UNIVERSITY of RWANDA COLLEGE OF SCIENCE AND TECHNOLOGY ACE-ESD AFRICAN CENTER OF EXCELLENCE IN ENERGY FOR SUSTAINABLE DEVELOPMENT

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EMPIRICAL ANALYSIS ON ECONOMIC IMPACTS OF INTERGRATING RENEWABLE ENERGY ON NATIONAL GRID

The Case of Rwanda

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DECLARATION

I KARASIRA UWASE Ahmed, hereby declare to the best of our knowledge that this work entitled**: "EMPIRICAL ANALYSIS ECONOMIC ON IMPACTS OF INTERGRATING RENEWABLE ENERGY ON NATIONAL GRID. THE CASE OF 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.

KARASIRA UWASE Ahmed

Signature: ………………………………………

Date………/………/2025

CERTIFICATION

This is to certify that the present research project entitled: **"EMPIRICAL ANALYSIS ON ECONOMIC IMPACTS OF INTERGRATING RENEWABLE ENERGY ON NATIONAL GRID. THE CASE OF RWANDA**" was conducted by **KARASIRA UWASE Ahmed** under my supervision and is now ready for submission.

Supervisor: Dr. HAKIZIMANA Jean de Dieu

Signature ....

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

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List of Abbreviations:

SDGs: Sustainable Development Goals

NISR: National Institute of Statistics of Rwanda

UN: United Nations

IRENA: International Renewable Energy Agency

GDP: Gross Domestic Product

PCREEE: Pacific Centre for Renewable Energy and Energy Efficiency

IEA: International Energy Agency

Mw: Mega Watt

RE: Renewable Energy

Thermo: The contribution of thermal oil energy to the national grid.

Hydro: Contribution of hydropower into the national grid.

ϵt: Error term incorporating omitted factors.

ABSTRACT

This study investigates the impacts of integrating renewable energy into Rwanda's national grid, emphasizing its economic, environmental, and policy dimensions. using a Generalized Method of Moments (GMM) estimation model, the research analyzes the contributions of hydroelectric (LHYDRO) and thermal oil power (LTHERMO) to Rwanda's Gross Domestic Product (GDP). The findings reveal that renewable energy significantly contributes to economic growth, with hydroelectric power showing a positive coefficient of 0.193980 (p = 0.0000) and thermal oil power possessing a coefficient of 0.355263 (p = 0.0000). These results proves the pivotal role of renewable energy in driving economic development while highlighting the reliance on thermal oil power as a transitional energy source.

The study further explores the environmental implications, revealing that renewable energy sources, such as hydropower, promote sustainability by reducing reliance on fossil fuels, whereas thermal oil power negatively impacts environmental goals due to high carbon emissions. Diagnostic tests confirm the robustness of the results, validating the model's explanatory power (R-squared = 0.748365) and the normality of residuals.

Policy recommendations include expanding investments in renewable energy technologies, phasing out high-emission energy sources, enhancing energy efficiency, and fostering regional energy cooperation. Strengthening regulatory frameworks, increasing access to finance, and building technical capacity are critical for accelerating Rwanda's energy transition. This research highlights the transformative potential of renewable energy integration in achieving economic growth, environmental sustainability, and energy security, offering valuable insights for policymakers and stakeholders in Rwanda and similar emerging economies.

KEY WORDS:

RE: Renewable Energy, HYDRO: Hydro power energy contribution, THERMO: Thermal oil energy contribution, GDP: Gross Domestic Product

CHAPTER ONE: GENERAL INTRODUCTION

0. Introduction

On the global context most of human history renewable energy has been the only energy option available. Only during the last few centuries has fossil and lately nuclear energy sources were used in a non-renewable way. They took over because they seemed much cheaper than the renewable sources. However, environmental problems of a local as well as a global magnitude are becoming evident, and questions are now being raised: are the fossil and nuclear choices indeed the cheapest; could a full account of indirect costs be attempted? In any case, the renewable options have only been developed in some areas of the world, and the reasons for their successes and failures have to be discussed.

Solar Energy, Early uses date back to ancient Greece and Rome with burning mirrors. Modern solar development began in the 1950s, expanding significantly in the 1970s during the energy crisis. Innovations in solar cells, large-scale power plants, and distributed systems (e.g., rooftop solar) have driven rapid growth. Solar energy contributed 1,300 TWh globally in 2022, with increased adoption by companies for ESG goals. Wind Energy, Windmills were historically used for mechanical tasks like grinding grain and pumping water. The late 19th century saw the first wind turbines for electricity. Interest surged in the 1970s, leading to large-scale wind farms in Denmark, California, and Europe. Wind turbines now produce over 2,100 TWh annually, with offshore wind farms growing in importance. Hydropower, Ancient civilizations used hydropower for mechanical applications. Electricity generation began in the late 19th century, with innovations like the Francis turbine. Major projects like the Three Gorges Dam and Itaipu Dam underscore hydropower's global significance. Pumped storage systems enhance grid reliability by storing surplus energy. Geothermal Energy, Humans have utilized geothermal energy since prehistoric times for bathing. The first geothermal power plant was built in Italy in 1904. Advances in technology could enable geothermal power development in more regions, complementing renewable energy mixes. Bioenergy, Biomass, including wood and plant oils, has been a key energy source throughout history. Modern biofuels like ethanol and biodiesel emerged in the 19th century, with renewed interest after the 1970s energy crises. Advances focus on sustainable feedstocks like algae and food waste, with renewable diesel gaining traction as a cleaner alternative to petroleum diesel. *(Bent Sørensen Volume 19, 1991)*

This study will look on the reason to choose renewable energy over nonrenewable energy, according to the studies we find the environmental issues with the fossil fuels which was a major global issue and particularly Rwanda and then to sustain the livelihood of the people renewable energy came in to solve those problems

Again the renewable energy like solar and hydropower will reduce the imported thermal oil in Rwanda thereby signify the economic growth

This study chose hydropower because in Rwanda it's the main electricity provider compared to other renewable sources which contributes 51% of the power generated

1. Background

1.1 Renewable energy in Africa

in 2020, 9 % of all energy generated in Africa came from renewable sources, with a strong reliance (6.8 percent) on hydropower. The report by PricewaterhouseCoopers does however indicate that progress is being made in this area. From 2019 to 2020 alone, solar and wind capacity increased by 13 percent and 11 percent, respectively, while hydropower soared 25 percent. "Total installed renewable energy capacity in Africa has grown by over 24 GW since 2013". Looking further forward, forecasts to 2050 predict an extra 27.3 exajoules (EJ) compared to the current 1.8 EJ.

1.2.Energy Profile of Rwanda

Currently, the total installed capacity to generate electricity in Rwanda is 332.6 MW from different power plants. By generation technology mix, 51% is from thermal sources, followed by hydro sources (43.9%) and solar sources with 4.2%. As part of the efforts to increase the current capacity, a number of projects to build new power plants are underway and will add more capacity on the existing national grid by the year 2024. These include among others Hakan peat to power plant which will add 80MW, Rusumo Falls Hydropower plant (26MW), Rusizi III (48.3MW), Shema (56 MW) and Nyabarongo II (43.5 MW).

Currently, the total installed capacity to generate electricity in Rwanda is 332.6 MW from different power plants. By generation technology mix, 51% is from thermal sources, followed by hydro sources (43.9%) and solar sources with 4.2%. (REG, 2024).

Hydropower is the world’s largest renewable electricity source, generating around 16% of global power in 2008, with potential for much more. Its energy production depends on water flow and elevation (head), with the best sites having both high flow and high head. While many developed countries have tapped most of their hydropower potential, emerging markets like China have room for growth. Hydropower's costs can rise with diminishing suitable sites, and environmental impacts, like disruptions to fish migration, can pose challenges. Innovations like "run-of-river" systems aim to reduce environmental costs but can still increase energy production costs.

2. Problem statement

In particular, the potential of renewable energy sources such as hydropower, geothermal and solar energy is huge. Hydropower is the country's primary energy source for power generation. Similarly, the scope of Rwanda's energy sector is not limited to electricity, but also includes biological products such as wood fuel, charcoal, and biogas, as well as petroleum products such as diesel, kerosene, liquefied petroleum gas, and natural gas such as methane (Usengimana et al., 2016). Compared with Kenya (140 kWh), Tanzania (85 kWh) and Uganda (66 kWh), Rwanda’s per capita electricity consumption (30 kWh) is the lowest in the East African Community (EAC); about 25% of the neighbors imports petroleum products for use in thermal power plants to generate electricity (Munyaneza et al.,2016).

Since the end of December 2021 accessibility to electricity was around 63%. Only 11% of available capacity is imported, while the rest is produced domestically. Rwanda energy strategic plan is to achieve 100% household's electricity access by 2024 (52% through extended grid and 48% through off-grid technology) [(REG,2019) The government has also made improvements to the grid network, including reducing system losses and improving reliability, as well as connecting with neighboring countries and importing and exporting electricity across borders. while renewable energy is often cheaper in the long term, the high upfront costs and limited access to financing can present barriers to widespread adoption.

October 2023, The Rwanda Utilities Regulatory Authority (RURA) announced a 2-month increase in fuel prices, effective October 4, 2023. The maximum retail price for gasoline increased to Rwf1,822 per liter, and the price of diesel increased to Rwf1,662 per liter. The RURA attributed the increase to international price changes for petroleum products.

2021, The government of Rwanda stabilized fuel prices by reducing some taxes on petroleum product imports. This was done to avoid the negative effects of higher fuel prices on the economy, such as inflation. Early 2020, International prices of imported commodities, including fuel, have been increasing steadily since the beginning of the COVID-19 pandemic. The crisis in Ukraine has also contributed to the increase. Rwanda imports all of its petroleum products from abroad, as there is no local production.

These recent scenarios show how thermal oil prices surged and this affected the economy of the country at large

Fossil fuels are the primary cause of global climate change, accounting for over 75% of greenhouse gas emissions. These emissions trap heat in the atmosphere, causing the Earth to warm faster than ever before. This leads to: Rising sea levels, Extreme weather events, Habitat disruption, Threats to biodiversity and Ocean acidification, which makes it harder for marine organisms to build shells and coral skeletons

Land degradation, the process of extracting, processing, and moving fossil fuels takes a toll on the landscape. This includes: Leasing large areas of land for infrastructure, such as wells, pipelines, and access roads Strip mining, which destroys forests and mountaintops Fragmenting and destroying wildlife habitat

Pollution Burning fossil fuels releases pollutants into the environment, including: Acid rain: Gases released from burning fossil fuels make precipitation acidic Carbon monoxide: A poisonous gas released when fuels are incompletely burned Sulfur dioxide: A corrosive and suffocating gas released from burning coal and diesel Oxides of nitrogen: Released from petrol Unburnt carbon particles: Dangerous pollutants that can cause respiratory diseases like asthma. (ees, 2021)

These issues are the main reasons for this study since it is programed that renewable energy would be a solution to these problems affecting our country and their economic growth.

3. **Research Objectives**

3.1. General objectives

1. The main objective of this study is to analyze the impact of integrating renewable energy on nation grid of Rwanda

3.2. Specific objectives

The study's specific goals were as follows:

2. Assess the current status and contribution of renewable energy on Rwanda's nation grid

3. Analyze the economic effect of integrating renewable energy into the national grid in Rwanda

4. Study questions

1. What is the economic impact of integrating renewable energy into the national grid in Rwanda?

2. How does the integration of renewable energy affect environmental sustainability in Rwanda??

3. What is the current contribution of renewable energy to Rwanda's national grid?

4. What policy measures are required to enhance the integration of renewable energy in Rwanda?

Basing on the objectives and methodology to be used in this research, it is expected that the effects of each selected independent variable will have statistically signifying the impact of integrating renewable energy on national grid on the economy.

5. Scope of the Study

The scope of this study encompasses an in-depth analysis of the impact of integrating renewable energy into Rwanda's national grid. The research focuses on the quarterly period from January 2010 to December 2023, offering a comprehensive examination of the technical, economic, and social dimensions of renewable energy integration during this timeframe. Key aspects to be analyzed including grid stability, and the implications for energy contribution on economic growth.

The study will involve a meticulous exploration of relevant energy policies, infrastructure developments, and external factors influencing the integration process. By adopting this temporal scope, the research aims to provide a nuanced understanding of the long-term impacts and evolving dynamics associated with renewable energy integration in Rwanda.

6. The Significance of the Study

The integration of renewable energy into Rwanda's national grid holds immense significance for the country's sustainable development, economic resilience, and environmental stewardship. This study's analysis of the impact of integrating renewable energy into Rwanda's national grid provides critical insights that serve multiple stakeholders in various ways

The findings of this study of will provide valuable evidence-based recommendations to policymakers and energy regulators, such as the Rwanda Utilities Regulatory Authority (RURA) and Rwanda Energy Group (REG). This can guide the formulation of policies to optimize the renewable energy mix, promote investment in sustainable energy projects, and enhance grid stability. The research will also help align Rwanda's energy strategies with global climate change mitigation goals and national energy access targets, such as achieving 100% electricity access by 2024.

By exploring the economic implications of integrating renewable energy, the study highlights opportunities for cost savings, reduced reliance on imported fossil fuels, and improved energy security. This analysis can attract foreign and domestic investments into Rwanda's renewable energy sector by showcasing its potential for economic growth, job creation, and poverty reduction.

The study emphasizes the role of renewable energy in mitigating climate change by reducing greenhouse gas emissions and minimizing reliance on fossil fuels. It underscores the environmental benefits of clean energy solutions, such as reduced pollution and conservation of natural ecosystems, while addressing global and national climate commitments. Insights from this research will encourage the adoption of innovative renewable energy technologies, such as smart grids and energy storage systems. This can enhance grid reliability, reduce power outages, and improve energy efficiency, which are crucial for Rwanda's industrial and technological advancement.

This study fills a critical gap in understanding the specific challenges and opportunities of renewable energy integration in Rwanda, a context that remains underexplored. The findings can serve as a reference for future research and comparative studies in other developing countries facing similar energy transition challenges.

In summary, this study is significant for advancing Rwanda's energy sector and achieving its sustainable development goals. It offers actionable insights for decision-makers, investors, and researchers to harness the transformative potential of renewable energy while addressing economic, social, and environmental challenges.

7. Organization of the Study

This thesis is composed of five chapters. Chapter one deals with the study background, problem statement, research questions and objectives, scope and, hypothesis statement and the significance of the study. Chapter Two reviews literature on possibility of fully integrating renewable energy on grid. Further, this chapter also discusses the theoretical and conceptual framework of the study. The third chapter deals with the methods of the study. This include, the selection and study area description, data type and source, research design and research strategy, sampling design and procedures, data collection and instruments, data collection procedure, data processing, definition and description of variables as well as model specification are discussed. Chapters four and five deals with analysis, discussion, conclusion and recommendations respectively.

CHAPTER TWO

2 LITERATURE REVIEW

0. Introduction

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

2.1. Theoretical Literature

2.1.1 Definition of Key Concepts

2.1.1.1 Renewable energy

Renewable energy is energy derived from natural sources that are replenished at a higher rate than they are consumed. Water fall, for example, is such source that is constantly being replenished. Renewable energy sources are plentiful and all around us.

2.1.1.2 Hydropower

Hydropower harnesses the energy of water moving from higher to lower elevations. It can be generated from reservoirs and rivers. Reservoir hydropower plants rely on stored water in a reservoir, while run of river hydropower plants harness energy from the available flow of the river.

Hydropower reservoirs often have multiple uses providing drinking water, water for irrigation, flood and drought control, navigation services, as well as energy supply. Hydropower currently is the largest source of renewable energy in the electricity sector. It relies on generally stable rainfall patterns, and can be negatively impacted by climate-induced droughts or changes to ecosystems which impact rainfall patterns.

The infrastructure needed to create hydropower can also impact on ecosystems in adverse ways. For this reason, many consider small-scale hydro a more environmentally friendly option, and especially suitable for communities in remote locations. (UN,2014)

2.1.1.3 Thermal oil energy

A thermal oil is commonly used as a working fluid that circulate through the absorber tube and transform the energy irradiation into thermal energy and carries heat to heat exchangers or analogous for driving a Rankine steam turbine. Thermal oils include mineral and synthetic oils. Mineral oils are refined petroleum-based hydrocarbons produced through distillation. These oils comprise paraffins, napthenes, and aromatic oils (Rowe, 2009, pp. 113–144).

Oil power, or oil-based power generation, refers to the process of producing electricity by burning oil (usually petroleum or diesel) in power plants or engines. While its role in global energy production has declined in recent decades due to environmental concerns and the shift to cleaner energy sources, oil still plays an important role in certain regions and specific sectors.

