values: 1% level	-3.574446	
5% level	-2.923780	
10% level	-2.599925	

*Mackinnon (1996) one-sided p-values.

Null Hypothesis: D(URBR) has a unit root
 Exogenous: Constant, Linear Trend
 Lag Length: 8 (Automatic - based on AIC, maxlag=10)

	t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic	-4.972957	0.0011
Test critical values: 1% level	-4.170583	
5% level	-3.510740	
10% level	-3.185512	

*Mackinnon (1996) one-sided p-values.

Null Hypothesis: D(URBR) has a unit root
 Exogenous: None
 Lag Length: 6 (Automatic - based on AIC, maxlag=10)

	t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic	-5.940562	0.0000
Test critical values: 1% level	-2.614029	
5% level	-1.947816	
10% level	-1.612492	

*MacKinnon (1996) one-sided p-values.

A.5. ADF at level for POPGR

Null Hypothesis: POPGR has a unit root
 Exogenous: Constant
 Lag Length: 7 (Automatic - based on AIC, maxlag=10)

	t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic	-2.046977	0.2665
Test critical values: 1% level	-3.574446	
5% level	-2.923780	
10% level	-2.599925	

*MacKinnon (1996) one-sided p-values.

Null Hypothesis: POPGR has a unit root
 Exogenous: Constant, Linear Trend
 Lag Length: 10 (Automatic - based on AIC, maxlag=10)

	t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic	-4.659664	0.0027
Test critical values: 1% level	-4.175640	
5% level	-3.513075	
10% level	-3.186854	

*MacKinnon (1996) one-sided p-values.

Null Hypothesis: POPGR has a unit root
 Exogenous: None
 Lag Length: 7 (Automatic - based on AIC, maxlag=10)

	t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic	-0.599559	0.4524
Test critical values: 1% level	-2.614029	
5% level	-1.947816	
10% level	-1.612492	

*MacKinnon (1996) one-sided p-values.

A.6. ADF at First difference for POPGR

Null Hypothesis: D(POPGR) has a unit root
 Exogenous: Constant
 Lag Length: 10 (Automatic - based on SIC, maxlag=10)

	t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic	-6.490419	0.0000
Test critical values: 1% level	-3.588509	
5% level	-2.929734	
10% level	-2.603064	

*MacKinnon (1996) one-sided p-values.

Null Hypothesis: D(POPGR) has a unit root
 Exogenous: Constant, Linear Trend
 Lag Length: 10 (Automatic - based on SIC, maxlag=10)

	t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic	-6.345185	0.0000
Test critical values: 1% level	-4.180911	
5% level	-3.515523	
10% level	-3.188259	

*MacKinnon (1996) one-sided p-values.

Null Hypothesis: D(POPGR) has a unit root
 Exogenous: None
 Lag Length: 10 (Automatic - based on SIC, maxlag=10)

	t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic	-6.353847	0.0000
Test critical values: 1% level	-2.618579	
5% level	-1.948495	
10% level	-1.612135	

*MacKinnon (1996) one-sided p-values.

[A.7. ADF at level for IR](#)

Null Hypothesis: IR has a unit root
 Exogenous: Constant
 Lag Length: 0 (Automatic - based on SIC, maxlag=10)

	t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic	-3.488780	0.0120
Test critical values: 1% level	-3.555023	
5% level	-2.915522	
10% level	-2.595565	

*MacKinnon (1996) one-sided p-values.

Null Hypothesis: IR has a unit root
 Exogenous: Constant, Linear Trend
 Lag Length: 0 (Automatic - based on SIC, maxlag=10)

	t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic	-3.964484	0.0157
Test critical values: 1% level	-4.133838	
5% level	-3.493692	
10% level	-3.175693	

*MacKinnon (1996) one-sided p-values.

Null Hypothesis: IR has a unit root
 Exogenous: None
 Lag Length: 0 (Automatic - based on SIC, maxlag=10)

	t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic	-1.628559	0.0970
Test critical values: 1% level	-2.607686	
5% level	-1.946878	
10% level	-1.612999	

*MacKinnon (1996) one-sided p-values.

A.8. ADF at first difference IR

Null Hypothesis: D(IR) has a unit root
 Exogenous: Constant
 Lag Length: 0 (Automatic - based on SIC, maxlag=10)

	t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic	-9.423824	0.0000
Test critical values: 1% level	-3.557472	
5% level	-2.916566	
10% level	-2.596116	

*MacKinnon (1996) one-sided p-values.

Null Hypothesis: D(IR) has a unit root
 Exogenous: Constant, Linear Trend
 Lag Length: 0 (Automatic - based on SIC, maxlag=10)

	t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic	-9.363763	0.0000
Test critical values: 1% level	-4.137279	
5% level	-3.495295	
10% level	-3.176618	

*MacKinnon (1996) one-sided p-values.

Null Hypothesis: D(IR) has a unit root
 Exogenous: None
 Lag Length: 0 (Automatic - based on SIC, maxlag=10)

	t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic	-9.488709	0.0000
Test critical values: 1% level	-2.608490	
5% level	-1.946996	
10% level	-1.612934	

*Mackinnon (1996) one-sided p-values.

