Rwanda University

College of Science and Technology

Title of the Project: RENEWABLE ENERGY AND ENERGY SUPPLY DEFICIT IN RWANDA

A proposal submitted to the African Center of Excellence in Energy studies for sustainable development (ACE-ESD)

In partial fulfillment of the requirement for the degree of MASTER OF SCIENCE IN ENERGY ECONOMICS.

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Declaration

The undersigned hereby certifies that the project proposal is entirely original to me and hasn't been submitted for credit at the University of Rwanda or any other institution of higher learning. To properly recognize all sources of information used in the work, the proper academic format was used.

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Date of Submission: ______ ______

Approval

I certify that the candidate completed the work presented in this research thesis under my supervision and with my permission before submitting it.

Thesis Advisor: **Dr. Richard KABANDA**

Signature:

Submission date:

Dedication

I dedicated to my mum, brothers, and sister, my relatives and friends.

Acknowledgement

I thank the Almighty God first and foremost for keeping me safe and granting me peace every day of my life on this planet.

I want to thank my supervisor, Dr. Richard Kabanda, from the bottom of my heart for giving me the courage, inspiration, and constructive criticism I needed to complete this study.

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God's blessings on you!

Abstract

Renewable energy is clean energy that does not pollute the environment and is a key strategy for improving energy security. This study focused on the variables influencing demand for renewable energy, the influence of this demand on general energy demand, and the reciprocal relationship between Rwanda's energy deficit and renewable energy. Hence, the energy per capital consumption is pretentious by old and small grid infrastructure, speedy growth in demand, supply disturbance and inefficiencies. The failure to increase energy generation despite rising energy consumption has a negative impact. We also hypothesize a pressure on households to demanding renewable energy resulting from observed higher energy supply deficit. According to the literature analysis, the main factors influencing Rwanda's energy demand are the country's GDP, its ability to obtain electricity, and foreign direct investment. When working with data from times series, it is essential to determine the stationarity of the series by looking for a unit root. This happens as a result of time series' non-stationarity. In most cases, non-stationary data used for econometric analysis yields incorrect results.The Johansen Cointegration test was widely used in this study (1991, Johansen). It is used to It is active to demonstrate that the explained and explanatory factors have an ongoing relationship. The ARDL Long Run Form and the Bound Test were used to determine the relevance of the factors. The outcomes discovered that renewable energy plays a vital role on energy supply deficit means it is filling energy supplied gap in order to meet the demand. This study recommended that government should be encouraging people to be more renewable energy efficiency, to make more value on environmental goods and services. Renewable energy generation reduces greenhouse gas emissions from fossil fuels while also reducing energy deficit.

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List of symbols and acronyms

ACCEL: Access to Electricity

CE: Consumption of Energy

CO2: Carbon dioxide

E: energy demand

ep: Price elasticity

EPC: Energy per Person

ESD: Energy Supply Deficit

ESSs: Energy storage systems

FDI: Foreign Direct Investment

GDP: Growth domestic product

K: Capital

KWh: Kilowatt/h

L: Labour

M: Materials

MINIFRA: Ministry of Infrastructure

MW: Megawatt

P present the price of energy

pE: price of Energy

pM: price of Material

Q: Output

R: rent

RE: Renewable energy

REGC: Renewable Energy Generation Capacity

VAT: Value Added Tax

W: wage

Y: Income

1. INTRODUCTION

1.1 Background

Sources of renewable energy include sun, plants, and water, and it is frequently used to generate electricity, heat or cool water, transport people, and provide rural energy services. Rwanda Energy Group (2018) reported that Rwanda's total installed power generating capacity plants were 218 MW, with renewable energy accounting for 113.14 MW of total energy consumption in Rwanda. Renewable energy has the potential to increase the nation's energy security, enhance the environment, and deliver dependable, affordable energy (Blimpo & Cosgrove-Davies, 2019). Hydropower accounts for the majority of installed capacity (47%) and is followed by thermal energy, which includes diesel and heavy fuel generators, methane gas (14%), peat 7%, and solar 5%. (Eustache et al., 2019).

Due to its technological maturity, hydropower sources account for a substantial portion of renewable energy, whereas other forms of the development of renewable energy is still in its early phases and have an impact on the energy deficit. Utilizing renewable energy sources has been shown to be a sustainable way to enhance generation capacity, increase supply, and decrease the energy deficit. reducing the impact of excessive usage of fossil fuels contributes to climate change (Schwerhoff, 2017). Therefore, in order to address its energy deficit, Rwanda must efficiently utilize the potential of its renewable energy resources.

The current situation shows that Rwanda has achieved tremendous progress in expanding its energy industry. The nation's energy access rate climbed from 10% in 2010 to 51% in 2020, with 37% using on-grid systems and 14% utilizing off-grid systems. The nation's power generation capacity nearly quadrupled from 88 MW in 2010 to 221 MW in 2020. (World Bank, 2019). According to Baringanire, Malik, and Ghosh Banerjee (2014), Rwanda played a crucial role in advancing renewable energy technology through collaboration with International development partners on a bilateral and multilateral basis, as well as unwavering support for funding in the energy industry Despite efforts to improve it, the country's energy supply remains insufficient in comparison to the size of its expanding economy and population demand. Rwanda continues to struggle to meet its energy demand in a reliable and efficient manner (Mukeshimana *et al*., 2021).

According to Rwanda's national development strategy 2017–2024, the nation wants to reach middle-income status by 2035 and high-income status by 2050. The provision of dependable, affordable, and efficient energy from renewable sources is the main priority of the country. In order to achieve its goal of complete electrification by 2024, Rwanda has committed to increasing its generation capacity to 556 MW, with 52% of the population having access to grid connections and 48% living off the grid (MINIFRA, 2018). Effective energy policy evaluation is required for Rwanda to reduce its energy deficit and increasing the proportion of renewable energy generation in the nation's energy mix, we can guarantee a sustainable energy supply.