Historically, oil has been a significant source of energy for electricity generation. However, its share has declined substantially since the mid-20th century. According to the International Energy Agency (IEA), the global share of oil in electricity generation is relatively small today, with natural gas, coal, and renewable energy sources taking precedence. As of recent years, oil accounts for only about **2-3%** of global electricity generation, down from a larger share in the 1970s and 1980s. In some regions, oil is still a primary fuel source for power generation, especially in countries with abundant oil reserves and limited access to other energy sources. Countries like Saudi Arabia, Kuwait, and the UAE, which are rich in oil reserves, historically relied on oil-fired power plants. However, many are increasingly turning to natural gas and renewable energy. Small island nations or areas with limited infrastructure sometimes rely on diesel generators for electricity, especially for emergency power or in places with limited access to natural gas or coal. In some developing nations, oil is still used as a backup fuel, especially in regions where grid infrastructure is not fully developed. **Oil-Fired Power Plants** burn crude oil or refined petroleum products (such as diesel or heavy fuel oil) in boilers to produce steam, which drives turbines connected to electricity generators. **Diesel Generators** Smaller, standalone diesel generators are often used for off-grid power generation in remote areas, or as backup power during outages. Oil power plants can be turned on and off relatively quickly, making them useful for meeting peak demand or providing backup power. Diesel and other oils are relatively easy to transport and store, making them convenient for use in isolated areas or during emergencies. Many existing oil power plants and related infrastructure still exist, allowing for continued use of oil in areas that have not yet transitioned to other energy sources. Oil combustion produces significant amounts of carbon dioxide (CO_2), sulfur dioxide (SO_2), and nitrogen oxides (NO_x), contributing to air pollution and climate change. These environmental impacts have led many countries to phase out or reduce oil power generation in favor of cleaner energy sources. The pollution from oil-based power plants can contribute to smog and respiratory problems, especially in areas where oil is used extensively for power generation.

However, in many parts of the world, oil has been replaced by cheaper, more efficient, and cleaner sources of energy. Natural gas, in particular, has become a dominant fuel for electricity generation due to its lower emissions and higher efficiency. Whereas Solar, wind, hydro, and other renewable sources of energy have also displaced oil power in many countries, driven by environmental concerns and government policies aimed at reducing carbon emissions Global efforts to transition to a low-carbon economy have led to significant investments in renewable energy, further reducing the role of oil in power generation. While oil's role in large-scale power generation is expected to continue declining, it will still be used in remote or off-grid areas, especially in countries with limited access to alternative energy sources, Oil will likely continue to play a role in transitional energy systems, where countries or regions are moving from coal or other fossil fuels to cleaner sources like natural gas or renewable **(REN21)**

Rwanda imports most of its petroleum products, which are used primarily for transportation, industry, and some power generation. The country has limited domestic oil reserves, so it depends heavily on imports from neighboring countries such as Uganda and Tanzania. Oil consumption in Rwanda is mostly focused on transportation as a large portion of oil is used for fuel in vehicles, motorcycles, and public transportation. While Rwanda has been working to reduce its reliance on diesel and fuel-based power generation, there are still some isolated areas that depend on oil-powered electricity generation. However, this is not the norm for the national grid, which is primarily powered by renewable sources. Oil products are also crucial in Rwanda's industrial sector for activities like manufacturing and agriculture.

In industries like shipping, aviation, and transportation, oil remains a dominant fuel source. However, increasing pressure for decarbonization may lead to innovations in cleaner fuels. oil's contribution to power generation is relatively small in today's global energy mix, but it continues to play an important role in specific regions and applications, particularly for backup power and in areas with limited energy infrastructure. The shift towards cleaner and more efficient energy sources, including natural gas and renewables, is expected to further reduce oil's role in electricity generation (World bank).

2.1.1.4 Economic growth

Economic growth is an increase in the production of economic goods and services in one period of time compared with a previous period. It can be measured in nominal or real terms. Traditionally, aggregate economic growth is measured in terms of gross national product (GNP) or gross domestic product (GDP), although alternative metrics are sometimes used. Economic growth is an increase in the production of goods and services in an economy. Economic growth is commonly measured in terms of the increase in aggregate market value of additional goods and services produced, using estimates such as GDP. (Investopedia)

2.1.1.5 Taxes

Taxes are defined broadly as mandatory financial charges or levies imposed by a government on individuals or entities to fund public services and government operations. The book explains that taxes are essential for the functioning of a society, as they help finance infrastructure, education, defense, healthcare, and other government programs. (Eric Tyson and Margaret A. Munro, 2024)

2.1.1.6 Agricultural Output

According to George W. Norton, Jeffrey Alwang, and William agriculture is broadly defined as the science, art, and business of cultivating the soil, producing crops, and raising livestock for food, fiber, and other products essential to human life and economic activity. it encompasses the entire system of food production, distribution, and consumption. (George W. Norton, Jeffrey Alwang, William A. Masters, 2014)

2.1.1.7 Service Output

According to Victor R. Fuchs, services are broadly economic activities that do not result in the ownership of physical goods but provide value through intangible benefits, such as knowledge, expertise, or experiences. (Fuchs, 1965) direct interactions between producers and consumers and focus on meeting needs like healthcare, education, entertainment, and professional expertise.

2.1.1.8 Industrial Output

Industry output is defined within economic performance and industrial organization as the total quantity of goods or services produced by firms within a specific industry over a given period. (Don E. Waldman and Elizabeth J. Jensen, 2013).

2.2. Renewable Energy and National Energy Security

A short case study on Countries such as Norway has successfully completed their energy transition journey, displacing all fossil fuels in the power sector. We consider similar countries as well as countries that have achieved some level of renewable energy grid integration to identify five key actions that made them successful. Grid Integration Study: Grid Integration studies are often commissioned to assess challenges and solutions to successful implementation. These studies, staged towards increasing clean energy goals, provide opportunities for planners, operators, and regulators to gain experience, formulate creative solutions, and ensure the economic and reliable operation of a transformed electric system. Countries like Mexico, the USA, and Vietnam used this approach to deal with changes and uncertainties in energy demand and supply. By preparing for anticipated and unexpected changes in output and keeping reserves for frequency regulation, the system adapts to these variations.

Capacity Building Activities: Capacity building involves improving the skills and knowledge of those personnel involved in energy system planning. Organizations such as the International Renewable Energy Agency (IRENA) and the Pacific Centre for Renewable Energy and Energy Efficiency (PCREEE) have emphasized the importance of capacity building in promoting investments and creating sustainable energy policies in the renewable energy sector. A noteworthy project that achieved this was the collaboration between Peru, Mexico, and IRENA which led to the development of tools for grid planning and distributed energy in both countries, enhancing their ability to forecast renewable energies and plan for a sustainable energy future.

Multilateral Collaboration: To integrate renewable energy into global power networks, Ghana, Mexico, and Peru have partnered with groups such as the International Partnership for Energy Efficiency Cooperation, Renewable Energy and Energy Efficiency Partnership, and Sustainable Energy for All. These partnerships encourage innovation, knowledge sharing, and common goals in the areas of sustainable development and climate change, improving countries ability to handle the challenges of global grid integration. Promotion of Innovation and Learning: Countries like India, Vietnam, and the USA have discovered new solutions to enhance renewable energy integration by fostering a culture of innovation and learning.

This has allowed them to overcome institutional, financial, and technical obstacles. Some specific steps that can support this objective include promoting research and development, exchange of knowledge, and cooperation between various energy sector players.

2.3. Impact on Electricity Supply and Reliability

With the help of strategic policy and regulatory initiatives, Ghana and India have made great progress toward fostering fair competition and enabling the integration of renewable energy. According to a report by the International Energy Agency (IEA), India has established a strong legal and regulatory framework to address various aspects of renewable energy integration, including pricing, tariffs, subsidies, standards, regulations, contracts, and governance. Ghana, on the other hand, has created a strong legal system to support renewable energy projects by working with local financial institutions, regulatory organizations, and legal professionals.

To conclude, Renewable energy integration is essential for a sustainable future. However, certain challenges may hinder success. Innovative techniques have been applied by countries such as Mexico, the USA, Vietnam, India, Ghana, and Peru, to address obstacles such as limited infrastructure, intermittent energy generation, regulatory difficulties, and energy storage constraints. The solutions are research and innovation-driven, focused on developing capacity and collaboration with other countries. Through these practices, the energy transition becomes more feasible. Lithuania's electricity sector has one of the EU's highest dependency rates, with about seventy percent of consumed electricity being generated abroad. This high rate was accentuated by the fact that until 2015 the dependency was on a sole country, namely the Russian Federation. With virtually no primary energy resources of its own, Lithuania progressed from a pro-nuclear to a renewable national energy strategy in just one decade. A variety of technologies and natural resources, such as petroleum-based fuels [15], hydro, solar, methane gas, peat, geothermal, biomass, waste, and wind [16]; contribute to the generation of electricity. Likewise, in Rwanda the energy sector scope goes beyond electricity and includes bio-products, such as wood fuel, charcoal, and biogas, as well as petroleum products, such as diesel, kerosene, Liquid Petroleum Gas and natural gas such as methane gas. As shown, of total primary energy consumption in Rwanda, Biomass contributes 85% of primary energy consumed of which wood contributes a percentage of 57%, Charcoal 23%, Crop residues and peat of 5% [17]. Non-Biomass sources contribution is 14% of which Petroleum products equal to 11% and electricity contribution is approximately 4%. The count of electricity is still small but in the country there are many Private Companies participating in the projects of raising the electricity generation capacity. The most important projects are KivuWatt developing 100 MW from methane gas by ContourGlobal (US), Turkish company "Hakan" developing 120 MW from peat, Symbion Power from USA to develop 50 MW from methane gas, Goldsol II developing 10 MW from Solar (Portugal, South Africa and Rwanda), Ngali Energy developing Micro hydropower project for 45 MW (Rwanda), Gigawatt Global operating 8.5 MW from solar (Israel). These projects are expected to considerably reduce the usage of expensive sources (fuel) and change the generation technology mix as indicated in the graph below:

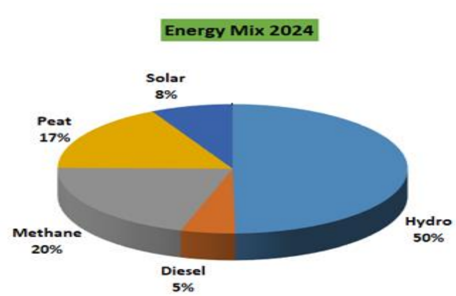


Figure1: Energy mix pie chart

2.4. status of renewable energy in Rwanda

Plant name	Q1 2023	Q2 2023	Q3 2023	Q4 2023	Q1 2024
Nyabarongo HPP	32,099,100	36,537,200	17,035,400	27,262,300	43,287,600
Ntaruka HPP	8,488,674	8,186,000	6,233,000	4,858,000	6,481,000
Mukungwa HPP	16,924,380	17,302,150	18,265,527	17,004,242	14,328,249
Jabana 1 TPP	1,989,310	479,300	-	-	-
Jabana 2 TPP	22,038,400	8,408,982	3,957,920	1,881,280	2,462,240
Nasho solar	1,133,127	1,229,807	1,301,855	1,031,865	1,021,237
Nyabahanga MHPP	197,124	246,462	200,320	176,997	222,396
Jali Solar	28,281	26,171	29,999	25,077	24,587
Gisenyi MHPP	2,484,803	2,062,717	1,785,411	2,040,343	2,218,780
Gihira MHPP	2,236,321	2,283,408	1,602,329	1,966,370	2,532,457
Rukarara 1 HPP	14,083,908	15,549,032	11,321,436	14,948,920	15,827,515
Rukarara 2 MHPP	3,941,919	4,301,104	3,232,681	3,934,988	3,474,722
Murunda MHPP	164,537	52,984	-	-	-
Rugezi MHPP	2,475,858	3,735,744	1,630,647	2,464,319	3,528,104
Keya MHPP	0.0	1,873,686	2,419,869	2,908,168	3,328,667
Cyimbili MHPP	457,820	437,200	345,850	391,010	425,960
Mazimeru MHPP	715,638	889,192	783,553	889,858	876,775
Nkora MHPP	891,120	887,420	641,980	762,410	904,000
Musarara MHPP	827,617	830,286	518,038	911,108	877,731
Mukungwa 2 HPP	5,697,125	6,175,521	5,503,292	5,614,542	4,756,103
Giciye I HPP	2,973,734	3,722,410	2,449,990	4,019,743	4,993,984
GigaWatt Global	3,169,110	3,164,800	3,568,790	3,130,010	3,070,540
Janja MHPP	220,622	291,598	314,456	306,935	300,439
Kivuwatt	50,055,287	55,025,413	56,544,338	48,455,536	55,908,155
Giciye II HPP	3,260,368	4,159,300	2,584,571	4,538,264	5,259,977
Mutobo MHPP	409,439	410,742	406,937	415,020	379,684
Gaseke MHPP	230,086	223,081	-	-	-
So Energy Mukungwa 1	8,961,060	5,911,100	384,560	-	-
So Energy Masoro	11,137,340	8,247,830	315,650	-	-
So Energy Birembo	7,369,160	5,126,200	298,380	-	-
Gashashi	237,658	357,962	210,465	270,097	338,121
Rwaza-Muko MHPP	5,054,111	4,953,769	4,823,455	4,251,384	4,462,241
Rukarara V-Mushishito	8,206,448	9,089,132	6,562,542	8,677,529	8,830,940
Rubagabaga MHPP	437,516	255,036	12,623	229,219	233,368
Agatobwe MHPP	497,248	473,399	257,783	427,570	465,967
Nyirantaruko MHPP	1,290,242	1,921,096	1,168,980	1,706,133	1,574,273
Kigasa MHPP	293,503	329,948	263,974	307,238	294,769
Giciye III	6,948,966	8,637,052	6,336,386	12,407,105	12,912,138
Nyirabuhombohombo	751,559	1,045,370	862,281	1,051,092	254,873
Hakan QP	28,666,305	14,096,726	38,595,150	36,547,200	8,065,500
Gishoma PPP	18,728,820	21,324,270	12,771,990	-	-
Kavumu Mwange	68,560	443,147	272,058	469,423	489,151
Shema Power	248,490	16,851,110	23,485,420	48,590,080	60,486,800
Ntaruka A HPP	25,411	181,071	4,053,838	4,605,739	4,240,713
Total domestic generation	**276,116,106**	**277,735,928**	**243,353,725**	**269,477,114**	**279,139,758**
Regional shared HPP	18,452,000	21,268,000	20,820,844	37,683,425	40,850,839
Imports	7,353,011	15,387,690	61,000,830	26,049,663	22,082,219
Total	**301,921,117**	**314,391,618**	**325,175,399**	**333,210,202**	**342,072,816**

Source: EUCL-REG

In the first quarter of 2024, a total of 342.073 GWh of electricity was generated in Rwanda. Domestic power plants contributed 81.6% of the total electricity generation, the Regional Shared plants contributed 11.9% of the total electricity generation, while 6.5% of the total electricity generation was imported. Compared to the similar quarter in 2023, the total electricity generated in the first quarter of 2024 had increased by 13.3%, reflecting the growth of the energy sector in Rwanda.

2.5. Impact on Energy Prices

Category	Consumption block	Frw/kWh (VAT & Regulatory fee exclusive)
Residential	[0-15] per month (kWh)	89
	]15-50] per month (kWh)	212
	>50 per month (kWh)	249
Non-residential	[0-100] per month (kWh)	227
	>100 per month (kWh)	255
Water Treatment Plants & Water Pumping Stations	All consumed kWh	126
Telecom towers	All consumed kWh	201
Hotels	All consumed kWh	157
Health Facilities	All consumed kWh	186
Broadcasters	All consumed kWh	192
Commercial data centers	All consumed kWh	179

Source: Board Decision N°01/BD/ER-EWS/RURA/2020

1.2. Tariffs for Industrial Customer Categories

Industrial customers are defined as those registered as industries with the Rwanda Development Board (RDB). Those customers are classified according to their consumption level, which is outlined as follows:

Table 5: Categorization of industrial customers

Industry category	Annual consumption (kWh/year)
Small	≤ 22,000
Medium	]22,000- 660,000]
Large	>660,000

Source: Board Decision N°01/BD/ER-EWS/RURA/2020

the electricity tariffs applied to different categories of customers in Rwanda, as determined by the Rwanda Utilities Regulatory Authority (RURA) in Board Decision N°01/BD/ER-EWS/RURA/2020, effective from January 21, 2020.