A.9. ADF at level INFL

Null Hypothesis: INFL has a unit root
 Exogenous: Constant
 Lag Length: 0 (Automatic - based on SIC, maxlag=10)

	t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic	0.212045	0.9710
Test critical values: 1% level	-3.555023	
5% level	-2.915522	
10% level	-2.595565	

*Mackinnon (1996) one-sided p-values.

Null Hypothesis: INFL has a unit root
 Exogenous: Constant, Linear Trend
 Lag Length: 0 (Automatic - based on SIC, maxlag=10)

	t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic	-0.820323	0.9572
Test critical values: 1% level	-4.133838	
5% level	-3.493692	
10% level	-3.175693	

*Mackinnon (1996) one-sided p-values.

Null Hypothesis: INFL has a unit root
 Exogenous: None
 Lag Length: 0 (Automatic - based on SIC, maxlag=10)

	t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic	0.730658	0.8697
Test critical values: 1% level	-2.607686	
5% level	-1.946878	
10% level	-1.612999	

*MacKinnon (1996) one-sided p-values.

A.10. ADF at first difference INFL

Null Hypothesis: D(INFL) has a unit root
 Exogenous: Constant
 Lag Length: 0 (Automatic - based on SIC, maxlag=10)

	t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic	-7.412836	0.0000
Test critical values: 1% level	-3.557472	
5% level	-2.916566	
10% level	-2.596116	

*MacKinnon (1996) one-sided p-values.

Null Hypothesis: D(INFL) has a unit root
 Exogenous: Constant, Linear Trend
 Lag Length: 0 (Automatic - based on SIC, maxlag=10)

	t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic	-7.839136	0.0000
Test critical values: 1% level	-4.137279	
5% level	-3.495295	
10% level	-3.176618	

*MacKinnon (1996) one-sided p-values.

Null Hypothesis: D(INFL) has a unit root
 Exogenous: None
 Lag Length: 0 (Automatic - based on SIC, maxlag=10)

	t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic	-7.323407	0.0000
Test critical values: 1% level	-2.608490	
5% level	-1.946996	
10% level	-1.612934	

*MacKinnon (1996) one-sided p-values.

A.10 . ADF at level GDPGR

Null Hypothesis: GDPGR has a unit root
 Exogenous: Constant
 Lag Length: 7 (Automatic - based on SIC, maxlag=10)

	t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic	-4.304229	0.0013
Test critical values: 1% level	-3.574446	
5% level	-2.923780	
10% level	-2.599925	

*MacKinnon (1996) one-sided p-values.

Null Hypothesis: GDPGR has a unit root
 Exogenous: Constant, Linear Trend
 Lag Length: 7 (Automatic - based on SIC, maxlag=10)

	t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic	-4.250106	0.0079
Test critical values: 1% level	-4.161144	
5% level	-3.506374	
10% level	-3.183002	

*MacKinnon (1996) one-sided p-values.

Null Hypothesis: GDPGR has a unit root
 Exogenous: None
 Lag Length: 4 (Automatic - based on SIC, maxlag=10)

	t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic	-0.712595	0.4031
Test critical values: 1% level	-2.611094	
5% level	-1.947381	
10% level	-1.612725	

*MacKinnon (1996) one-sided p-values.

A.11. ADF at first difference GDPGR

Null Hypothesis: D(GDPGR) has a unit root
 Exogenous: Constant
 Lag Length: 3 (Automatic - based on SIC, maxlag=10)

	t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic	-7.423407	0.0000
Test critical values: 1% level	-3.565430	
5% level	-2.919952	
10% level	-2.597905	

*MacKinnon (1996) one-sided p-values.

Null Hypothesis: D(GDPGR) has a unit root
 Exogenous: Constant, Linear Trend
 Lag Length: 3 (Automatic - based on SIC, maxlag=10)

	t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic	-7.354985	0.0000
Test critical values: 1% level	-4.148465	
5% level	-3.500495	
10% level	-3.179617	

*MacKinnon (1996) one-sided p-values.

Null Hypothesis: D(GDPGR) has a unit root
 Exogenous: None
 Lag Length: 3 (Automatic - based on SIC, maxlag=10)

	t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic	-7.502510	0.0000
Test critical values: 1% level	-2.611094	
5% level	-1.947381	
10% level	-1.612725	

*MacKinnon (1996) one-sided p-values.

A.12. ADF at level EI

Null Hypothesis: EI has a unit root
 Exogenous: Constant
 Lag Length: 0 (Automatic - based on SIC, maxlag=10)

	t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic	-7.095706	0.0000
Test critical values: 1% level	-3.555023	
5% level	-2.915522	
10% level	-2.595565	

*MacKinnon (1996) one-sided p-values.

Null Hypothesis: EI has a unit root
Exogenous: Constant, Linear Trend
Lag Length: 0 (Automatic - based on SIC, maxlag=10)

	t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic	-7.040294	0.0000
Test critical values: 1% level	-4.133838	
5% level	-3.493692	
10% level	-3.175693	

*MacKinnon (1996) one-sided p-values.

Null Hypothesis: EI has a unit root
Exogenous: None
Lag Length: 0 (Automatic - based on SIC, maxlag=10)

	t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic	-6.366983	0.0000
Test critical values: 1% level	-2.607686	
5% level	-1.946878	
10% level	-1.612999	

*MacKinnon (1996) one-sided p-values.