1.2 Statement of the Problem

The goals of Rwanda's electricity industry are to guarantee a supply of energy that is adequate, dependable, sustainable, and more reasonably priced. Rwanda energy policy report 2004 mentioned that the rapid growth in population density and industrialization experienced Rwanda energy deficit. The consequence after is a rapid grow of energy cost per KWh, 82 Frw in 2005 and 112 Frw in 2006 (VAT excluded). Hence, the Rwandan government has urgently considered the option of renting thermal power plants and has studied energy challenges in light of the growth of renewable energy (RE), with a goal of 60% by 2023. (Uwase, 2019). RE has significant potentials that might help Rwanda fulfil its energy needs to a greater extent (Okoro &Madueme, 2006; Lujara & Kaunde, 2007). Unfortunately, there is no long-term solution to the energy deficit today. Donor support, improved power distribution capacity, and the development of new renewable energy projects are all timely. This could help the country overcome its current energy shortage. Safari (2009), on the other hand, claimed that the fluctuations in renewable energy sources did not completely match the grid's fluctuating electricity demand. Because of old and small grid infrastructure, rapid growth in demand, supply disruption, and inefficiencies, energy per capital consumption is pretentious. Failure to increase energy generation despite rising energy consumption is a serious problem. We also hypothesize that the observed higher energy supply deficit will put pressure on households to demand renewable energy.

1.3 Objectives

1.3.1 General objective

This study's overarching goal is to determine the effect of renewable energy on the energy supply deficit.

1.3.2The specific objectives

i. To investigate the factors that influence demand for renewable energy in Rwanda

ii. To determine the effect of demand for renewable energy on total energy demand in Rwanda

iii. To establish bidirectional of relationship between renewable energy and Rwanda's energy deficit.

1.4 Research hypothesis

Renewable energy demand does significant affect energy supply deficit in Rwanda

1.5 Scope of the study

This research investigates how renewable energy can affect energy deficits, which lead to various activities that Increase the country's economy by starting new businesses. The study examines the linkage between renewable energy and Rwanda's energy supply deficit from 1990 to 2021. We also hypothesize that as the energy supply deficit grows so will Rwanda's demand for renewable energy. The time period in question corresponds to when the data used in this investigation were accessible.

1.6 Expected outcomes and significance of the study

1.6.1Expected outcome of the study

This research shows how boosting renewable energy can help to reduce energy supply deficits by developing new renewable energy businesses in rural and urban areas.

1.6.2 Significant of the Study

The study explains how renewable energy contributes to the structural energy shortage in Rwanda. Underrating the magnitude of this effect would be capital information for the government of Rwanda, leading to appropriate formulation of its policies regarding energy supply, pressure on households to demanding renewable energy as a response to expectations on energy prices to rising, as well as industries energy deficit forecasts. It also sheds light on business opportunities in both urban and rural areas, as well as expectations for lower energy costs.

2. LITRATURE REVIEW

This section of the thesis includes the theoretical literature, and empirical literature

2.1 Definition of key concepts

2.1.1 Renewable energy

Renewable energy (RE) doesn't pollute the environment and is a crucial technique for boosting energy security. When compared to the utilize of fossil fuels, sustainable energy has a low negative impression on human health during production, a high potential for influencing environmental and economic considerations, and a strong emphasis on sustainable development for the future. Wee et al. (2012) provided a supply-side evaluation of renewable energy sources as well as an analysis of RE that focused on four key areas: renewable energy supply, performance, roadblocks, and development plans.

2.1.2 Energy supply deficit

Energy supply is the transfer of energy to the point of consumption; it may include the extraction, transmission, generation, distribution, and storage of energy, which is sometimes referred to as energy flow. The energy supply deficit is happened when electricity production and imports are not sufficient to cover demand. One of the world's biggest problems now is the availability of energy, and it has been studied in order to apply modern methods to energy supply networks (Hong, How and Lam, 2016).

2.2 Theoretical literature

2.2.1 Theory on renewable energy

Olz (2011) argued that renewable energy might reduce carbon dioxide emissions by taking the place of fossil fuels in the industry that produces electricity. CO2 emissions from renewable energy technologies are far lower than those from fossil fuels. In order to lower energy unit costs and make clean energy sources a competitive alternative to conventional energy sources due to the negative externalities associated with the production of conventional energy, it is essential to support renewable energy supply technologies and increase the power produced by clean energy sources.

Production and supply of renewable energy are inescapably growing on a global scale. A key strategy for reducing energy use and, consequently, CO2 emissions, as well as for addressing the challenge of climate change, is improving energy efficiency.

The spatial association between socioeconomic growth and per capita power consumption is significant in Africa where energy supply and demand are more unequal. Power demand and supply will be impacted by the economic structure, which will be aided by (Liao & Wei, 2010). In order to balance energy supply and demand in order to fulfill domestic energy consumption, Africa is experiencing rapid economic development, and by creating this hypothesis, which is supported by data, Africa has placed more attention on the current situation of Africa's energy supply and demand (Sun *et al*., 2008).

Security of supply and a desire to cut CO2 emissions are the driving forces behind the use of renewable energy technology. Alternative energy sources have a significant impact on climate change, and many countries have developed infrastructure that uses renewable energy sources to create electricity. Energy efficiency in the production, transmission, distribution, and use of electricity can all be investigated. The development of renewable energy is driven by factors such as energy security, economic impact, and a reduction in carbon dioxide emissions.