Tariffs for Non-Industrial Customers.

Non-industrial customers include residential, commercial, and specific sectors like health facilities, telecom towers, and water treatment plants. Their charges are based on consumption levels (measured in kilowatt-hours or kWh). The pricing structure is as follows:

Residential customers:

If usage is 0–15 kWh/month, the rate is 89 Frw/kWh (cheaper for low-consumption users). If usage is 15–50 kWh/month, the rate increases to 212 Frw/kWh. If usage exceeds 50 kWh/month, the rate is 249 Frw/kWh.

Non-residential customers:

If usage is 0–100 kWh/month, the rate is 227 Frw/kWh. If usage exceeds 100 kWh/month, the rate is 255 Frw/kWh.

Specific sector tariffs (flat rate per kWh):

Water treatment plants & pumping stations – 126 Frw/kWh, Telecom towers – 201 Frw/kWh, Hotels – 201 Frw/kWh, Health facilities – 157 Frw/kWh, Broadcasters – 186 Frw/kWh, Commercial data centers – 192 Frw/kWh.

2. Tariffs for Industrial Customers

Industrial customers are classified based on annual electricity consumption: Small: ≤ 22,000 kWh/year, Medium: Between 22,000 and 660,000 kWh/year, Large: > 660,000 kWh/year

Industrial customers are charged differently based on whether they have smart meters installed.

Industrial Customers with Smart Meters: Smart meters allow time-based billing, meaning electricity costs vary depending on the time of use: Off-peak hours (11:00 PM – 07:59 AM): Cheapest rates, Shoulder hours (08:00 AM – 05:59 PM): Medium rates, Peak hours (06:00 PM – 10:59 PM): Most expensive rates

Example charges: Small industries pay 134 Frw/kWh (off-peak), 1,691 Frw/kWh (shoulder), and 4,008 Frw/kWh (peak). Medium industries pay 103 Frw/kWh (off-peak), 1,292 Frw/kWh (shoulder), and 3,588 Frw/kWh (peak). Large industries pay 94 Frw/kWh (off-peak), 886 Frw/kWh (shoulder), and 2,004 Frw/kWh (peak).

Additional charges for industries: Maximum demand charge (Frw/kVA/month) – Fixed monthly charge based on the highest power demand.

Customer service charge – 10,000 Frw/month for all industrial customers.

Flat Rates for Industrial Customers without Smart Meters:

Industries that do not have smart meters are billed at a fixed rate per kWh:

Small industries – 151 Frw/kWh.

Medium industries – 123 Frw/kWh.

Large industries – 106 Frw/kWh.

Rwanda's electricity tariffs are structured to accommodate various customer categories, including residential, non-residential, and industrial users. This tiered pricing approach is designed to promote equitable access to electricity and encourage efficient energy consumption.

Current Electricity Prices in Rwanda: Residential Customers: As of June 2024, the average electricity price for residential users is RWF 256.550 per kWh (approximately USD 0.183).

GLOBAL PETROL PRICES: Business Customers: The electricity price for businesses stands at RWF 96.000 per kWh (approximately USD 0.069).

Comparison with Global Averages: Rwanda's residential electricity prices are 130.51% of the world average and 166.77% of the average price in Africa. Business electricity rates in Rwanda are 49.61% of the world average and 67.78% of the average in Africa.

Trends in Electricity Pricing: The average electricity price in Rwanda has experienced fluctuations over the years. Notably, it decreased from USD 196.69 per MWh in 2022 to USD 176.67 per MWh in 2023.

Energy Production Costs: The mix of energy sources, including hydropower and natural gas, impacts production expenses. Infrastructure Investments: Ongoing developments in energy infrastructure can affect overall costs., by the help of Government Policies including Subsidies and regulatory decisions play a role in setting end-user prices. Rwanda's electricity tariffs are structured to reflect consumption patterns across different customer categories, aiming to balance affordability with the financial sustainability of the energy sector. While residential rates are higher than regional averages, business rates remain competitive, supporting industrial and commercial activities.

2.6. Energy Access and Poverty Reduction

Electricity access in Rwanda quadrupled in the last 7 years as more households get connected

Imagine living in a world with little or no light when the sun set. That was the plight of an estimated 1380 residents in Ngeruka sector in Bugesera District until they got connected to the national grid early this December

According to one of the residents in Ngeruka sector Mukarugamba Innociata 40 years, they were not always left completely in the dark. Kerosene lamps and the fire wood sticks used to provide some sort of light while cooking.

But these options take a toll on time and health. That’s why the residents are so thankful to the government for having made it possible for them to have electricity in their village.

“I am really happy now that even when darkness falls I will still be able to get along with enough light. Previously with my aging eyes, I used to dread darkness because it meant that the day was over and we would retire for the night unlike today, thanks to the electricity that they brought for us” says Mukarugamba.

Like her neighbors, Mukarugamba feels that there is going to be a lot of developments in their village and more services are springing up because of the electricity access.

“We can now charge our phones and also have services that require electricity brought to our village unlike then when we had to walk miles to get them. I am planning to save and get a small television now that we have power” she concludes. Starting from an extremely low base, the Government has expanded electricity access.

According to statistic from Rwanda Energy Group (REG), the number of households accessing electricity has increased from 10% in 2010 to 41% in October 2017. Among the 41% accessing to electricity, 30% of the households are connected to the national grid while 11% are accessing through off-grid solution, mainly solar energy.

As the Government of Rwanda targets a 100% access to electricity in only 7 years, 82% of households in the City of Kigali (CoK) are currently accessing at a rate , followed by Eastern province with 39% access, the Western Province with 38%, Northern province 34% and the Southern province that has the lowest access of 30%.

Government's Plan

According to Clémentine Umugwaneza, the Coordinator of the Electricity Access Rollout Program, EARP, the program implementing the Government's rural electrification targets, there are various ongoing and upcoming projects funded by the Government and development partners.

Statistics show that by October 2017, 39% of households in the Eastern Province already had access to electricity, including 26% connected to the national grid and 13% using off-grid solutions

According to Umugwaneza, rural electrification targets include not only on-grid access but also off-grid solutions as these are fast to install and cheaper.

"We realized that we can speed up access to electricity in rural areas through having more off grid connections. The terrain of Rwanda also slows the on grid connections which require time to connect electricity to people in scattered areas across the country" she explained.

There are other electrification projects in the Western and Northern Provinces funded by the African Development Bank which will provide electricity to more than 30,000 households in Gicumbi, Rulindo, Nyabihu, Ngororero, Rusizi, Karongi and Nyamasheke Districts.

There is another project currently ongoing in the Eastern Province which will soon provide access to 8,104 households.

There is also another ongoing project bankrolled by the Saudi Fund for Development being implemented in Gisagara and Nyanza Districts. This project will provide electricity to approximately 15,500.

Umugwaneza explained also that EARP has signed contracts with Districts to provide access to electricity to more than 40,000 households in a bid increase the number of households connected

Expanding electricity access in Rwanda plays a crucial role in poverty reduction by improving livelihoods, increasing productivity, and fostering economic development. Economic Empowerment and Job Creation enables small businesses to operate efficiently and for longer hours. For example, residents like Mukarugamba can now start small businesses such as phone charging, barbershops, or retail stores, Rural electrification encourage entrepreneurship, allowing people to engage in income-generating activities such as welding, tailoring, and milling.

Hybrid Mini-Grids in Refugee Camps, A case study of the Nyabiheke refugee camp in Rwanda explored the potential of solar-diesel hybrid mini-grids. The study found that such systems could lead to substantial cost savings (up to 32%) and emissions reductions (up to 83%), highlighting the benefits of renewable energy solutions in improving living conditions and reducing poverty in vulnerable communities

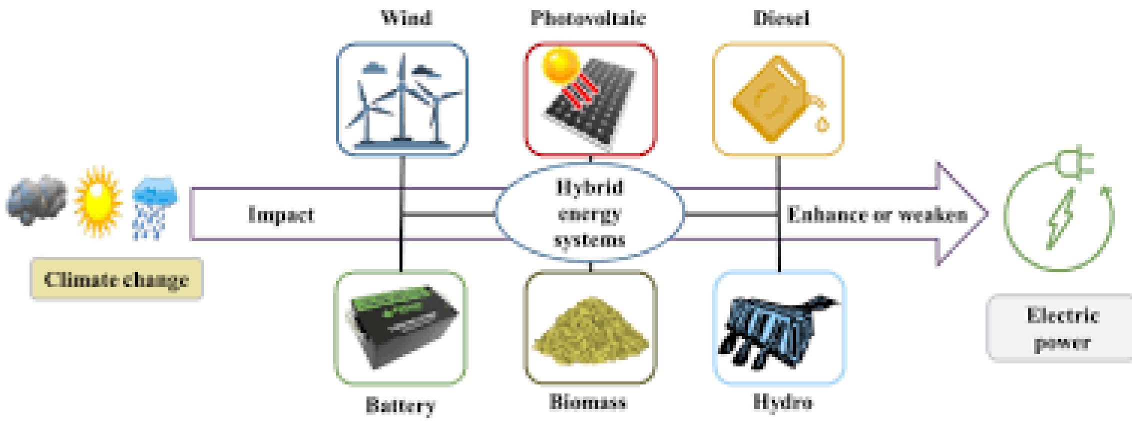
2.7. Environmental and Social Impacts

Fossil fuel consumption is increasing dramatically due to excessive anthropogenic activities and industrial expansion to meet energy demands. The increase in fossil fuel consumption has risen by 96% since 1965 (Caglar et al. 2022), leading to adverse environmental impacts. Fossil fuels negatively impact air quality, the environment, health, and water resources. The gaseous emissions that can be released into the air due to fossil fuel consumption include greenhouse gases such as carbon oxides (carbon monoxide and carbon dioxide), sulfur oxides (sulfur dioxide and sulfur trioxide), nitrogen oxides (nitrous oxide and nitrogen dioxide), and volatile organic compounds and aerosols such as particulate matter. It was reported that about 72.5% of the global carbon dioxide equivalent emissions could be released from coal consumption (Sayed et al. 2021), causing the global warming phenomenon. The estimated gaseous emissions for various fossil fuels per megawatt-hour (MWh) of power generated (Turconi et al. 2013). One of every five deaths worldwide is induced by pollution from fossil fuel consumption (Azarpour et al. 2022).

As a result of pollution, 350,000 people passed away in the USA in 2018. The annual cost of the health effects caused by fossil fuel consumption in the USA was reported to be 886.5 billion dollars (Azarpour et al. 2022). To mitigate the adverse impacts associated with fossil fuel consumption and achieve sustainability, the United Nations organization has established 17 goals for sustainable development (SDGs). Nevertheless, the growing environmental pollution from fossil fuel consumption infuences sustainable development goals, especially goal no. 13 of climate action.

Climate conditions significantly affect renewable energy generation, with factors like daylight hours, weather, and wind speed influencing energy output. Solar energy is impacted by nightfall and cloudy weather, while wind and hydroelectric power can be affected by seasonal changes such as droughts or heavy rainfall. Hybrid energy systems, which combine sources like solar and wind power, are more adaptable to these fluctuations, ensuring stable, reliable energy production. They offer greater flexibility than single-source systems, helping to mitigate the impacts of climate change on energy supply while improving efficiency and reliability across varying conditions.

Figure2: climate change



2.8. Cost Savings of renewable energy

The transition to renewable energy is driven by several factors, including environmental concerns (e.g., climate change), the finite nature of fossil fuels, and advances in technology. Over time, renewable energy has become more cost-effective due to the decreasing costs of technology and the free nature of fuel sources like sunlight, wind, and water. This transition can help stabilize energy prices and reduce reliance on volatile fossil fuel markets.

Historically, energy transitions have accompanied economic growth. In the 19th and 20th centuries, as firewood and other biomass sources proved insufficient, societies turned to hydropower, coal, oil, and natural gas. In the mid-20th century, nuclear power was introduced. Today, fossil fuels dominate energy production, but the 21st century is beginning to see a shift toward renewable sources of energy. This transition is driven not just by fossil fuel depletion, but by the urgent need to mitigate climate change.

Key examples of efficiency improvements in response to past energy crises include a doubling of car fleet fuel economy between 1973 and 1980 and the significant improvement in refrigerator efficiency by the late 1990s. During the 1973 oil crisis, the U.S. also reduced oil's share of power generation from 17% to about 2.5%, with coal and nuclear power taking a larger share.

The energy transition away from fossil fuels is considered inevitable, as fossil fuels are finite and renewables are increasingly viable. The challenge now is to accelerate this transition to avoid the worst effects of climate change, even as fossil fuel extraction technologies may extend the life of reserves. The move toward renewable energy is not just an environmental necessity but a significant economic issue as well. (IEA 2013)

2.9. Economic Impacts of Renewable Energy Job Creation

Developing renewable energy infrastructure creates significant economic benefits, including job growth in construction, maintenance, and operation. Renewable energy has become a key driver of economic recovery, especially after the 2020 health and economic crisis, proving to be flexible, cost-effective, and resilient. In 2023, the renewable energy sector employed an estimated 11.5 million people globally, with expectations to create an additional 5.5 million jobs over the next three years. By 2030, renewable energy jobs are projected to reach nearly 30 million. Key sectors like solar photovoltaics (3.8 million jobs), bioenergy (3.6 million jobs), and wind power (1.2 million jobs) are major contributors to this growth. Many of these jobs support rural and remote communities, with solar and bioenergy contributing to off-grid applications in agriculture, healthcare, and other sectors. Wind power also has a notable gender diversity, with over 20% of workers being women. The shift to renewable energy not only fosters economic recovery but also supports sustainable development and long-term resilience. (IRENA, 2020)

Research has shown a positive correlation between the use of renewable energy and economic growth, particularly in terms of expanding Gross Domestic Product (GDP). Studies, such as those by Apergis and Payne, and Martinez-Duart and Garcia-Muros, highlight that increasing renewable energy utilization can contribute to economic advancement. These findings suggest that renewable energy not only helps address environmental challenges but also stimulates economic development by reducing reliance on non-renewable energy sources. The results emphasize the importance of promoting renewable energy adoption and investing in its infrastructure to achieve long-term, sustainable economic growth. (demons Sustainability 2023).

2.10. Renewable Energy Investment and Financial Flows

The positive economic and employment impacts of investments in renewable energy technologies. Nanda (2015) highlights that such investments stimulate capital flows, economic growth, and job creation, both directly and indirectly, in related sectors. Omri, Chtourou, and Bazin (2015) argue that the global economic crisis of 2007-2008 presented an opportunity to accelerate the spread of renewable energy, contributing to a "green" recovery. International organizations such as the OECD, UNEP, and the World Bank emphasize the importance of "green" growth strategies, which integrate environmental protection with economic recovery, often through incentives like investment subsidies and low-interest loans.

2.11. Grid Infrastructure and Technological Development

Technological innovation is central to achieving "green" growth, and investments in renewable energy technologies, such as photovoltaic power, can drive both environmental benefits (e.g., reducing greenhouse gas emissions) and economic growth. These innovations foster the creation of new jobs, with renewable energy industries providing significant employment opportunities. The World Bank (2012) identifies four key effects of "green" policies: input, efficiency, stimulus, and innovation effects. Notably, the innovation effect, driven by advancements in renewable technologies, plays a crucial role in economic development.

The renewable energy sector has seen substantial job creation. In 2015, approximately 8.1 million people were employed in the global renewable energy sector, with solar photovoltaic and wind power leading the way in job growth. Moreover, the European Union's 1999 study estimated that renewable energy could create over 900,000 new jobs by 2020. These trends support the idea that renewable energy technologies play a critical role in economic development, employment creation, and the broader transition to a sustainable "green" economy. (Ecotec, 2002).

2.12. Empirical study

The relationship between renewable energy (RE) and economic growth (EG) has been extensively studied, with a significant focus on EU countries and other regional contexts. Some notable studies include:

Tutak and Brodny (2022): This study analyzes the impact of renewable energy on economics, environmental factors, and conventional energy sources.

provides valuable insights into the role of renewable energy in shaping economic, environmental, and conventional energy frameworks. Investments in renewable energy enhance energy self-sufficiency by reducing reliance on imported fossil fuels, which is a key goal for TSI countries. This economic shift can stabilize energy costs and reduce vulnerability to external energy market fluctuations.

While the initial costs for renewable energy infrastructure are high, the long-term benefits include reduced operational costs compared to conventional energy sources. The growth of renewable energy reduces the share of conventional energy sources like coal and natural gas, which are more prevalent in TSI countries like Poland and Bulgaria, as noted in the study. The integration of renewables creates a more balanced and resilient energy mix, reducing risks associated with over-reliance on any single source

The study underscores the importance of tailored strategies to enhance energy security. In essence, the findings suggest that renewable energy serves as a critical pathway to achieve economic growth, environmental sustainability, and greater energy security, thereby addressing the regional disparities identified in the study.

Smolović et al. (2020): Using the pooled mean group (PMG) estimator in a dynamic panel setting (ARDL model), this research explores the nexus between renewable energy consumption and economic growth in both traditional and new EU member states.

The study finds a positive long-term relationship between renewable energy consumption and GDP growth in both traditional and new EU member states. This suggests that increasing renewable energy usage significantly contributes to economic growth over time by enhancing energy independence and promoting sustainable development.

In the short run, the impact of renewable energy consumption on GDP is less pronounced. This reflects the time lag associated with renewable energy investments and their ability to yield measurable economic benefits, such as infrastructure development and market adaptation. These countries show positive long-term potential, their short-term impact is more volatile due to transitional challenges, including outdated energy systems and limited financial resources for large-scale renewable energy project.

Renewable energy development stimulates economic activity across multiple sectors, including manufacturing, construction, and technology. This diversification enhances GDP growth, especially in countries with policies supporting green technology adoption.

Mechanisms Linking Renewable Energy to GDP

Cost Efficiency: Renewable energy reduces energy import dependency, freeing resources for domestic economic development.

Green Innovation: Investments in renewable technologies foster innovation, which contributes to productivity and economic expansion.

Job Creation: The renewable energy sector generates employment, particularly in installation, maintenance.

The study highlights the importance of tailored policies to maximize the economic benefits of renewable energy: By linking renewable energy to GDP growth, Smolović et al. (2020) underscore the strategic role of renewables in achieving sustainable economic development while transitioning to low-carbon economies.

Koengkan, Fuinhas, and Marques (2019): Their research, employing the panel vector autoregression (PVAR) model, examines the relationship between financial openness, renewable and non-renewable energy consumption, CO2 emissions, and economic growth in 12 Latin American countries. The study highlights how integrating renewable energy into the energy mix contributes to economic growth by diversifying energy sources and reducing dependency on renewable energy projects create jobs, stimulate industrial development, and enhance the resilience of energy systems in Latin American economies, the study identifies a negative association between renewable energy consumption and CO_2 emissions, reinforcing its environmental benefits. As financial openness supports renewable energy adoption, Latin American countries can achieve economic growth while adhering to global climate targets, such as the Paris Agreement.

The research reveals that renewable and non-renewable energy consumption exhibit complex relationships with economic growth. While non-renewable energy initially drives industrial growth, its environmental costs (e.g., higher CO_2 emissions) make a strong case for transitioning to renewables.

Renewable energy integration can mitigate the negative externalities of non-renewable energy, fostering long-term sustainable growth.

Investments in renewable energy infrastructure are crucial for integrating renewables into the energy mix effectively. Policies should focus on gradually reducing dependence on non-renewable energy while increasing renewable energy capacity, ensuring energy security and economic stability during the transition. Koengkan, Fuinhas, and Marques (2019) provide empirical evidence of the significant role renewable energy integration plays in achieving sustainable economic growth and environmental sustainability in Latin America. By leveraging financial openness, these countries can accelerate renewable energy adoption, reduce CO_2 emissions, and build resilient, future-ready economies.

Lorente et al. (2022): This study finds an Inverted-U and further N-shaped relationship between economic complexity and CO2 emissions for Portugal, Italy, Ireland, Greece, and Spain.

Initial Phase: Economic Growth and Rising CO_2 Emissions:

At the early stages of increasing economic complexity, industrialization and resource-intensive activities drive up CO_2 emissions. This stage is consistent with the upward slope of the Inverted-U curve.

Economic complexity initially relies on energy-intensive industries, especially in economies transitioning from agriculture or simpler manufacturing bases.

As economic complexity advances further, there is a structural shift toward high-tech, knowledge-intensive, and service-oriented sectors.

These sectors are typically less energy- and emissions-intensive, leading to a reduction in CO_2 emissions.

This stage underscores the challenges of achieving decoupled economic growth (growth without proportional environmental impact) at very high levels of complexity.

A successful transition to renewable energy sources is essential to decouple emissions from economic complexity. This is especially important for countries experiencing the second upward phase of the N-shaped curve.

Policy Alignment: Policies must balance economic development goals with emissions reduction targets. Examples include promoting green innovation, incentivizing energy efficiency, and adopting circular economy principles. The study underscores the importance of targeted policies to manage the environmental impacts of increasing economic complexity included Investing in clean energy.

Lorente et al. (2022) provide evidence that economic complexity has a dual-edged impact on CO_2 emissions. While complexity can lead to emissions reductions through innovation and structural shifts, it also poses risks of emissions resurgence if not managed with strong environmental policies and clean energy transitions. Their findings serve as a call for integrating environmental sustainability into economic planning at all stages of complexity.

Despite these contributions, a systematic review analyzing the broader relationship between renewable energy and economic growth across developed, developing, and underdeveloped countries has been lacking. This research gap, particularly in the context of G7 and N-11 countries, is the focus of the current study.

Konuk et al. (2021): In their study of N-11 countries, they found a long-term co-movement between economic growth and biomass energy consumption.

Jenniches (2018): In his review of renewable energy transitions, he stresses the importance of defining technologies and assessment periods for accurately assessing regional economic impacts.

Doytch and Narayan (2021): This study found that renewable energy supports growth in high-growth sectors like services in high-income economies and manufacturing in middle-income economies.

Acheampong et al. (2021): Their research on 45 African countries concluded a bidirectional causal relationship between renewable energy consumption and economic growth, specifically in sub-Saharan Africa.

Ugur and Sari (2003): This older study examined the causal relationships between energy consumption and economic growth in top emerging economies and G7 countries. They found bidirectional causality in Argentina, and GDP to energy consumption causality in Korea and Italy, while countries like Argentina, Brazil, and others in Latin America showed low renewable energy participation.

Key Findings and Research Gaps:

Renewable Energy & Economic Growth Nexus: A key question remains whether transitioning to renewable energy hinders or supports economic growth. Despite numerous studies on individual countries or regions, no comprehensive review exists that captures the relationship across diverse economies, including developed and developing nations.

The current research aims to address the lack of a systematic review that considers the connection between renewable energy consumption and economic growth across various global contexts. This is an important area of study given the rising debates about the costs and benefits of transitioning to renewable energy sources, especially when considering the external and internal factors that affect energy policy and economic development. (Koengkan et al., 2020b).

2.13. Challenges and Measures within the Electricity Sector in Rwanda

In Rwanda, the main policy objectives for the electricity sector are to ensure sufficient, reliable, sustainable and more affordable power supply. However, there are a number of challenges that might be overcome first through different measures. The challenges and corresponding measures are the following: High cost of electricity: Rwanda has a relatively high cost of electricity compared to other countries in the region, and at the same time, extremely low average volumes of consumption. This problem can be solved by realizing a better coordination and an integrated planning over investments and an implementation of 70% energy access and electrification, along with giving more priority to big consumers of electricity. Generation capacity and demand are not aligned: This challenge is causing lack of maintained efficient tariff. If demand fails to keep pace with increased generation capacity, then the tariff will increase. To address this issue, the cost of generation and losses should be regulated and by diversifying resources and increasing the share of clean power generation in the total generation mix. Insufficient reserve margin: Current reserve margins are not adequate to maintain quality of supply standards. The strategies to tackle this issue would be to start by estimating the actual peak demand of power consumption and setting out a reserve margin of 15% according to international best practice. For example, if the total Demand is 473 MW, then Supply should be 563 MW. High system losses: A loss in energy between generation and consumption is an inherent feature of electricity networks. Current network distribution losses stand at 23%, which is above average for the region and is a serious issue that requires more attention. Whilst these losses cannot be eradicated completely, they can be materially reduced cost-effectively through better network planning and maintenance

2.14. Theoretical and Conceptual Framework

2.14.1 Theoretical framework

The integration of renewable energy into the power grid involves various economic analyses to understand its impacts, costs, and benefits. Several theories and approaches are commonly used to analyze these aspects

2.14.1.1 Cost-Benefit Analysis of Renewable Energy Integration

The theory states that despite growing concerns about energy supply, there remains skepticism about renewable energy sources (RES), particularly regarding installation costs and anticipated benefits. The Cost-Benefit Analysis (CBA) technique is commonly used to evaluate these investments. However, the conventional CBA approach is hindered by uncertainties in cost-benefit parameters, which can undermine its reliability. These uncertainties include monetary values (such as purchase costs, interest rates, maintenance costs, and future energy prices) and factors affecting these values (like product lifespan, malfunction frequency, expected savings on conventional energy, meteorological variability, and system performance test results). The proposed work introduces a modified CBA approach using Monte-Carlo simulation to better handle these uncertainties.

This method aligns with current practices for managing information under uncertain conditions using traditional metrological tools. The assessment of economic indices for investments in renewable energy faces challenges due to significant uncertainties in the parameters influencing these estimations. This problem can be addressed using metrology tools to handle uncertainty propagation.

The specific methodology proposed focuses on acquiring stochastic information for evaluating the economic performance of a solar domestic hot water system investment. This method utilizes the Monte-Carlo simulation technique, favored in metrology for its effectiveness when analytical sensitivity calculations are infeasible. By applying this methodology, one can assess the probability distribution of the Internal Rate of Return, providing realistic conclusions about the investment's effectiveness. (Energy challenges, 2013)

2.14.1.2 Levelized Cost of Electricity (LCOE)

LCOE represents the per-unit cost (typically per megawatt-hour) of building and operating a generating plant over an assumed financial life and duty cycle. LCOE is calculated by dividing the total life-cycle costs of a renewable energy project by the total energy output. It allows comparison of different energy sources on a consistent basis, considering both upfront and ongoing costs.

LCOE is a key metric representing the average revenue per unit of electricity needed to break even over the lifecycle of a power plant. It includes costs for building, operating, and maintaining the plant. Based on the discounted cash flow (DCF) method, LCOE takes into account the time value of money. Renewable energy technologies, being capital intensive and having low or zero fuel costs, are greatly influenced by the weighted average cost of capital (WACC). LCOE is widely used for comparing the economic competitiveness of different renewable energy projects. Metrics like Levelized Cost of Storage (LCOS) and Levelized Avoided Cost of Electricity (LACE) complement LCOE for a fuller economic evaluation.

Projects launched in 2016 aim to improve utility companies' reliance on solar resources. Advanced technologies like machine learning have improved solar power production forecasts by 30%. The 21st century has seen significant growth in renewable energy installations. Renewable energy sources comprised 84% of new electricity production capacity in 2017, up from 10% in the early 2000s. LCOE is advantageous for simplifying investment decisions by condensing complex data into a single, clear metric.

Significant cost reductions have been observed in solar PV (80% decrease over the past decade) and onshore wind (40% decrease). Wind and solar technologies are becoming increasingly attractive to investors. However, ecological impacts, such as recycling wind blades, remain challenges.

Case Study in Bosnia and Herzegovina LCOE calculations for real projects showed the lowest costs for wind, followed by solar, with higher costs for hydropower due to high initial investments. Hydropower cost reductions are expected mainly from civil engineering advancements. Despite its limitations, LCOE remains the most popular energy cost metric due to its simplicity and clarity. There are proposals for more comprehensive metrics like System LCOE, which considers wider system impacts, but these were not evaluated in the current study due to data limitations. (Faris Durakovic, 2021)

2.14.2 Conceptual Framework

A conceptual framework visually represents the relationships between the variables in this study. It defines and clarifies the research problem and objectives by outlining the primary concepts and their interrelationships. This helps ensure that the study remains focused and aligned with its goals. Here's a conceptual framework based on the research objectives and questions for integrating renewable energy into the national grid in Rwanda.

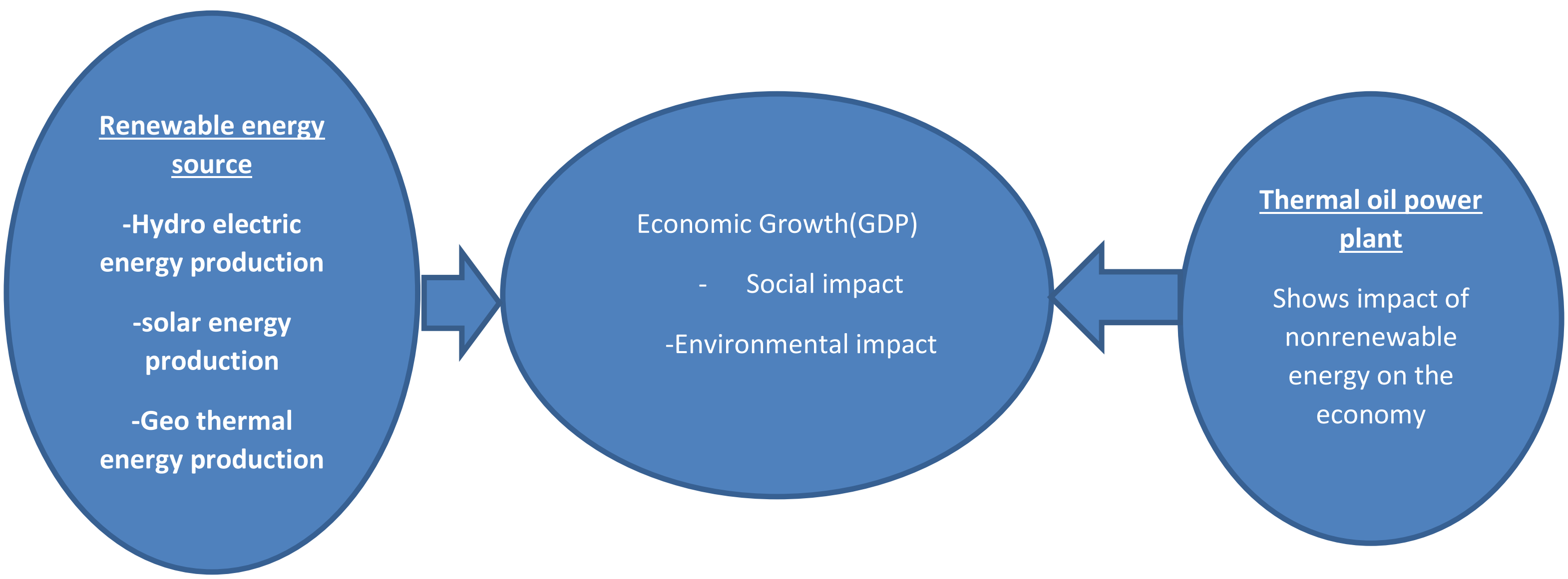


Figure3: Conceptual framework

Source: author generate

CHAPTER THREE

RESEARCH METHOLOGY

3.0 Introduction

In social science, research methodology is a process designed and used in the generation and analysis of gathered data. Essentially, the procedures by which researchers go about their work of describing, explaining, and predicting phenomena are called research methodology.

This chapter presents the research methodology adopted in conducting the empirical analysis on integrating renewable energy into the national grid of Rwanda. The study adopts a quantitative approach to analyse the relationship between integration of renewable energy and economic performance. Based on this, using GMM as the base econometric model, the key variables and instruments are identified that may capture the dynamics during the period of 2010-2023. The methodology ensures that the results are robust by rigorous data processing, cleaning, and analysis while responding to challenges such as data dispersion and gaps. This chapter focuses on the research designs, sources of data, the instruments utilized in the data collection process, the sampling procedure as well as how the data was analyzed.

3.1 Research Design

This study will adopt the mixed method approach in the data gathering process. Mixed methods research can be described as a model of inquiry that combines qualitative and quantitative models of research so that evidence may be mixed and findings derived in a more meaningful manner than either approach could achieve alone. Qualitative research involves an interpretive, naturalistic approach to the world. This means that qualitative researchers study things in their natural settings, attempting to interpret phenomena in terms of the actual meanings. This methodology usually investigates the “what, why, where and when” of the phenomena understudy to make a decision. (Dadzie, 2018)

Quantitative research is based on the measurement of quantity or amount. Quantitative research conversely is concerned with quantities and measurements aimed at making scientific generalizations and predictions in a research activity (Biggar, 2008).

This methodology allows the researcher to observe the relationship between a dependent and independent variable and identify cause and affect relationships (Creswell, J.W, 2013).