2.2.1.1 Energy security theory

The constant supply of energy, which is essential for removing energy shortages and preserving the economy's smooth operation, is the foundation of the theory of energy security (Kruyt et al., 2009). Access to energy is a major financial challenge for both developed and developing countries due to the close ties between energy production and consumption (Edenhofer *et al*., 2011). There are opportunities to provide global energy security because renewable energy sources are less widely dispersed than fossil fuels globally, which lowers energy imports while also increasing supply options and reducing price volatility. In areas with insufficient grid access that can help meet energy demand, the use of renewable energy has an impact on the dependability of energy services, according to (Edenhofer *et al*., 2011).

2.2.1.2 Energy access theory

According to Edenhofer et al. (2011), the percent of the people who has right to use electricity measures how many households have a source of electricity that they can afford to use to power very basic uses. Access is linked to an understanding of the local context because, in most countries, electrification in rural and urban areas is clearly different. Renewable energy grids are often more viable in rural locations with large populations.

Steward (2017) asserts that financial institution investments in electricity in developing nations have had a important influence on GDP growth, that improvements to the nation's electricity infrastructure can boost its economic activity, and that there is mounting evidence of the socioeconomic advantages of renewable energy sources like solar home systems. The people in Rwanda who buy these systems utilize them to boost business activity, which raises the GDP and average income of the various countries.

2.2.1.3 Energy consumption theory

Power generation capacity is designed to meet peak demand in order to guarantee quality in supply. Rwanda's energy balance shows that biomass, petroleum, and hydroelectric sources account for the majority of the country's primary energy consumption, with some residents having access to electricity through the grid and others through off-grid sources. To satisfy energy consumption, increase energy efficiency, and lower energy costs, the government has improved renewable energy. Large commercial and industrial electrical users are being compelled to control the equipment to minimize energy losses and assure effective use of electrical energy (Tanasic, Jankes & Stamenic, 2014).

Rwanda is experiencing a serious electrical shortage, which is increasing energy consumption. The regional drought has severely limited its installed generation capacity, which includes hydropower, as a result of the rapid drawdown of reservoirs. In order to address this issue, the government and business sector are producing greater energy capacity to boost the sub-competitiveness region's in the energy sector. This drought has an impact on neighboring countries. The Rwandan government researches new technologies to enhance energy services in both urban and rural areas. The program focuses on off-grid technologies including solar energy and connecting rural areas to the grid (GTZ, 2007).

2.2.1.4 Environment theory

Accelerated deforestation in Rwanda results in a shortage of biomass energy and a weakening of the electricity generation and distribution system (Theuri, 2007). A large number of people used firewood at no cost to end users, which has implications for offering alternatives to promote environmental protection. The installed capacity for energy generation is rather little. According to MINIFRA (2009), a segment of the rural population lacks access to power.The government fills this gap with electricity imported from the DRC and Uganda in order to reduce deforestation and charcoal production for environmental protection and energy production, such as hydropower energy.

2.2.1.5 Gross Domestic Product (GDP)

Richer countries consume more energy per person than poorer countries, whereas poorer countries consume less. Energy consumption per capita rises in tandem with GDP per capita. Economic growth has accelerated the growth in energy demand for goods like refrigerators, air conditioners, and laundry machines. Lighting, smart appliances, and other applications will significantly reduce the energy intensity of homes. The GDP has an influence on energy use, and this relationship has been very stable. Due to their importance in the process of developing policies, the link between gross domestic product and energy consumption is of tremendous interest to policy makers (Zeshan & Ahmad, 2013).

2.2.1.6 Foreign Direct Investment (FDI)

FDI may have an impact on energy consumption through the advancement of technology and corporate productivity through the implementation of cutting-edge management approaches (Berensztien, De Gregorio & Lee, 1998). The link between foreign direct investment (FDI) and developing-country energy usage reveals that FDI growth could lower the intensity of energy consumption, FDI could change a country's economic output, but FDI could not improve the intensity of energy consumption and its environmental benefits. Cole (2006) asserts that the rate of economic expansion, the nature of the economy, and the cost of energy in various countries all have an impact on how much foreign direct investment is made there. The government should direct FDI transfers to capital- and technology-intensive industries, encourage FDI firms to adopt and share cutting-edge energy-saving technology, and properly control energy use.

2.2.1.7 Energy supply shortage theory

Due to the unpredictability of energy generation output, issues with power shortage and surplus arise in the energy system. Additional grid failures could exacerbate the effects of both power shortages and surpluses, necessitating the adoption of clean energy systems. Energy storage systems can be used to alleviate dependability issues using extra energy, but due to their high cost, their installation should be maintained to a minimum. Power surpluses may be amplified by grid outages, necessitating the formation of a fault-tolerant system of renewable energy. The impact of a power outage on supply dependability in a hybrid power system that uses renewable energy and ESSs. Several approaches have been developed to reduce power surplus issues, including combining geographical areas and connecting energy storage systems (ESSs) to a power grid (Atwa & El-Saadany, 2010).

2.2.2 Energy demand theory

According to Galli (1998), the value of energy is determined by its capacity to provide a set of required services. Particularly when combined with capital, energy makes it easier to deliver goods and services to industry and the household. The amount and type of capital equipment to buy, as well as the rate of capital use, determine energy consumption at the individual, home, and business levels. Capital type is differentiated by technological attributes including efficiency and fuel input type.

Many factors complicate demand in the long and short run, including economic progress, which causes changes in production structure, which can alter the rate at which demand grows in relation to income (Johansson & Schipper, 1997). Other factors include the development of technology, how energy costs affect the composition, effectiveness, and use of allocated capital, as well as the influence that legislation can have on demand by changing pricing. Political changes have an impact on energy demand since they stifle a nation's energy market and signal price unpredictability. The main objective in both situations is to restrain the rise of the energy demand without having a negative impact on economic wellbeing. Energy security and the environment are also discussed as part of the energy policy debate.

2.2.2.1 Energy demand in long run

At the macro level, technology and economic structure both have a significant impact on energy demand. Energy intensity, or the quantity of energy used per unit of economic production, is influenced by each of these variables. An economy's economic structure typically shifts toward a more service-oriented one as it develops. When a unit of services output takes less energy input than a unit of manufacturing output, energy strength will decline accordingly. Technology, according to Johansson and Schipper (1997), enables economic activity to increase while lowering the amount of energy needed to produce a certain level of production.

2.2.2.2 Modelling energy demand

The choice to use energy includes a number of immediate options, including the decision to invest in capital stock, the decision to select a particular form of capital stock, and the decision to select the rate of capital consumption. To attain the desired level of energy services, an investment option must be made because each choice influences the quantity of energy services needed. Thus, models that take into account dynamic investment behaviour are best suited to reflect both the short- and long-term reactions of energy demand to changes in economic variables (Diewert, 1974).

2.2.2.3 A static model of the representative firm

In most cases, it is considered that the firm's aim is to minimize costs or maximize profits for a particular level of output. Energy and other inputs are required by the business to produce its output. As a result, it is possible to demonstrate that a firm's need for energy is a function of both its production and the cost of inputs, including energy of course. Consider a hypothetical firm that seeks to maximize profits (Q) while minimizing costs (C). Q depends on money (K), work (L), energy (E), and resources (M), therefore Q = f. (K, L, E, M). are the total sum of payments made to the various production-related inputs (C = rK + wL + pE + pM), where pE stands for the price of energy, pM for the cost of raw materials, w for the wage paid to labor, and r for the rent paid to capital.

2.2.2.4 Elasticity of energy demand

The percentage change in energy demand brought on by a one percentage point increase in income is known as the income elasticity of energy demand. Numerous empirical studies have been conducted to evaluate the elasticity of income and price on energy demand. Elasticities are of particular relevance since they are dynamic when anticipating energy demand (Gately & Huntington, 2002).

$$e_y = \frac{\%\, DE}{\% DY} = \frac{\Delta E}{\Delta Y} * \frac{Y}{\mathrm{E}}$$

A large component of the empirical literature has long claimed that the income elasticity of energy demand is close to zero when E is energy demand and Y is income, which is frequently measured as GDP. However, several researchers have suggested that for developed nations, this may be much exaggerated, especially in light of studies showing an inverse relationship between energy intensity and economic growth (Galli,1998; Judson et al., 1999; Medlock &Soligo, 2001). This is crucial because any nonlinearity in income elasticity generated by economic development and structural change must be taken into account, particularly when predicting. Energy demand price elasticity is equally well-defined, with energy demand as a percentage of a 1% change in energy price.

$$e_P = \frac{\%\, DE}{\% DP} = \frac{\Delta E}{\Delta P} * \frac{P}{\mathrm{E}}$$

Where P represents the energy price, the practice is more common when modelling the demand for a specific energy source and when there is a competing energy source alternative. The own price elasticity is frequently used as an indicator of the impact of several protection policies, such as energy taxes or subsidies, for example. If an accurate estimate of price elasticity is available, it is possible to approximate the reduction in carbon emissions. A specific tax will influence some reduction in energy demand, which will lead to emission reduction.

The income and price elasticities of energy consumption typically serve as a guidance for energy policy. There is no consensus on the ideal value of income and price elasticity, according to a review of the economic literature on the subject. The researcher chooses certain model requirements for the investigation (Medlock & Soligo, 2001). It can be challenging to separate the effects of changes in technology, capital stock composition and utilization, economic structure, and energy policy, which contributes to certain specification inconsistencies. In a given country and time period, each of these variables has varied degrees of relevance and significance. In empirical investigations, the log-linear demand equation is a popular specification for energy demand. The model below depicts energy demand.

$$\ln E_t = \alpha_0 + \alpha_1 \ln Y_t + \alpha_2 \ln PE_t + \alpha_3 \ln X_t + \varepsilon_t$$

Where E is long-term demand of energy quantity, Y is the income, pE is the price of energy, X is a variable from the group of variables that may affect demand, and are the calculated coefficients. The variable X may be crucial in getting accurate estimations of the parameters. Along with other factors like weather and the cost of alternative energies, characteristics like population and capital stock may be taken into account as independent variables. The other crucial factors for determining the demand for personal energy, whose consumption is seasonal (Kenneth, 2009).

2.3 Empirical literature

Practical studies have been directed in numerous nations, with the first energy shock occurring in 1973 as a notable reference. The methodologies and findings of these research have varied depending on the unique characteristics of each nation. With the exception of being criticized by Akarca and Long (1980) due to the unstable nature of the analysis period, Kraft and Kraft's (1978) major empirical studies of the causal relationship between energy demand and supply in the United States during the period (1947–1974) showed a unidirectional causal relationship between energy supply and demand. As a result, many strategies have been created to better comprehend the connection between energy supply and consumption.

Some researchers used the correlation approach, while others used the causality approach, and occasionally both, when analyzing the causal relationship between energy demand and supply from the causal test of Engle et al. (1988), which revealed a long-term relationship between energy demand and supply for developing and developed countries. A analysis of several articles pertaining to Asian countries revealed a long-term relationship between energy demand and supply in the circumstances of India, Pakistan, and Indonesia using the methodology recommended by Johansen, Masih, and Masih (1996). The growth of an electrical supply in developed nations based on renewable energy is correlated with the amount of power used, according to studies by Ferguson, Wilkinson, and Hill (Hill 2000).