Mixed research methodology recognizes the value of knowledge as constructed through qualitative means such as perceptions, as well as experience based on the factual aspects of the world in which people live. Another key characteristic of the mixed-method research approach is that it rejects the dualism that sets qualitative or fact-based and quantitative or subjectively based methodologies as having value only in exclusivity from each other (Bamundekere, 2019). By comparing Quantitative, Qualitative methods versus mixed method research, Creswell & Plano Clark (2007)

It offers also a complete description and analysis of research subject, without limiting the scope of the research and the nature of the participant’s responses while the quantitative research focus on using numbers as its basis for making generalizations about a phenomenon. It is also concerned with analyzing statistical, mathematical and numerical data through polls, questionnaires and surveys (Langkos, Spyros, 2014).

The reasons for using the mixed method research approach was that it takes into account the context where qualitative and quantitative research methods are not sufficient to be used alone, because of the inherent weaknesses of each approach. For instance, quantitative research does not adequately investigate personal stories and meanings or deeply investigate the perspective of individuals. While qualitative research does not enable to generalize from a small group of people to a large population, it does not precisely measure what people in general feel (Creswell, J.W, 2013). Which lead us to conclude that all research methods have both strengths and weaknesses and the combination of the strengths of both provide a good rationale for using mixed method (Bamundekere, 2019)

This study follows a quantitative research design, laying emphasis on numerical and statistical data to analyse the relationships between variables. Quantitative research allows for objective evaluation of hypotheses using statistical techniques and models. By focusing on GMM, the study captures dynamic relationships while accounting for endogeneity issues inherent in econometric analysis. In this design, it ensures a structured approach that allows easy replication, hence reliability of the findings.

In this study, numerical figures and descriptive information will be obtained, giving it both a quantitative and qualitative research dimension. The study hence will use both qualitative and quantitative approaches in data collection and analysis. This mixed research methodology used involves qualitative and quantitative data collected and analyzed concurrently to answer a certain research question beginning with specific observations which are used to produce generalized theories and conclusions (Creswell, 2013).

3.2 Sample Size and Sampling Procedures

Secondary data will be collected for the period of 2010-2023 on a quarterly basis from Rwanda Energy Group and the National Institute of Statistics of Rwanda. The documentation technique, which consists of a careful review of institutional reports, various publications, and datasets to retrieve relevant information, is followed in collecting secondary data. Sources were chosen according to data availability and reliability. These institutions are recognized for their comprehensive and consistent data on energy and economic indicators, thus ensuring the validity of data in this study.

3.3 Type and Sources of Data

The secondary sources of data collection will be employed in this study. Secondary data are data sources that already exist and can be used by others other than the original collector and for a purpose other than it was originally intended. These can be assessed in books, journals, newspapers, and online sources (Salkind, Neil J., ed, 2010).

For this study, the secondary sources were gathered from books, journals, articles, and other online sources. The Library, Institute of Statistical, Social and Economic Research and Regional

Institute of Population Studies Library of the University of Rwanda as well as other electronic sources including Jstor, Sage, and Google Scholar were used.

3.4 Data Collection Instruments

To obtain an in-depth understanding of the topic, a qualitative phenomenological approach will be employed. Also, the quantitative data collected will be analyzed using the Monte-Carlo simulation model. Descriptive statistics such as frequencies and percentages will be presented in bar and pie charts and in tables.

The study processes data using extrapolation techniques to convert annual data into quarterly estimates for missing intervals. This approach ensures consistent time-series data for analysis. Data processing also includes regression modelling using EViews 10 software to examine relationships between renewable energy sources and GDP growth. EViews facilitates statistical operations such as stationarity tests, parameter estimation, and hypothesis testing, enabling precise analysis and interpretation.

3.5 Data Cleaning

Data cleaning was done using Microsoft Excel to organize, tabulate, and validate the datasets. This process ensured missing values, duplicates, and inconsistencies were removed and all variables fell in line for analysis. A systematic cleaning process guarantees integrity of data, minimizes errors, and increases the accuracy of results. Observations have been cross-checked with original sources to maintain fidelity to the data collected.

3.6 Methods of Data Analysis

This study has applied GMM to analyse the impact of integrating renewable energy into the national grid on economic performance. GMM is a robust econometric estimation technique for addressing endogeneity, heteroscedasticity, and problems of autocorrelation that always characterize dynamic panel data models. It works particularly well when the dependent variable depends on its lagged values and when some of the explanatory variables are potentially endogenous. This method ensures that the estimations of parameters are consistent and efficient since moment conditions derived from the model will be utilized.

3.7. Econometric Model

The multiple linear regression models. is specified below:

$$GDP_t = \alpha + \beta_1 Thermo + \beta_2 Hydro + \epsilon_t$$

Where:

GDP: Quarterly Gross Domestic Product.

Thermo: The contribution of thermal oil energy to the national grid.

Hydro: Contribution of hydropower into the national grid.

ϵ_t: Error term incorporating omitted factors.

3.7.1 Instruments in GMM

First and foremost why use GMM?

The **Generalized Method of Moments (GMM)** is used because it gives **consistent and efficient estimates** when ordinary least squares (OLS) or even fixed/random effects models may not work well — especially when:

- The model includes **lagged dependent variables** (past values of the dependent variable).
- There is **endogeneity** (some explanatory variables are correlated with the error term).
- There are **unobserved individual effects** that can bias the results.
- The data are **panel data** (cross-sectional and time series combined)

It controls for endogeneity

- In your study, variables like **energy consumption** or **GDP** can influence each other (a two-way relationship).
- OLS or Fixed Effects would give **biased results** in this case.
- GMM uses **instrumental variables** (internal instruments like lagged values) to fix this problem.

It handles dynamic effects

- Economic growth models often include the **lag of GDP** (e.g., GDPt−1GDP_{t-1}GDPt−1) to capture how past growth affects current growth.

- That makes the model **dynamic**, and traditional methods (OLS, FE) can't handle that properly — but GMM can.

It reduces bias in small samples

- When you have panel data (few years, few countries), **Difference GMM** or **System GMM** performs better than other estimators.

d) It allows testing for validity

- GMM provides statistical tests like:
  - **Sargan/Hansen test** → checks if the instruments are valid.
  - **Arellano-Bond test** → checks for serial correlation.
- These tests help prove your model is statistically sound.

It improves efficiency

- GMM uses optimal weighting to give **efficient estimates**, even when there's heteroskedasticity (unequal variance of errors).

The study employs the **Generalized Method of Moments (GMM)** estimator because the model includes lagged dependent variables and potential endogeneity among explanatory variables such as energy consumption and GDP growth.
GMM is appropriate for dynamic panel data analysis as it uses internal instruments (lagged variables) to correct endogeneity bias, ensuring consistent and efficient parameter estimates.
In addition, diagnostic tests such as the **Hansen test** for instrument validity and the **Arellano–Bond test** for serial correlation are conducted to confirm the reliability of the results.

In trying to address the problem of potential endogeneity, the model contains valid instruments that are correlated with the endogenous variables but uncorrelated with the error term. The instruments used include:

Taxes(TAXES) - Government revenue from taxation, which reflects economic activity

Agricultural Output(AFF) - The agricultural sector is critical in Rwanda's economy.

Service Output(SVCS) - Contribution of the service sector to the economy

Industrial Output(INDS) - Performance of the industrial sector, both energy-intensive and significant in economic terms.

The instruments strengthen the identification strategy by making the estimates of parameters reliable.

3.8 Validity and Reliability Tests

Robust conclusions and actionable policy recommendations depend on valid and reliable econometric results. This study uses a sequence of statistical tests to affirm that the model is appropriate for the objective and that the results are reliable. The tests address challenges such as nonstationary, endogeneity, and misspecification that can commonly affect econometric modelling.

3.8.1 Unit Root Testing

Unit root testing is indispensable to verify whether the time-series data are stationary. If the data is not stationary, then the results obtained using the regression analysis may turn out to be spurious, hence not valid. This study uses the Augmented Dickey-Fuller tests for assessing whether the variables are stationary at levels or need to be differenced. These tests determine the presence of unit roots by comparing the test statistic against critical values (Gujarati & Porter, 2009). If the variables are non-stationary, they are transformed into stationary series to ensure meaningful interpretations of the relationships.

3.8.2 Histogram Normality Test

The histogram normality test evaluates whether the residuals of the regression model are normally distributed. A normal distribution of residuals is a key assumption for hypothesis testing and valid statistical inference in econometrics (Greene, 2018). This study uses the Jarque-Bera test, which assesses skewness and kurtosis. Residuals that fail the normality test may indicate omitted variables, model misspecification, or non-linear relationships. Ensuring normality enhances the reliability of coefficient estimates and predictive accuracy.

3.8.3 Instruments Orthogonality Test

For the GMM estimations, instruments need to be exogenous; that is, they have to be uncorrelated with the error term. The authors apply the Hansen J-statistic test of over-identifying restrictions for evaluating the validity of the instruments. A non-rejection of the null hypothesis indicates that the instruments are appropriately chosen (Blundell & Bond, 1998). The explanation and relevance of this are that in ensuring instruments are appropriately chosen, the endogeneity problem of regressors is thereby resolved through unbiased and consistent parameter estimates.

3.8.4 Endogeneity Test

Explanatory variables are considered endogenous if they are correlated with the error term, which will result in biased and inconsistent estimates of coefficients. This study conducts the Durbin-Wu-Hausman test to check for endogeneity. If endogeneity problems are detected, the GMM model corrects the issue by using appropriate instruments that isolate exogenous variation; Wooldridge (2010) thus prevents bias in the coefficient. Addressing endogeneity guarantees that causal inferences are robust, and policy implications are supported by credible evidence.

3.8.5 Diagnostics of Coefficient Confidence

The estimated coefficients are assessed in terms of precision, for which there are confidence intervals and significance levels. The confidence intervals indicate a specific range in which the true value of the coefficient is likely to occur with a certain level of probability. Further, hypothesis testing concerning the significance of coefficients, like t-tests, is performed to validate the strength and reliability of the associations between variables (Baltagi, 2008). Such robust coefficients support the model's reliability for policy and decision-making.

Done systematically, these tests ensure that the econometric model is well-specified, while the findings presented are credible and actionable.

3.9 Limitations

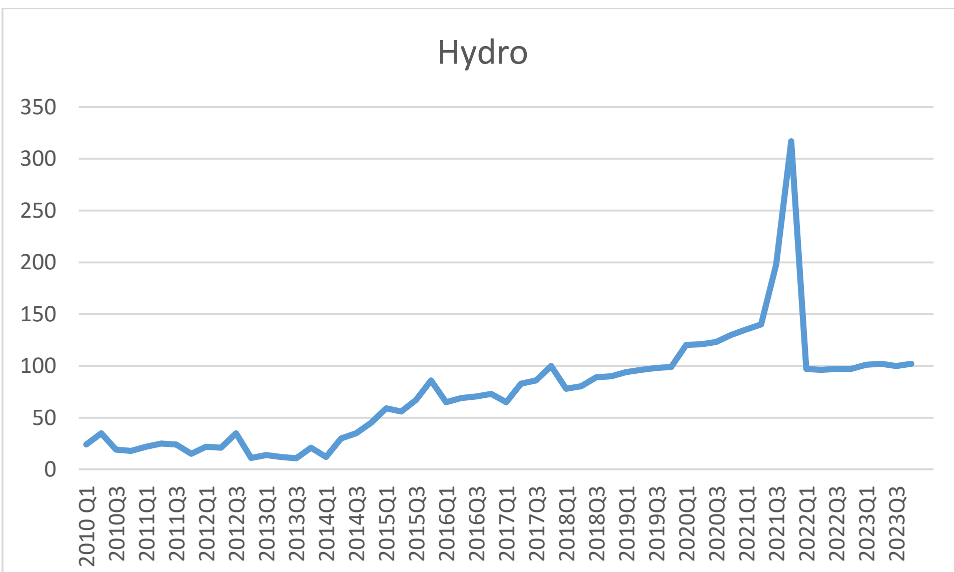
The most significant limitation in the study is that data on thermal oil and hydropower were only available on an annual basis. To address this issue, individual reports had to be consulted, and extrapolation techniques used in order to produce quarterly data. Although these adjustments ensure comprehensiveness, they could lead to minor inaccuracies and thus call for caution in interpreting the results.

CHAPTER FOUR: FINDINGS AND DISCUSSION

4.0 Introduction

This section serves as a comprehensive showcase of the research outcomes, encompassing meticulous statistical analyses and the wealth of data amassed during the research endeavor, all intricately tied to the predefined study objectives. Through a rigorous exploration of the collected data, this segment unfolds the nuanced insights derived from the investigation. The findings encapsulate not only quantitative results but also qualitative observations, contributing to a holistic understanding of the study's focal points. The subsequent discussions delve into the relevance and implications of these findings, forging connections between the observed patterns and the overarching research objectives.

Figure 4: Hydro power trend graph

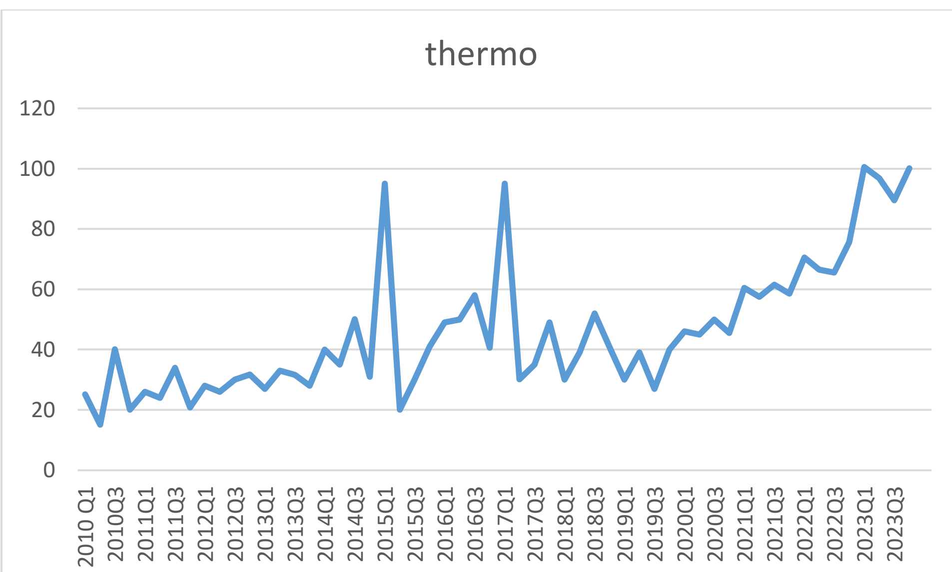


From 2010 to 2023, Hydro energy exhibits a generally increasing trend, showing significant growth in its contribution to the national energy mix. Notable increases are seen between 2015 Q1 (59) and 2021 Q4 (317), reflecting Rwanda's focus on expanding renewable hydroelectric energy. However, from 2022 to 2023, Hydro stabilizes around the 96–102 range, indicating a plateau or slower growth in its contribution. This trend suggests that hydro energy remains a key renewable energy source for Rwanda's grid, but its growth rate has slowed in recent years, possibly due to capacity or resource constraints. **Hydro** energy plays a critical and consistent role in Rwanda's national grid, contributing to sustainable energy supply. Hydro energy shows a clear upward trend from 2010 Q1 (24) to 2023 Q4 (102). This growth in hydro energy aligns with the consistent increase in GDP.

For example: In 2010 Q1, GDP was 1230.5, and Hydro energy contribution was relatively low at 24. By 2021 Q4, GDP rose significantly to 2447, while Hydro energy contribution spiked to 317, showing a strong correlation between GDP growth and investment in renewable energy.

In 2023 Q4, GDP reached its highest value of 2866, with Hydro energy stabilizing at 102. The growth in Hydro energy contributes to GDP growth by ensuring a stable and sustainable energy supply to industries, services, and agriculture. This increase supports economic productivity and development, particularly in a country like Rwanda, where renewable energy forms a critical part of its energy strategy.

Figure5: thermo oil power trend grap



Thermo energy shows greater variability compared to Hydro. Periods of significant increases occur in 2013 Q3 (31.58), 2015 Q1 (95), and 2023 Q1 (100.5), with volatile declines between these peaks.