Other research, however, have concentrated on identifying the relevance of causality between power supply and consumption because correlation does not always imply causation (Ghosh, 2002; Shiu & Lam, 2004).

3. METHODOLOGY

The techniques and tools used to gather and assess information on Rwanda's energy supply gap and renewable energy sources are described in this section. Theoretical underpinnings, an empirical model, data gathering techniques, and data analysis techniques are all covered.

3.1. Empirical specification and variables choice

According to this study's literature review, the key factors impacting Rwanda's energy demand are GDP, availability to power, price, and foreign direct investment. As a result, Rwanda's energy demand equation is very consistent with estimates from various empirical researches. This is what it says:

CE = *f* (GDP, ACCEL, P, FDI) (1)

Where:

CE: The entire amount of ending energy consumed by all sectors locally, measured in (ktoe: Kilotonne of Oil Equivalent, an unit that quantifies the amount of energy produced) (industries, residences, etc.),

GDP stands for Gross Domestic Product (measured in billions of dollars), ACCEL: Access to electricity (as a percentage of the population), FDI: Foreign Direct Investment

P: Electricity cost expressed in (Meg Watt hour)

The logarithmic transformation of variables that compress numbers is used to prevent heteroskedasticity issues in statistical analysis, producing the most accurate empirical findings and best estimations. After a logarithmic transformation, the model is represented by the following equation:

$Ln\ CE = \alpha + \beta 1\ Ln\ GDP + \sigma 1\ Ln\ ACCEL + \varphi 1\ Ln\ DFI + ʄ\ Ln\ P + \varepsilon$ (2)

Where:

ε: is the disturbance, (β, σ, φ, ʄ): Elasticities, in turn, are the long-term values for GDP, ACCEL, DFI, and P.

The following model shows how some energy demand variables are the same as renewable energy demand variables.

Renewable energy generation capacity (REGC), gross domestic product (GDP), energy per person EPC, foreign direct investment (FDI), and electricity access are the factors influencing Rwanda's renewable energy demand and energy supply deficit (ACCEL). The model that represents these variables is shown below.

$$LnESD = \alpha_0 + \alpha_1 LnGDP + \alpha_2 LnREGC + \alpha_3 LnACCEL + \alpha_4 LnEPC + \alpha_5 LnFDI + \varepsilon \quad (3)$$

Where:

ESD: Energy Supply Deficit

GDP: Gross domestic Product

REGC: Renewable Electricity Generation Capacity (watt-hour)

ACCEL: Access to Electricity

EPC: Energy per Capita

FDI: Foreign Direct Investment

ε : Error term

3.2 Data collection

The data ranges from 1990 to 2021. Due to data availability, the study period was constrained. Our key figures sources are data on power access from the International Energy Agency (Annual Report, 2018). This study incorporates data from the World Bank's annual report 2019 for renewable energy use, energy pricing, and other variables. Using the aforementioned model, this study examined the connection between renewable energy and Rwanda's energy supply deficit.

3.3 Unit Root Tests

A times series must be tested for the presence of a unit root in order to ascertain its stationarity. The non-stationary nature of time series is to blame for this. The results of econometric study that uses non-stationary data are frequently wrong. The log-linearized time series (GDP, ACCEL, P, and FDI) were tested for stationary behavior using the Philip Phillips-Peron (PP) and Augmented Dickey-Fuller (ADF) unit root tests.

3.4 Johansen Cointegration Test

In this study, the Johansen Cointegration test was frequently used (Johansen, 1991). It is used to establish the existence of a long-term relationship between the explanatory and explained variables.

3.5 Estimation of the model

ARDL estimations is utilized in technique for estimating model parameters, for linear regression, the autoregressive distributed lag model estimate the model parameters α_o and $\alpha_1, \alpha_2 \ldots\ldots \alpha_7$ are noted by b0 and b1. Using these estimate an estimated regression equation is $\hat{y} = b_0 + b_1 x$

4. RESULTS AND DISCUSSIONS

This section contains a study that uses the autoregressive distributed lag model and reveals the causal relationship between the renewable energy and the energy supply deficit.

4.1 Test for total energy consumption and energy demand

4.1.1 Correlation matrix

The correlation coefficients between various variables are displayed in the correlation matrix below. One method for quantifying this link is to use the Pearson coefficient, which evaluates the linear correlation between two variables. It ranges from -1 to 1, with 1 denoting a wholly adverse linear correlation between two variables. Zero or 0 is equivalent to the linear correlation of two variables. The perfect positive linear correlation between two variables is represented by a score of one.

Table 1: Correlation matrix for model one

	LNFDI	LNACCEL	LNGDP	LNP
LNFDI	1	0.7795604546	0.8651387334	-0.3718588231
LNACCEL	0.7795604546	1	0.6008868238	-0.5917738148
LNGDP	0.8651387334	0.6008868238	1	-0.4093336904
LNP	-0.3718588231	-0.5917738148	-0.4093336904	1

Each table cell displays the correlation between two specific variables. For instance, the higher correlation cell above reveals that "foreign direct investment" and "gross domestic product" have a correlation of (0.86), demonstrating a favorable link between the two factors. According to the lower correlation cell above, the correlation between GDP and foreign direct investment is -0.59, showing a substantially unfavorable association between the two variables. Because each variable has a complete association with itself, the correlation coefficients along the diagonal of the table are all equal to 1.