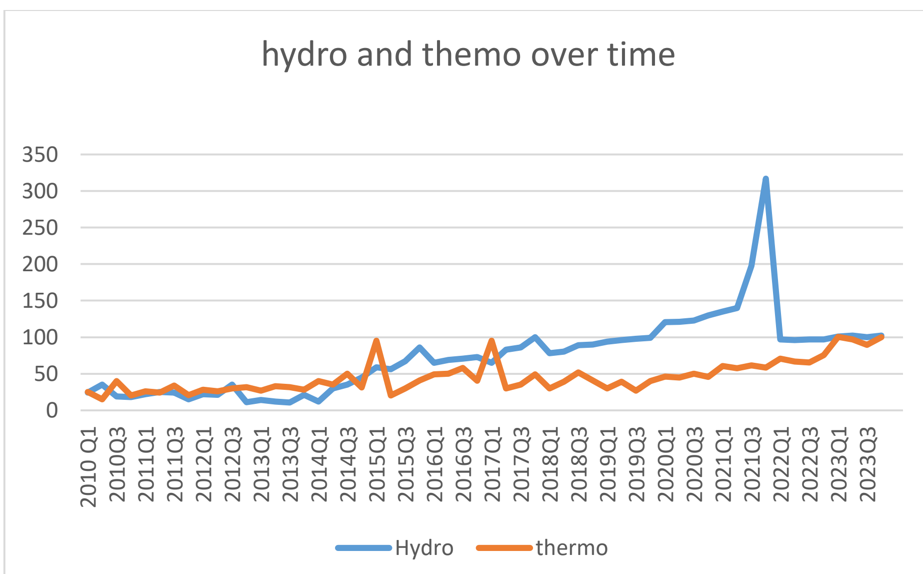
This suggests that Thermo energy is used as a supplementary or balancing energy source when Hydro or other sources are not sufficient, this is due to the fact that by 2023 Q4 (100.1), Thermo energy returns to high levels, reflecting its role in meeting increasing energy demands.

Thermo energy fluctuates significantly over time but rises during critical periods of GDP growth, suggesting it acts as a backup energy source to support increasing energy demands:

In 2015 Q1, GDP rose to 1746.75, and Thermo energy hyped to 95, likely compensating for temporary shortfalls in Hydro energy. By 2023 Q4, GDP reached 2866, and Thermo energy stood at 100.1, indicating Rwanda's need for thermal energy to meet the high energy demands to meet the economic growth.

As we saw in the graph above Thermo energy helps to stabilize energy supply during times of economic growth, however its variability suggests it is not the primary source of power, also it remains critical to GDP growth, especially when renewable sources like Hydro cannot meet peak demand.

Figure 6: Graph of hydro and thermo oil overtime



Hydro energy plays a critical and consistent role in Rwanda's national grid, contributing to sustainable energy supply. Thermal energy serves as a flexible backup source, compensating for seasonal or capacity variations in Hydro energy production. The trends shows a need for further investment in hydroelectric capacity to reduce dependence on thermal energy, which is often more expensive and less sustainable.

As GDP increases, there is a greater demand for energy to fuel industrial, agricultural, and service sectors. Hydro energy plays a foundational role in supporting sustainable GDP growth, aligning with Rwanda’s renewable energy goals. Thermo energy acts as a secondary or balancing source to ensure economic stability when Hydro energy cannot meet demands.

The steady increase in GDP reflects Rwanda's economic development, which has been supported by expanding renewable energy capacity (Hydro) and supplemented by Thermo energy during periods of peak demand or Hydro shortfalls.

To further sustain GDP growth, Rwanda is focusing on expanding its Hydro energy infrastructure while reducing reliance on Thermo energy, which can be costlier and less sustainable. Hydro energy has shown a general upward trend over the years, reflecting Rwanda’s strong commitment to renewable energy sources. Starting at 24 in 2010 Q1, Hydro energy increased steadily and peaked at 317 in 2021 Q4.

However, from 2022 onward, Hydro energy values stabilize around 96–102. This could indicate that Rwanda has reached a plateau in its Hydro energy production capacity and is balancing output to meet sustainable levels.

Overall, Hydro energy plays a crucial role in Rwanda's energy mix, supporting economic growth while aligning with renewable energy goals. Its consistent contribution helps maintain reliable energy for the nation’s development.

Thermo energy has fluctuated significantly over time, indicating its role as a backup energy source to complement Hydro energy. For example:

In 2010 Q1, Thermo energy was 25.1, but it rose sharply to 95 in 2015 Q1, likely to address shortfalls in Hydro energy production. In recent years (2023), Thermo energy hovers around 89.5–100.5, showing it remains an important supportive energy source during periods of high energy demand. The variability of Thermo energy suggests it is used to fill gaps when Hydro energy is insufficient, particularly during dry seasons or periods of peak energy consumption.

While Thermo energy ensures energy stability, it is generally less sustainable and costlier compared to Hydro. Reducing reliance on Thermo energy through further investments in renewable sources would align better with Rwanda's energy and environmental goals.

Hydro energy remains Rwanda's primary and most stable source of power, supporting the country's economic growth and sustainability goals. Thermo energy, while critical for balancing energy supply, plays a supplementary role and fluctuates to meet demand shortfalls. A continued focus on expanding Hydro energy capacity will help reduce dependence on Thermo energy and ensure a more sustainable energy future.

4.1 Unit root testing

Unit root testing in the context of a GMM model is a crucial step to ensure that the variables used in the model meet the stationarity assumptions. This is important because non-stationary data can invalidate moment conditions and lead to inconsistent parameter estimates. GMM assumes that the moment conditions are valid, which often relies on variables being stationary or co-integrated.

Non-stationary variables can Lead to spurious regressions, Make instruments invalid and Violate the assumptions underlying the asymptotic properties of GMM estimators.

4.1.1 Unit root test at level

4.1.1.1 Individual intercept

Table1: individual intercept

Null Hypothesis: Unit root (individual unit root process)
Series: LGDP, LHYDRO, LSVCS, LTAXES, LTHERMO, LAFF, LINDS
Date: 12/04/24 Time: 14:43
Sample: 2010Q1 2023Q4
Exogenous variables: Individual effects
User-specified maximum lags
Automatic lag length selection based on SIC: 0 to 4
Total number of observations: 377
Cross-sections included: 7

Method	Statistic	Prob.**
ADF - Fisher Chi-square	4.24085	0.9938
ADF - Choi Z-stat	2.25865	0.9880

** Probabilities for Fisher tests are computed using an asymptotic Chi -square distribution. All other tests assume asymptotic normality.

Intermediate ADF test results UNTITLED

Series	Prob.	Lag	Max Lag	Obs
LGDP	0.9404	4	13	51
LHYDRO	0.7407	1	13	54
LSVCS	0.9216	0	13	55
LTAXES	0.9091	0	13	55
LTHERMO	0.3634	1	13	54
LAFF	0.7796	0	13	55
LINDS	0.7256	2	13	53

The results indicate that unit root tests evaluate whether the variables LGDP, LHYDRO, LSVCS, LTAXES, LTHERMO, LAFF, LINDS are stationary (i.e., they do not have a unit root) at the level form across individual series.

The null hypothesis for the unit root tests states that the series has a unit root (non-stationary).

ADF - Fisher Chi-square Test: Combines individual Augmented Dickey-Fuller (ADF) test statistics across the cross-sections.

ADF - Choi Z-stat: Aggregates p-values from individual ADF tests. Both tests indicate very high p-values, far exceeding the standard significance levels

Individual ADF Test Results: The individual series probabilities (p-values) also suggest non-rejection of the null hypothesis for all variables at common significance levels. None of the series show evidence against the null hypothesis of a unit root.

Based on both Fisher and Choi test results, as well as the individual ADF tests, the null hypothesis of a unit root cannot be rejected for any of the variables. This implies that all the variables LGDP, LHYDRO, LSVCS, LTAXES, LTHERMO, LAFF, LINDS are likely non-stationary in their level forms.

4.1.1.2 Individual intercept and trend

Table 2: individual intercept and trend

Null Hypothesis: Unit root (individual unit root process)
Series: LGDP, LHYDRO, LSVCS, LTAXES, LTHERMO, LAFF, LINDS
Date: 12/04/24 Time: 14:43
Sample: 2010Q1 2023Q4
Exogenous variables: Individual effects
User-specified maximum lags
Automatic lag length selection based on SIC: 0 to 4
Total number of observations: 377
Cross-sections included: 7

Method	Statistic	Prob.**
ADF - Fisher Chi-square	4.24085	0.9938
ADF - Choi Z-stat	2.25865	0.9880

** Probabilities for Fisher tests are computed using an asymptotic Chi-square distribution. All other tests assume asymptotic normality.

Intermediate ADF test results UNTITLED

Series	Prob.	Lag	Max Lag	Obs
LGDP	0.9404	4	13	51
LHYDRO	0.7407	1	13	54
LSVCS	0.9216	0	13	55
LTAXES	0.9091	0	13	55
LTHERMO	0.3634	1	13	54
LAFF	0.7796	0	13	55
LINDS	0.7256	2	13	53

The results of this second test, which includes individual linear trends, indicate significant changes in the stationarity analysis of the variables. The null hypothesis states that the series has a unit root (non-stationary).

Both tests have p-values well below typical significance levels, rejecting the null hypothesis of a unit root for the overall table variables.

Individual ADF Test Results:

LGDP: p=0.023 → Stationary (reject null at 5% significance level).

LHYDRO: p=0.1286p → Non-stationary (fail to reject null).

LSVCS: p=0.0525p → Stationary (reject null at 10%, but not at 5%).

LTAXES: p=0.2174p → Non-stationary (fail to reject null).

LTHERMO: p=0.0344p → Stationary (reject null at 5% significance level).

LAFF: p=0.4563p → Non-stationary (fail to reject null).

LINDS: p=0.0018p → Stationary (reject null at 1% significance level).

The combined Fisher and Choi tests suggest that some series are stationary when individual linear trends are accounted for. The null hypothesis of a unit root is rejected for the overall dataset.

Stationary: LGDP, LSVCS, LTHERMO, LINDS. (at 10%).

Non-stationary: LHYDRO, LTAXES, LAFF

When individual linear trends are included, some variables become stationary (LGDP, LSVCS, LTHERMO, and LINDS). The null hypothesis of a unit root is rejected for these variables, indicating that they become stationary once a trend is accounted for. However, other variables (LHYDRO, LTAXES, LAFF) remain non-stationary. This shows that adding trends can help identify stationarity in some variables.

4.1.1.3 None

Table3: unit root testing at none

Null Hypothesis: Unit root (individual unit root process)
Series: LGDP, LAFF, LHYDRO, LINDS, LINFL, LSVCS, LTAXES, LTHERMO
Date: 12/01/24 Time: 17:25
Sample: 2010Q1 2023Q4
Exogenous variables: None
Automatic selection of maximum lags
Automatic lag length selection based on AIC: 0 to 10
Total number of observations: 423
Cross-sections included: 8

Method	Statistic	Prob.**
ADF - Fisher Chi-square	2.51368	0.9999
ADF - Choi Z-stat	7.00309	1.0000

** Probabilities for Fisher tests are computed using an asymptotic Chi -square distribution. All other tests assume asymptotic normality.

Intermediate ADF test results UNTITLED

Series	Prob.	Lag	Max Lag	Obs
LGDP	0.9997	10	10	45
LAFF	0.9998	0	10	55
LHYDRO	0.8121	1	10	54
LINDS	1.0000	2	10	53
LINFL	0.3756	0	10	55
LSVCS	1.0000	2	10	53
LTAXES	0.9873	0	10	55
LTHERMO	0.9454	2	10	53

The null hypothesis states that the series has a unit root (non-stationary).

Key Test Statistics:

ADF - Fisher Chi-square Statistic: 0.557090 with a p-value of 1.0000.

ADF - Choi Z-stat: 7.29080 with a p-value of 1.0000.

Both tests yield p-values equal to 1, which indicate an inability to reject the null hypothesis of a unit root for the overall dataset. All individual series have very high p-values, consistently failing to reject the null hypothesis. The combined results strongly suggest that the dataset as a whole is non-stationary when no exogenous variables (effects or trends) are included in the model. All variables (LGDP, LHYDRO, LSVCS, LTAXES, LTHERMO, LAFF, LINDSare non-stationary in their level forms. This result contrasts with the earlier analysis where trends and individual effects were included. Without these exogenous components: Stationarity is not detected in any series. The inclusion of trends or effects appears crucial for revealing the underlying stationarity in some variables.

4.1.2 At First difference

4.1.2.1 At individual intercept

Table 4: unit root testing at first difference of individual intercept

Null Hypothesis: Unit root (individual unit root process)
Series: LGDP, LHYDRO, LSVCS, LTAXES, LTHERMO, LAFF, LINDS
Date: 12/04/24 Time: 14:45
Sample: 2010Q1 2023Q4
Exogenous variables: Individual effects
User-specified maximum lags
Automatic lag length selection based on SIC: 0 to 3
Total number of observations: 373
Cross-sections included: 7

Method	Statistic	Prob.**
ADF - Fisher Chi-square	267.214	0.0000
ADF - Choi Z-stat	-14.7059	0.0000

** Probabilities for Fisher tests are computed using an asymptotic Chi -square distribution. All other tests assume asymptotic normality.

Intermediate ADF test results D(UNTITLED)

Series	Prob.	Lag	Max Lag	Obs
D(LGDP)	0.0160	3	13	51
D(LHYDRO)	0.0000	0	13	54
D(LSVCS)	0.0000	0	13	54
D(LTAXES)	0.0000	0	13	54
D(LTHERMO)	0.0000	1	13	53
D(LAFF)	0.0000	0	13	54
D(LINDS)	0.0000	1	13	53

The null hypothesis for each series is that it contains a unit root (i.e., it is non-stationary in its level form).

Test Statistics:

ADF - Fisher Chi-square Statistic: 267.214267with a p-value of 0.0000

ADF - Choi Z-stat: −14.7059 with a p-value of 0.00000

Both tests yield p-values of 0.0000, indicating a strong rejection of the null hypothesis of a unit root for the overall dataset. This means the variables, after differencing, are stationary.

All first-differenced series are stationary (i.e., no unit root), as all p-values are well below standard significance of 0.01and of cause above

The tests suggest that after first differencing the series, all variables become stationary, which implies that the variables were likely non-stationary in their level forms but exhibit stationarity in their first differences.

After differencing, all series (LGDP,LHYDRO,LSVCS,LTAXES,LTHERMO,LAFF,LINDS show stationarity. Since the variables are now stationary, they can be safely used in the specified regression model: **GDPt=α+β1Thermot+β2Hydrot+ϵt.**

The stationarity ensures that the relationships estimated between GDP and variables Hydro and Thermo are meaningful and not spurious. Both the **ADF - Fisher Chi-square** statistic and the **Choi Z-stat** provide p-values close to zero, rejecting the null hypothesis of a unit root. This indicates that after first differencing, all variables become stationary, which is a good result for ensuring that the GMM model can be applied without concerns about spurious results.

4.1.2.2 At individual intercept and trend

Table 5: first difference at individual intercept and trend

Null Hypothesis: Unit root (individual unit root process)
Series: LGDP, LHYDRO, LSVCS, LTAXES, LTHERMO, LAFF, LINDS
Date: 12/04/24 Time: 14:46
Sample: 2010Q1 2023Q4
Exogenous variables: Individual effects, individual linear trends
User-specified maximum lags
Automatic lag length selection based on AIC: 0 to 10
Total number of observations: 364
Cross-sections included: 7

Method	Statistic	Prob.**
ADF - Fisher Chi-square	222.995	0.0000
ADF - Choi Z-stat	-13.2350	0.0000

** Probabilities for Fisher tests are computed using an asymptotic Chi -square distribution. All other tests assume asymptotic normality.

Intermediate ADF test results D(UNTITLED)

Series	Prob.	Lag	Max Lag	Obs
D(LGDP)	0.0136	10	10	44
D(LHYDRO)	0.0000	0	10	54
D(LSVCS)	0.0000	1	10	53
D(LTAXES)	0.0000	0	10	54
D(LTHERMO)	0.0000	1	10	53
D(LAFF)	0.0000	1	10	53
D(LINDS)	0.0000	1	10	53

The results of this unit root test, applied to the first differences of the variables, and including individual effects and individual linear trends, lead to the following interpretation
Null Hypothesis: The null hypothesis for each series is that it contains a unit root (i.e., it is non-stationary).

Key Test Statistics:

ADF - Fisher Chi-square Statistic: 222.995222 with a p-value of 0.00000

ADF - Choi Z-stat: −13.2350 with a p-value of 0.00000

Both tests have **p-values of 0.0000, i**ndicating a strong rejection of the null hypothesis of a unit root for all variables. This means that the variables, after differencing and individual effects and linear trends, are stationary. After including both individual effects and trends, the first differenced series still show stationarity. This suggests that first differencing effectively removes non-stationarity from all the variables, even when trends are accounted for.