4.1.2 Descriptive statistics

The mean, median, minimum, and maximum measures of central tendency must be determined before performing regression analysis. In order to assess if a data set is accurately described by a normal distribution and to calculate the probability that a random variable underlying the data set is normally distributed, normality tests are utilized. Normative tests Jarque-Bera to determine if the data was evenly distributed, the model was put to the test. The data is normal if the Jarque-Bera test value is greater than 0.05. The data considerably departs from a normal distribution if it is less than 0.05.

Table 2: Descriptive statistics

	LNTEC	LNGDP	LNP	LNFDI	LNACCEL
Mean	3.888531	7555.594	0.426469	123898.5	13.40941
Median	3.413000	3692.500	0.426000	44521.00	7.960000
Maximum	7.119000	91927.00	0.714000	898792.0	48.92000
Minimum	2.632000	1293.000	0.240000	1000.000	0.980000
Std. Dev.	1.220286	15703.77	0.096173	182385.8	14.14229
Skewness	1.165881	5.060508	0.462768	2.567875	1.269606
Kurtosis	3.302303	27.75365	4.025446	11.14984	3.411336
Jarque-Bera	7.371338	953.5708	2.544209	123.7278	8.822391
Probability	0.025080	0.000000	0.280241	0.000000	0.012141

As a measure of the asymmetry of the series distribution around its mean in this conclusion, skewness is used. A symmetric distribution like the normal distribution lacks skewness. While negative skewness indicates a long left tail in the distribution, positive skewness indicates a long right tail the series distribution's kurtosis affects whether it is flat or peaks. As a result, kurtosis is determined: The normal distribution's kurtosis is 3. If the kurtosis is greater than three, the distribution is peaked relative to the normal; if it is less than three, the distribution is flat relative to the normal.

Because 3.30>3, the right tail of TEC is leptokurtic and lengthy (positive skewness).

Because 27.70>3, GDP's right tail is lengthy (positive skewness) and leptokurtic.

Because 11.04>3, the right tail of FDI is lengthy (positive skewness) and leptokurtic.

P is leptokurtic (since 4.02>3) and has a long right tail, while ACCEL has a positive skewness with a long right tail (positive Skewness).

Jarque-Bera contrasts the skewness and kurtisis of the series with those of the normal distribution. A low probability value results in the rejection of the null hypothesis for the normal distribution when it comes to the likelihood that a Jarque-Bera statistic surpasses (in absolute value) the observed value under the null hypothesis.

In accordance with the aforementioned table, the probabilities of total energy consumption, GDP, foreign direct investment, and access to electricity are (0.02), (0.00), (0.00), and (0.01), respectively, which is less than 5% of the level of significance. For all variables, the null hypothesis is rejected since the probability value is very statistically significant. Given that the likelihood of price is 0.28>0.05, the null hypothesis cannot be disproved.

4.1.3 Unit root test

Unit root testing provides more information on how to do unit root tests in E-Views 10, as well as a discussion of stationary and non-stationary time series. The unit root was investigated using the ADF test and stationary nature of variables, and those determined to be non-stationary were differenced to remove the stochastic trend, a phenomena associated with time series data.

Table 3: Summary for stationarity test

Variables	ADFs	Critical value at 5% level of significance	Probability	Null hypothesis
D(LNACCEL,2)	-12.98991	-2.971853	0.0000	Rejected
D(LNGDP,2)	-1.785688	-2.967767	0.3798	Accepted
D(LNFDI)	-3.173936	-3.004861	0.0028	Rejected
D(LNTEC,2)	-3.557164	-2.963971	0.0131	Rejected
D(INP)	-7.052987	-2.963972	0.0000	Rejected

The access to electricity data series at the level and first difference is non-stationary, according to the unit root result from the table above, but stationary at the second difference because the probability of having access to electricity is below than 5% threshold of significance, hence the null hypothesis is rejected. Since gross domestic product series at the level is non-stationary, first and second difference even if trend and intercept are employed and it cannot be refuted because the null hypothesis' p-value is greater than 0.05. Foreign direct investment is stationary at the first difference, trend, and intercept, with a p-value of 0.000<05 so, null hypothesis is reject.

Finally, the series data for total energy consumption at level are non-stationary even though At the initial difference, the series data remain stationary since p-value of 0.01 is less than 5%. Price is stationary at the starting difference and intercept, but has a probability of 0.00, less than 0.05.

4.1.4 Regression analysis

A series of statistical methods known as regression analysis are used to determine correlations between one or more independent variables and a dependent variable in order to predict how those variables will interact in the future. When many quantities change over time, A vector autoregressive model is used to capture their relationship. The equation below represents the VAR model

$$\gamma_{1t} = \beta_{01} + \beta_{11}\chi_{1t-1} + \beta_{12}\chi_{2t-2} + \ldots\beta_{1n}\chi_{nt-n} + \varepsilon_{1t}$$

$$\gamma_{2t} = \beta_{02} + \beta_{21}\chi_{2t-1} + \beta_{22}\chi_{2t-2} + \ldots\beta_{2n}\chi_{nt-n} + \varepsilon_{2t}$$

A multi-variety kind of regression for time series, the vector autoregressive model is an extension of the (AR) and is used to examine the impact of previous data on present data.

Table 4: Regression analysis

Variable	Coefficient	Std. Error	t-Statistic	Prob.*
LNTEC(-1)	0.766252	0.101763	7.529737	0.0000
LNGDP	0.862105	0.512106	1.671519	0.0217
LNP	0.477807	0.871374	1.695950	0.1040
LNFDI	-0.712107	-1.450107	1.038565	0.3103
LNFDI(-1)	0.561006	6.653107	2.349188	0.0282
LNFDI(-2)	0.211106	0.174007	1.349226	0.0110
LNACCEL	0.048341	0.012474	4.668681	0.0407
C	20.04239	0.341268	0.124210	0.0023

R-squared	0.981212	Mean dependent var	3.917533
Adjusted R-squared	0.975234	S.D. dependent var	1.256009
S.E. of regression	0.197659	Akaike info criterion	-0.181365
Sum squared resid	0.859523	Schwarz criterion	0.192288
Log likelihood	10.72048	Hannan-Quinn criter.	-0.061830
F-statistic	164.1398	Durbin-Watson stat	2.027728
Prob(F-statistic)	0.000000		

*Note: p-values and any subsequent tests do not account for model selection.

Goodness-of-fit metric for a linear regression model is R-squared. The percentage difference between independent and dependent variables is displayed by this statistic. In this model's R-square of 0.98 indicates that pricing, foreign direct investment, access to electricity, and 98% of the variation in total energy use is accounted for by gross domestic product.

The Durbin-Watson test has a range of 0 to 4, with a value of 2 denoting no autocorrelation, a value of less than 2, and a value of more than 2, denoting negative autocorrelation. The DW in the aforementioned model is 2.0, demonstrating no autocorrelation in the model.

The regression model's variables are given a significance level using the F-statistic, and since this model's F-statistic is 164.1398 as well as the null hypothesis would be refuted if the p-value was less than 0.05 as 0.00. Price, FDI, access to power, and GDP all have statistically significant relationships with Rwanda's overall energy use.

4.1.5 ARDL Long Run Form and Bound Test

Johansen (1995) investigated the Cointegration property for time series data and discovered that there might be a variables have a long-term relationship with one another. For both t- and F-statistics, the bound test confirms the existence of long-term relationships, as seen in the table below. The linked bounds testing strategy for the three variables can be substituted with other Cointegration tests.

Table 5: ARDL Long Run Form and Bound Test

Restricted Constant and No Trend

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LNGDP	0.941205	3.452205	2.304661	0.0310
LNP	0.322229	3.145796	2.029739	0.0569
LNFDI	0.053206	0.022106	2.506370	0.0494
LNACCEL	0.035684	0.014738	3.797614	0.0336
C	86.18145	1.476339	0.122834	0.0034

LNTEC = 0.94*LNGDP + 0.3222*LNP + 0.05*LNFDI + 0.0357
*LNACCEL +86.18

F-Bounds Test — Null Hypothesis: No levels relationship

Test Statistic	Value	Signif.	I(0)	I(1)
			Asymptotic: n=1000	
F-statistic	6.282017	10%	2.2	3.09
k	4	5%	2.56	3.49
		2.5%	2.88	3.87
		1%	3.29	4.37
			Finite Sample: n=30	
Actual Sample Size	30			
		10%	2.525	3.56
		5%	3.058	4.223
		1%	4.28	5.84

The ARDL Long Run Form and Bound Test were displayed in table above to demonstrate the significance of the factors. For figuring out whether a variable and its dependent variable have long-term associations, the F-statistic is essential. The F-statistic for this model, which is 6.282017, has a significance level greater than 5% upper level bound of 3.49, showing the long-term existence term link. Similar to this, the lower level bound F-statistic of 2.56 has a higher F-statistic, demonstrating a long-term existence of link.

The long-term relationship results demonstrate that total energy consumption has a long-term relationship with gross domestic product (0.0310), as well as a long-term association with foreign direct investment (0.0494). While there is a long-term relationship between total energy use and access to electricity, the probability of this correlation (0.0336) is less than 0.05, indicating that this p-value is significant. Similarly, the p-value of (0.0569) for the price is equal to 0.05, indicating that this value is equally significant. The cost of power is not a huge burden in Rwanda because the government provides subsidies to its inhabitants.

For the above result, the t-statistic of GDP, price, FDI, and access to electricity shows that those variables are significance because the values of t-start (2.30), (2.02), (2.5), and (3.7) respectively are greater than 2. If t-start in absolute form is two or above two, the variable is significance or insignificance below two. Finally, we can examine the coefficients' long-term effects.

In long run, total energy consumption will increase by (0.94) for every 1% increase in GDP. When the price goes up by 1%, total energy consumption goes up by 0.32, whereas if foreign direct investment goes up by 1%, total energy consumption goes up by 0.05 over time, and if access to electricity changes by 1%, total energy goes up by 0.03 over time.

Numerous factors, such as economic development itself changing the production structure and altering how demand rises relative to income, complicate demand in the long run and short term (Johansson & Schipper, 1997). In addition, there are additional aspects to consider, including the impact that prices of energy have arrangement, effectiveness and usage of organized investment as well as the impact that policy can have on demand by altering costs. The political change has an effect to energy demand as factor which is disturbing the market of energy supply of a country and hints the price fluctuation. In addition, energy security and environment are the forecast of energy policy debate, in both cases trying to limit energy demand growth without harm to economic welfare as key goal.

4.2 Test for renewable energy and Energy supply deficit

4.2.1 Correlation matrix

This part of correlation shows the relationship between the capacity of renewable energy production, the GDP, energy consumption per person, foreign direct investment, and access to electricity.

Table 6: Correlation matrix

	LNREGC	LNGDP	LNEPC	LNFDI	LNACCEL
LNREGC	1	0.464593	-0.13541	0.68141	0.74408
LNGDP	0.464593	1	-0.63138	0.87107	0.58132
LNEPC	-0.13541	-0.63138	1	-0.53132	-0.26758
LNFDI	0.68141	0.87107	-0.53132	1	0.76674
LNACCEL	0.74408	0.58132	-0.26758	0.76674	1

The results of the research show that the correlation between GDP and renewable energy generation capacity is (0.46), showing a poor relationship between the two variables. Correlation is a measure of how closely two variables are related.