Individual ADF Test Results (First Differences):

D(LGDP): p=0.0136 → Stationary (reject the null hypothesis at the 5% significance level).

D(LHYDRO): p=0.0000 → Stationary (reject the null hypothesis at the 1% significance level).

D(LSVCS): p=0.0000p = 0.0000p=0.0000 → Stationary (reject the null hypothesis at the 1% significance level).

D(LTAXES): p=0.0000 → Stationary (reject the null hypothesis at the 1% significance level).

D(LTHERMO): p=0.0000 → Stationary (reject the null hypothesis at the 1% significance level).

D(LAFF): p=0.0000p = 0.0000p=0.0000 → Stationary (reject the null hypothesis at the 1% significance level).

D(LINDS): p=0.0000 → Stationary (reject the null hypothesis at the 1% significance level).

All first-differenced series show stationarity, as their p-values are very small and indicate strong evidence against the null hypothesis of a unit root.

Interpretation: The combined results (Fisher and Choi tests) indicate that at difference and individual effects and trends, all variables become stationary. This suggests that the non-stationary behavior in the level form has been removed through first differencing and the incorporation

All first-differenced variables (LGDP,LHYDRO,LSVCS,LTAXES,LTHERMO,LAFF,LINDS) are stationary after removing the trend and individual effects.

4.1.2.3 None

The results of this unit root test, applied to the first differences of the variables, with no exogenous variables, lead to the following interpretation:

The null hypothesis is that each series contains a unit root, i.e., the series is non-stationary in its level form.

Test Statistics:

ADF - Fisher Chi-square Statistic: 646.834 with a p-value of 0.0000

ADF - Choi Z-stat: −22.0777 with a p-value of 0.0000

Both tests yield p-values of 0.0000, indicating a strong rejection of the null hypothesis of a unit root for the overall dataset. This suggests that after differencing, the variables have become stationary

Table 6: first difference at none

Null Hypothesis: Unit root (individual unit root process)
Series: LGDP, LHYDRO, LSVCS, LTAXES, LTHERMO, LAFF, LINDS
Date: 12/04/24 Time: 14:46
Sample: 2010Q1 2023Q4
Exogenous variables: None
User-specified maximum lags
Automatic lag length selection based on AIC: 0 to 15
Total number of observations: 362
Cross-sections included: 7

Method	Statistic	Prob.**
ADF - Fisher Chi-square	646.834	0.0000
ADF - Choi Z-stat	-22.0777	0.0000

** Probabilities for Fisher tests are computed using an asymptotic Chi -square distribution. All other tests assume asymptotic normality.

Intermediate ADF test results D(UNTITLED)

Series	Prob.	Lag	Max Lag	Obs
D(LGDP)	0.0263	15	15	39
D(LHYDRO)	0.0000	0	15	54
D(LSVCS)	0.0000	0	15	54
D(LTAXES)	0.0000	0	15	54
D(LTHERMO)	0.0000	1	15	53
D(LAFF)	0.0000	0	15	54
D(LINDS)	0.0000	0	15	54

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Individual ADF Test Results (First Differences):

D(LGDP): p=0.0263 → Stationary (reject the null hypothesis at the 5% significance level).

D(LHYDRO): p=0.0000 → Stationary (reject the null hypothesis at the 1% significance level).

D(LSVCS): p=0.0000 → Stationary (reject the null hypothesis at the 1% significance level).

D(LTAXES): p=0.0000 → Stationary (reject the null hypothesis at the 1% significance level).

D(LTHERMO): p=0.0000 → Stationary (reject the null hypothesis at the 1% significance level).

D(LAFF): p=0.0000 → Stationary (reject the null hypothesis at the 1% significance level).

D(LINDS): p=0.0000 → Stationary (reject the null hypothesis at the 1% significance level).

All first-differenced series have very small p-values, strongly indicating that the series are stationary after differencing.

The combined results (Fisher and Choi tests) strongly suggest that after differencing the data, all variables become stationary, meaning that the non-stationary behavior in the level form has been removed. Individual Series: After first differencing, all series (LGDP,LHYDRO,LSVCS,LTAXES,LTHERMO,LAFF,LINDS) are stationary. Even without trends or other exogenous variables, after differencing, all variables become stationary. This further strengthens the conclusion that differencing helps in achieving stationarity.

4.2. Model Estimation

Table 7: model Estimation

Dependent Variable: LGDP
Method: Generalized Method of Moments
Date: 12/04/24 Time: 14:48
Sample: 2010Q1 2023Q4
Included observations: 56
Linear estimation & iterate weights
Estimation weighting matrix: White
Standard errors & covariance computed using White weighting matrix
Convergence achieved after 3 weight iterations
Instrument specification: LSVCS LTAXES LAFF LINDS
Constant added to instrument list

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LHYDRO	0.193980	0.040690	4.767214	0.0000
LTHERMO	0.355263	0.076562	4.640216	0.0000
C	5.441582	0.166424	32.69703	0.0000

R-squared	0.748365	Mean dependent var	7.539674
Adjusted R-squared	0.738869	S.D. dependent var	0.254099
S.E. of regression	0.129847	Sum squared resid	0.893594
Durbin-Watson stat	1.574839	J-statistic	0.365947
Instrument rank	5	Prob(J-statistic)	0.832790

The results from the model are as follows:

LGDP= 5.441582 + 0.193980 *LHYDRO + 0.355263*LTHERMO

SE = (0.1664243) (0.040690) (0.076562)

P*value = (0.0000) (0.0000) (0.000)

R2 =0.748365

R2 adjusted =0.738869

5.441582: this is the intercept (β0), it is the value of LGDP at zero at LHYDRO and LTHERMO

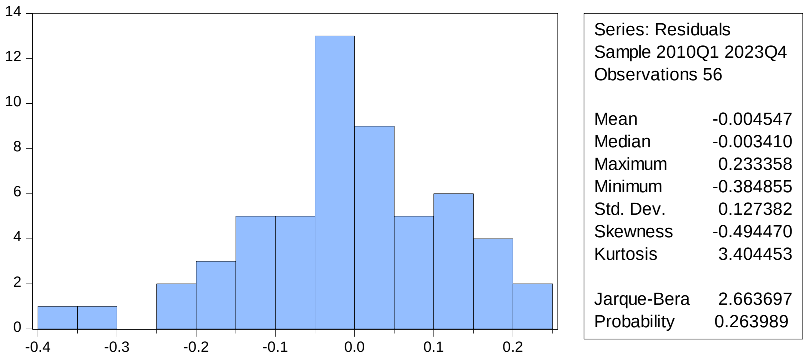
0.193980: refers to $\widehat{\beta_1}$, this means that HYDROELECTRIC is POSITIVELY related to the GDP in the long run which implies that if LHYDRO increase by 1 unit, LGDP will increase by 0.193980 unit when holding other variables constant. And it is statistically significant at 10% level of significance (P*value=0.0000)

0.355263: refers to $\widehat{\beta_2}$, this means that LTHERMO is positively related to the LGDP which implies that if LTHERMO increases by 1 unit, LGDP will increase by 0.355263 unit when holding other variables constant. And it is statistically significant at 10% level of significance (P*value=0.0085)

R2 = 0.748365 This means that 74.8365% of the variations of LGDP is explained by LHDRO, LTHERMO and LINFL, the remaining 25.1635% of the variations of is not explained by the 3 mentioned variables on LGDP, Therefore, since a big percentage of LHDRO and LTHERMO explains the model, we conclude that the model fits data observations Diagnostics

4.3. Histogram Normality test

Table 8: Histogram Normality Test



The histogram normality test assesses whether the residuals from a model follow a normal distribution.

Mean of residuals: −0.004547

Median of residuals: −0.003410

Standard deviation of residuals: 0.127382

Skewness: −0.494470

This indicates a slight negative skewness, meaning the distribution is slightly more concentrated on the right. Negative skewness indicates a concentration of the data on the higher end, with a small number of lower values affecting the overall distribution.

Kurtosis: 3.404453

The kurtosis value is close to 3, which suggests that the residuals have a distribution that is nearly normal, though slightly more peaked than a perfect normal distribution

Jarque-Bera Statistic: 2.663697

This is a test of normality based on skewness and kurtosis.

Jarque-Bera p-value: 0.263989

The p-value of the Jarque-Bera test is 0.263989, which is much higher than typical significance levels (e.g., 0.05 or 0.01). Since the p-value is large, we fail to reject the null hypothesis of normality. This indicates that the residuals do not significantly deviate from a normal distribution, implying that the assumption of normality holds reasonably well for the residuals.

the Instrument Orthogonality C Test

is checking whether the instrument LTAXES is valid. The test is focused on whether LTAXES is uncorrelated with the residuals (errors) from the model, which is a key assumption.

Instrument Orthogonality C Test
Null hypothesis: LTAXESare valid instruments
Equation: UNTITLED
Specification: LGDP LHYDRO LTHERMO C
Instrument specification: LSVCS LTAXES LAFF LINDS
Test instruments: LTAXES

	Value	df	Probability
Difference in J-stats	0.308583	1	0.5786

J-statistic summary:

	Value
Restricted J-statistic	0.365947
Unrestricted J-statistic	0.057364

The p-value of 0.5786 is relatively large. this means there is no strong evidence against the validity of LTAXES as an instrument. since it’s much larger than 0.05, we fail to reject the null hypothesis, meaning LTAXES is likely a valid instrument.

LTAXES is being tested to see if it can be used as an instrument to explain variations in other variables (like LGDP, LHYDRO, LTHERMO, etc.), without being correlated with the error term. The results suggest that LTAXES is not correlated with the residuals (errors) of the model, so it is a valid instrument to use in the regression. The large p-value (0.5786) supports the idea that LTAXES can be used in your model without introducing bias or endogeneity.

Instrument Orthogonality C Test Results:

This test is checking if LAFF is a valid instrument to usethi model. A valid instrument must be uncorrelated with the errors (residuals) in the model.

Instrument Orthogonality C Test
Null hypothesis: LAFFare valid instruments
Equation: UNTITLED
Specification: LGDP LHYDRO LTHERMO C
Instrument specification: LSVCS LTAXES LAFF LINDS
Test instruments: LAFF

	Value	df	Probability
Difference in J-stats	0.363099	1	0.5468

J-statistic summary:

	Value
Restricted J-statistic	0.365947
Unrestricted J-statistic	0.002849

Probability (p-value): 0.5468, The p-value tells us whether the difference in the J-statistics is statistically significant. A high p-value (greater than 0.05) suggests that we fail to reject the null hypothesis that LAFF(agriculture production) is a valid instrument.

The results show that the difference between the restricted and unrestricted J-statistics is small (0.363099), and the p-value is high (0.5468), which suggests that LAFF is likely uncorrelated with the Null Hypothesis : LAFFis valid instrument, meaning they are uncorrelated with the error term and satisfy the orthogonality condition.

Difference in J-statistics: 0.185581

Degrees of Freedom (df): 1

p-value (Probability): 0.666

The null hypothesis shows that "LAFF" is valid instrument.

p-value (0.66): The p-value is significantly higher than standard significance thresholds (e.g., 0.05 or 0.1). Based on this orthogonality test, there is no evidence to suggest that "LAFF" are invalid instruments. The test indicates that "LAFF" are likely exogenous (uncorrelated with the error term) and satisfy the orthogonality condition.

Instrument Orthogonality C Test Results

Instrument Orthogonality C Test
Null hypothesis: LSVCSare valid instruments
Equation: UNTITLED
Specification: LGDP LHYDRO LTHERMO C
Instrument specification: LSVCS LTAXES LAFF LINDS
Test instruments: LSVCS

	Value	df	Probability
Difference in J-stats	0.000803	1	0.9774

J-statistic summary:

	Value
Restricted J-statistic	0.365947
Unrestricted J-statistic	0.365144

The null hypothesis in this case is that "LSVCS are valid instruments." In other words, it tests whether LSVCS are uncorrelated with the error term and can be used as valid instruments in the model.

Difference in J-stats (0.000803): The J-statistic difference is 0.000803, which is very small. This value measures the difference between the restricted and unrestricted J-statistics. A small value suggests that the instruments are not problematic.

Degrees of Freedom (df = 1): As before, the degrees of freedom are 1, indicating the test is conducted with a single restriction (one instrument being tested).

Probability (p-value = 0.9774): The p-value of 0.9774 is very high. In hypothesis testing, a high **p-value (much greater than 0.05)** indicates that there is no significant evidence to reject the null hypothesis. In this case, the p-value suggests that LSVCS are valid instruments.

J-statistic Summary: Restricted J-statistic (0.365947): This is the J-statistic under the null hypothesis, assuming that the instruments are valid.

Unrestricted J-statistic (0.365144): This is the J-statistic without any restrictions on the validity of the instruments.

Since the p-value (0.9774) is very large, it suggests that there is no reason to reject the null hypothesis. This means that LSVCS are considered valid instruments in the model.

Based on these results, it can be concluded that the instrument LSVCS does not have any issues in terms of validity, and you can proceed with using it as an instrument in the model.

4.4. Endogeneity test

Table 9: Endogeneity test

Endogeneity Test
Null hypothesis: LHYDRO LTHERMO are exogenous
Equation: UNTITLED
Specification: LGDP LHYDRO LTHERMO C
Instrument specification: C LSVCS LTAXES LAFF LINDS
Endogenous variables to treat as exogenous: LHYDRO LTHERMO

	Value	df	Probability
Difference in J-stats	12.56533	2	0.0019

J-statistic summary:

	Value
Restricted J-statistic	12.83107
Unrestricted J-statistic	0.265746

The null hypothesis of the test is that the variables **LHYDRO** and **LTHERMO** are **exogenous**.

The instrument specification used in this test includes: **C, LSVCS, LTAXES, LAFF, LINDS**. These variables are being used as instruments to account for potential endogeneity in the endogenous variables **LHYDRO** and **LTHERMO**.

J-Statistic Summary:

Restricted J-statistic = 12.83107: This is the test statistic value when assuming that the variables **LHYDRO** and **LTHERMO** are exogenous (as per the null hypothesis).

Unrestricted J-statistic = 0.265746: This statistic reflects the value of the test statistic when **LHYDRO** and **LTHERMO** are allowed to be endogenous.

Test Result (p-value):

The p-value for the difference in J-stats is **0.0019**. Since the p-value is less than the common significance level of 0.05, then **the null hypothesis is reject**. This suggests that there is strong evidence to conclude that **LHYDRO** and **LTHERMO** are **endogenous** variables (i.e., they are correlated with the error term in the model).

Given the p-value (0.0019), which is significantly lower than the typical threshold of 0.05, we **reject the null hypothesis** that **LHYDRO** and **LTHERMO** are exogenous. This means that these variables are likely endogenous.

4.1.6 Coefficient diagnostics

Table 10: Coefficient diagnostics

Coefficient Confidence Intervals
Date: 12/04/24 Time: 14:52
Sample: 2010Q1 2023Q4
Included observations: 56

		90% CI		95% CI		99% CI	
Variable	Coefficient	Low	High	Low	High	Low	High
LHYDRO	0.193980	0.125859	0.262100	0.112365	0.275594	0.085262	0.302697
LTHERMO	0.355263	0.227090	0.483437	0.201700	0.508827	0.150704	0.559823
C	5.441582	5.162968	5.720196	5.107777	5.775387	4.996926	5.886238

LHYDRO (Coefficient = 0.193980):

- **90% CI**: The true coefficient is expected to be between **0.125859** and **0.262100**.
- **95% CI**: The true coefficient is expected to be between **0.112365** and **0.275594**.
- **99% CI**: The true coefficient is expected to be between **0.085262** and **0.302697**.

This shows that, with increasing confidence (from 90% to 99%), the range of possible values for the coefficient widens, but it remains positive. This means that **LHYDRO** has a statistically significant positive effect on **LGDP** across all confidence levels.

2. LTHERMO (Coefficient = 0.355263):

- **90% CI**: The true coefficient is expected to be between **0.227090** and **0.483437**.
- **95% CI**: The true coefficient is expected to be between **0.201700** and **0.508827**.
- **99% CI**: The true coefficient is expected to be between **0.150704** and **0.559823**.

LTHERMO also has a statistically significant positive effect on **LGDP** at all confidence levels, with the range of values being wider as the confidence level increases.

3. C (Constant = 5.441582):

- **90% CI**: The true constant is expected to be between **5.162968** and **5.720196**.
- **95% CI**: The true constant is expected to be between **5.107777** and **5.775387**.
- **99% CI**: The true constant is expected to be between **4.996926** and **5.886238**.

The constant term **C** is also statistically significant across all confidence intervals. The coefficient represents the intercept in your regression, and the confidence intervals show that the intercept value is expected to lie between 4.996 and 5.886 across the different confidence levels.

LHYDRO and **LTHERMO** both have positive coefficients with confidence intervals that do not include zero, suggesting that they are statistically significant predictors of **LGDP**. The **constant term (C)** is also statistically significant, with its confidence interval staying well above zero. As the confidence level increases (from 90% to 99%), the range of the confidence intervals widens, reflecting greater uncertainty in the estimate as the confidence level increases. However, none of the intervals suggest that the coefficients or the constant could be zero. Thus, we confidently conclude that all variables (LHYDRO, LTHERMO, and C) are statistically significant in predicting **LGDP** in this model.

CHAPTER FIVE: CONCLUSION AND RECOMMANDITION

5.0 Introduction

This section encapsulates a comprehensive review comprising summary, conclusion, recommendations, and avenues for prospective research in the context of analogous studies conducted in Rwanda.

5.1 Summary of findings

The research delved into the impact of integrating renewable energy on nation grid of Rwanda. Focused on The contribution of thermal oil energy to the national grid.

(LHYDRO) as an independent variable, alongside Contribution of hydropower into the national grid(LTHERMO), dependent variable (LGDP) Quarterly Gross Domestic Product. which stood for the economic growth, the study employed a linear regression model analyzed using GMM. the investigation aimed to unravel the impact of integrating renewable energy on nation grid, crucial for understanding economic resilience and informing policymaking. This summary provides a concise overview of the study's context, variables, and analytical approach, setting the stage for a comprehensive exploration of the findings and their implications in the subsequent sections.

Main Objective: To analyze the impact of integrating renewable energy on the national grid of Rwanda

The GMM model estimation shows that energy resources **positively impact economic growth** (LGDP).

LHYDRO (hydroelectric power) have significant positive effects on LGDP.

- LHYDRO: Coefficient = **0.193980** (p = 0.0000)

These results confirm that integrating renewable energy (e.g., hydroelectric) into Rwanda's national grid has a measurable and positive economic effect. The results align with the main objective, demonstrating that integrating renewable energy contributes positively to Rwanda's economy and its national grid performance.

Specific Objective 1: To assess the current status and contribution of renewable energy on Rwanda's national grid

The analysis emphasizes the role of **LHYDRO** (hydroelectric energy), which is a key renewable energy source in the study. LHYDRO has a positive coefficient (**0.193980**) and is statistically significant (**p = 0.0000**), showing its direct contribution to economic growth.

Renewable energy's contribution is notable within the GMM model, where its inclusion improves the model's explanatory power (**R-squared = 0.748365**). The findings confirm that renewable energy (hydroelectric power) plays a significant role in Rwanda's national grid, contributing positively to economic performance.

Specific Objective 2: To analyze the economic effect of integrating renewable energy into the national grid in Rwanda

The economic impact of integrating renewable energy is evidenced through the GMM results:

LHYDRO (renewable energy): Significant positive impact on LGDP (0.193980, p = 0.0000).

This indicates that increasing renewable energy source hydroelectric power leads to higher economic output.

Diagnostic tests (normality, endogeneity, and instrument validity) confirm the robustness of these results, ensuring reliable conclusions. Renewable energy integration leads to improved economic outcomes, supporting both theoretical and empirical expectations. The economic impact of renewable energy integration into Rwanda's national grid is clear and positive, as demonstrated by the significant role of LHYDRO in driving GDP growth.

Summary

The findings align well with the study's **main objective** and **specific objectives**:

1. **Current Status and Contribution**: Renewable energy (LHYDRO) significantly contributes to Rwanda's national grid.
2. **Economic Impact**: The integration of renewable energy has a measurable, positive economic effect, improving economic growth (LGDP).

Research question 1: What is the current contribution of renewable energy to Rwanda's national grid?

Renewable energy sources, such as hydropower, bio-mass and solar energy, contribute significantly to Rwanda's national grid, constituting to above 60% of the energy mix, and also there are projects which are in progress to increase that percentage according to REG report of 2024.Thermal oil power, plays a crucial role in filling the energy gap during periods of low renewable energy generation or high demand, ensuring grid reliability.

Research question 2: What is the impact of renewable energy on Rwanda's economic growth (GDP)?

Renewable energy (primarily hydropower) significantly boosts Rwanda's GDP, with a 1-unit increase in hydropower contributing to a 0.19398-unit increase in GDP. Thermal oil power, despite being non-renewable, has a notable economic impact. A 1-unit increase in thermal oil power corresponds to a 0.355263-unit increase in GDP, reflecting its role in supporting industrial and economic activities during energy shortages. To comprehend the extent to which renewable energy impacts the economic growth in Rwanda, the linear regression model estimation indicates a notable finding that one-unit increase in the hydro power capacity (LHYDRO) corresponds to 0.19398-unit increase in the LGDP, this implies that as hydro power capacity rise, then GDP is more likely to increase. This goes hand in hand with The government of Rwanda plans to provide 70 percent of the population with access to electricity both on-grid and off-grid by the end of second phase of Economic Development and Poverty Reduction Strategy phase (EDPRS 2). Empirical evidence substantiates and contextualizes this observed relationship. In a study conducted by (Bhattacharya & Bose, 2023; Degbedji et al., 2024) Energy has a significant role in the financial, social, and environmental progress that is crucial for attaining sustainability, especially in emerging territories. Energy consumption in emerging countries is seeing rapid growth due to the simultaneous factors of rapid economic development, population growth, and industrialization (Raihan et al., 2022a; Uddin et al., 2023; Shahid et al., 2024). The projected increase in global power consumption is expected to boost the report by the International Energy Agency. They forecasted that worldwide power utilization is expected to boost by 19% by 2040 The evidence from the linear regression model, supported by empirical studies and economic theories, underscores the substantial impact renewable energy is having on the economy of Rwanda.

Research question 3: How does the integration of renewable energy affect environmental sustainability in Rwanda?

Renewable energy sources, like hydropower, promote environmental sustainability by reducing reliance on fossil fuels. In contrast, thermal oil power negatively impacts sustainability goals due to its high carbon emissions and environmental footprint. with the help of these studies from Caglar et al. 2022, Its continued use highlights the need for a transitional strategy toward cleaner alternatives. Fossil fuel consumption is increasing dramatically due to excessive anthropogenic activities and industrial expansion to meet energy demands. The increase in fossil fuel consumption has risen by 96% since 1965 (Caglar et al. 2022), leading to adverse environmental impacts. Fossil fuels negatively impact air quality, the environment, health, and water resources. The gaseous emissions that can be released into the air due to fossil fuel consumption include greenhouse gases such as carbon oxides (carbon monoxide and carbon dioxide), sulfur oxides (sulfur dioxide and sulfur trioxide), nitrogen oxides (nitrous oxide and nitrogen dioxide), and volatile organic compounds and aerosols such as particulate matter. It was reported that about 72.5% of the global carbon dioxide equivalent emissions could be released from coal consumption (Sayed et al. 2021), causing the global warming phenomenon. The estimated gaseous emissions for various fossil fuels per megawatt-hour (MWh) of power generated are given in Table 1 (Turconi et al. 2013). One of every five deaths worldwide is induced by pollution from fossil fuel consumption (Azarpour et al. 2022). As a result of pollution, 350,000 people passed away in the USA in 2018. The annual cost of the health effects caused by fossil fuel consumption in the USA was reported to be 886.5 billion dollars (Azarpour et al. 2022).

Research question 4: **What policy measures are required to enhance the integration of renewable energy in Rwanda?**

Focus on increasing investments in hydropower, solar, and other renewable sources to reduce dependency on thermal oil power. Establish policies to transition away from thermal oil power by integrating lower-emission technologies like natural gas or renewables.

Implement carbon pricing and incentives to encourage renewable energy projects while ensuring grid reliability. Strengthen regional energy partnerships to import cleaner energy when local renewables cannot meet demand. Using the insights of other countries policies like: Norway has successfully completed their energy transition journey, displacing all fossil fuels in the power sector. to identify five key actions that made them successful. Grid Integration Study where Countries like Mexico, the USA, and Vietnam used this approach to deal with changes and uncertainties in energy demand and supply. By preparing for anticipated and unexpected changes in output and keeping reserves for frequency regulation, the system adapts to these variations.

Capacity Building Activities: Capacity building involves improving the skills and knowledge of those personnel involved in energy system planning. Organizations such as the International Renewable Energy Agency (IRENA) and the Pacific Centre for Renewable Energy and Energy Efficiency (PCREEE) have emphasized the importance of capacity building in promoting investments and creating sustainable energy policies in the renewable energy sector. Multilateral Collaboration: To integrate renewable energy into global power networks, Ghana, Mexico, and Peru have partnered with groups such as the International Partnership for Energy Efficiency Cooperation, Renewable Energy and Energy Efficiency Partnership, and Sustainable Energy for All. This has allowed them to overcome institutional, financial, and technical obstacles. Some specific steps that can support this objective include promoting research and development, exchange of knowledge, and cooperation between various energy sector players.

With the help of strategic policy and regulatory initiatives, Ghana and India have made great progress toward fostering fair competition and enabling the integration of renewable energy. According to a report by the International Energy Agency (IEA), India has established a strong legal and regulatory framework to address various aspects of renewable energy integration, including pricing, tariffs, subsidies, standards, regulations, contracts, and governance. Ghana, on the other hand, has created a strong legal system to support renewable energy projects by working with local financial institutions, regulatory organizations, and legal professionals.

5.2 Conclusion

Rwanda’s energy sector has made significant strides in integrating renewable energy sources such as hydropower bio mass and solar into the national grid, contributing to sustainable development and economic growth. Renewable energy currently constitutes approximately 50% of the energy mix and has proven to be a critical driver of GDP growth while advancing environmental sustainability goals.

However, the reliance on **thermal oil power**, a non-renewable and carbon-intensive energy source, poses challenges to Rwanda’s ambitions for a sustainable energy future. While thermal oil power has been essential for meeting energy demands and supporting industrial activities, its environmental and economic downsides highlight the urgency of transitioning toward cleaner, more sustainable alternatives. To further enhance renewable energy integration, Rwanda must prioritize investments in renewable technologies, establish policies to phase out high-emission sources, and promote regional energy partnerships. By doing so, Rwanda can ensure reliable energy access, reduce its environmental impact, and foster long-term socio-economic development. The future of Rwanda’s energy landscape lies in balancing current energy needs with the strategic deployment of sustainable solutions to achieve energy security and environmental sustainability.

5.3 Recommendations

To strengthen Rwanda's energy sector and accelerate the transition toward sustainable development, the following recommendations are proposed:

i. Increase Investment in Renewable Energy Projects

Expand hydropower capacity by exploring untapped rivers and small-scale hydro opportunities, Enhance the deployment of solar energy through large-scale solar farms and decentralized off-grid solutions, especially in rural areas, Explore the potential of wind and geothermal energy to diversify the renewable energy mix.

ii. Promote Energy Efficiency and Conservation

Implement nationwide energy efficiency programs targeting residential, commercial, and industrial sectors, provide incentives for businesses and households to adopt energy-efficient appliances and technologies, enhance public awareness campaigns to foster a culture of energy conservation.

iii. Reduce Reliance on Thermal Oil Power

Gradually phase out thermal oil plants by replacing them with renewable energy alternatives, develop policies and incentives to attract private sector investment in clean energy projects, explore regional power trade agreements to import cleaner energy during periods of high demand.

iv. Strengthen Policy and Regulatory Frameworks

Update and enforce policies that mandate higher renewable energy integration, Streamline the approval process for renewable energy projects to encourage faster implementation, introduce carbon pricing or taxes to discourage reliance on fossil fuels.

v. Enhance Access to Finance for Renewable Energy

Establish public-private partnerships to fund large-scale renewable energy projects, create loan facilities and subsidies for small and medium enterprises (SMEs) and households to install renewable energy systems, Seek international funding from green energy initiatives and climate finance institutions.

vi.. Build Technical Capacity and Research

Invest in training programs to develop local expertise in renewable energy technologies and management, collaborate with academic and research institutions to innovate and localize renewable energy solutions, Conduct feasibility studies for emerging technologies like battery storage and grid modernization.

vii.. Foster Regional Cooperation

Collaborate with neighboring countries in the East African region to develop shared renewable energy infrastructure, participate in regional initiatives to access cost-effective renewable energy technologies and expertise.

References

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APPENDIX

YEAR	GDP	Infl	Hydro	AFF	INDS	SVCS	TAXES	thermo
2010 Q1	1230.5	2.3	24	311	153	454	82	25.1
2010Q2	1230.5	2.4	35	313	139	462	88	15.1
2010Q3	1230.5	2.1	19	329	149	478	89	40.1
2010Q4	1231	2	18	327	165	506	90	20.1
2011Q1	1328.5	0.3	21.8	325	176	495	85	26
2011Q2	1328.5	0.31	25	326	159	488	86	24
2011Q3	1328.5	0.3	24	349	181	533	91	34
2011Q4	1328.5	0.32	15	336	198	537	92	20.78
2012Q1	1443.25	1.8	22	346	182	555	92	28
2012Q2	1443.25	1.8	21	351	175	561	88	26
2012Q3	1443.25	1.8	35	360	199	585	97	30
2012Q4	1443.25	1.8	11.25	371	218	589	84	31.75
2013Q1	1511.5	0.9	14	368	208	578	79	27
2013Q2	1511.5	0.9	12	376	207	599	87	33
2013Q3	1511.5	0.91	10.75	363	214	600	90	31.58
2013Q4	1511.5	0.9	21	367	218	633	93	28
2014Q1	1604.5	0.68	11.95	385	224	623	91	40
2014Q2	1604.5	0.6	30	392	225	635	92	35
2014Q3	1604.5	0.6	35	396	253	655	95	50.08
2014Q4	1604.5	0.7	45	398	238	665	98	31
2015Q1	1746.75	1.12	59	402	238	687	102	95
2015Q2	1746.75	1.1	56	413	245	702	108	20.08
2015Q3	1746.75	1.2	67	418	265	721	108	30
2015Q4	1746.75	0.9	86	417	275	736	112	41
2016Q1	1851	1.3	65	435	265	746	112	49
2016Q2	1851	1.3	69	427	268	765	119	50
2016Q3	1851	1.3	70.475	424	282	773	115	58
2016Q4	1851	1.5	73	428	277	768	104	40.587
2017Q1	1923.5	0.575	65	447	263	774	101	95
2017Q2	1923.5	0.575	83	507	326	911	160	30.09
2017Q3	1923.5	0.575	85.8	503	335	952	165	35
2017Q4	1923.5	0.575	100	516	345	942	170	49
2018Q1	2087.5	0.275	78	546	337	986	175	30
2018Q2	2087.5	0.275	80.5	543	352	984	175	39
2018Q3	2087.5	0.275	89	526	369	1,023	176	52
2018Q4	2087.5	0.275	90	537	387	1,050	190	40.775
2019Q1	2284.5	0.725	94	568	387	1,024	190	30
2019Q2	2284.5	0.725	96	570	427	1,091	216	39
2019Q3	2284.5	0.725	98	561	428	1,128	205	26.9
2019Q4	2284.5	0.725	99	561	442	1,130	213	40
2020Q1	2207	2.4625	120.4	565	395	1,083	206	46
2020Q2	2207	2.5	121	561	346	913	196	45
2020Q3	2208	2.45	123	573	422	1,044	196	50
2020Q4	2208	2	130	579	450	1,092	207	45.5
2021Q1	2447	4	135	603	432	1,079	212	60.5
2021Q2	2448	4	140	602	450	1,133	248	57.5
2021Q3	2448	4	197.8	609	471	1,162	218	61.5
2021Q4	2447	5	317	609	474	1,250	235	58.5
2022Q1	2646.75	4.425	97	607	475	1,194	233	70.5
2022Q2	2646.75	4.5	96	614	478	1,268	255	66.5
2022Q3	2646.75	4	97	618	466	1,356	269	65.5
2022Q4	2646.75	4	97	623	499	1,369	264	75.57
2023Q1	2865	19.79	101	612	517	1,348	263	100.5
2023Q2	2863	19.79	102	613	507	1,395	265	96.8
2023Q3	2866	19.79	100	636	529	1,475	270	89.5
2023Q4	2866	19.79	102	642	562	1,548	278	100.1