GDP has a negative association with energy per person (-0.63), renewable energy generation capacity has a negative correlation with energy per person (-0.13), and foreign direct investment has a positive correlation with renewable energy generation capacity (0.68141).

The correlation between GDP and energy per person is (-0.63), the correlation between renewable energy generation capacity and energy per person is (-0.13), and the relationship between FDI and REGC is (0.68141) there is positive correlation between variables.

Energy per person has a weakly negative connection (-0.26) with access to electricity, However, given that the value of access to power is higher than that of renewable energy producing capability, there is a strong positive connection between (0.74).

4.2.2 Descriptive statistics

In order to assess if a data set is accurately described by a normal distribution and to calculate the probability that a random variable underlying the data set is normally distributed, normality tests are utilized.

Table 7: Descriptive statistics

	LNESD	LNACCEL	LNEPC	LNFDI	LNGDP	LNREGC
Mean	2.328500	13.47612	412.2985	1.22E+08	7.34E+09	5.805625
Median	2.243000	7.964370	430.3050	24571983	3.13E+09	4.835000
Maximum	10.18100	46.60000	587.9420	8.99E+08	9.19E+10	11.20000
Minimum	-14.25000	0.987390	5.150000	1000.000	7.54E+08	2.110000
Std. Dev.	5.403625	13.91620	118.1906	1.83E+08	1.57E+10	2.662942
Skewness	-0.924437	1.192306	-1.106557	2.552009	5.054655	1.032994
Kurtosis	4.204897	3.195226	5.384847	11.04041	27.70716	2.610055
Jarque-Bera	6.493480	7.632652	14.11382	120.9323	950.1895	5.893823
Probability	0.038901	0.022009	0.000861	0.000000	0.000000	0.052502

Table 7 shows the descriptive statistics for the dependent variable energy supply deficit and the independent variables access to electricity, energy per person, foreign direct investment, GDP, and renewable energy generation capacity.

According to the table above, the maximum value of the energy supply deficit is (10.18), the minimum value is (-14.25), and the average value is (2.32).

According to the descriptive statistics, the minimum value of electrical access is (0.98), the maximum value is (46.60), and the mean value is (13.47).

Table 4 shows that the energy per person has a minimum value of (5.15), a maximum value of (587.94), and a mean value of (412.29). The gross domestic product has a minimum value of (7.54) and a maximum value of (9.19) based on the results of the description, with a mean value of (7.24).

According to Table 4, the least value for renewable energy generating capacity is (2.11), the highest value is (11.29), and the mean value is 5.80. Because their p-values are less than 5%, the results show that all variables are statistically significant. The Jarque-Bera probability are (0.03), (0.02), (0.00), (0.00), (0.00), and (0.05) in Table 4. These probabilities show that the null hypothesis is rejected because the significance level is set at p = 0.05. The data are therefore significantly outside of the usual distribution.

4.2.3 Unit root test

The results of unit root test for the levels and differences series are reported in the tables below. Because the ADF statistic's absolute value only initially exceeded the crucial value, the result indicates that all variables were non-stationary. Furthermore, the results in the tables reveal that the majority of the variables became non-stationary after then.

Table 8: Stationary test for renewable energy and energy supply deficit

Variables	ADFs	Critical value at 5% level of significance	Probability	Null hypothesis
D(LNACCEL,2)	-12.78339	-2.971853	0.0000	Rejected
D(LNEPC)	-1.322599	-2.967767	0.6053	Accepted
D(LNESD)	-3.684167	-3.562882	0.0387	Rejected
D(LNFDI)	-5.012654	-3.622033	0.0028	Rejected
D(LNGDP,2)	-1.785688	-2.967767	0.3798	Accepted
D(LNREGC)	-5.668066	-2.963972	0.0001	Rejected
D(INP)	-7.052987	-2.963972	0.0000	Rejected

We reject the null hypothesis because the probability of gaining access to electricity is less than 5%, the result from the table above shows the unit root, and the data series for access to electricity are series stationary at second difference. At the level of all differences, energy per person is non-stationary, and we cannot reject the null hypothesis because its p-value is greater than 0.05. Even with trend and intercept, the gross domestic product series is non-stationary at the level, first and second difference, and the null hypothesis is accepted since its p-value is greater than 0.05. With a p-value of 0.00<05, foreign direct investment is stationary at the initial difference, trend, and intercept, rejecting the null hypothesis. The series data for renewable energy generation capacity are stationary at level, trend, and intercept, and the p-value is less than 0.05, rejecting the null hypothesis.

4.2.4 Johansen Co-integration Test results

To ascertain the variables' long-term equilibrium relationship, co-integration testing is carried out. Table 9 displays the outcomes of the co-integration test. Trace Statistic and Max-Eigen Statistic are two statistics included in the Eviews output. An asterisk (*) denotes the rejection of the null hypothesis. If the probability value is 0.05 or below, the null hypothesis is likewise rejected.

Table 9: Cointegration Rank Test Trace and Max-Eigen value

Unrestricted Cointegration Rank Test (Trace)

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.**
None *	0.914763	235.1805	95.75366	0.0000
At most 1 *	0.877777	163.7732	69.81889	0.0000
At most 2 *	0.782626	102.8180	47.85613	0.0000
At most 3 *	0.767619	58.56000	29.79707	0.0000
At most 4 *	0.313718	16.23805	15.49471	0.0386
At most 5 *	0.167620	5.320529	3.841466	0.0211

Trace test indicates 6 cointegrating eqn(s) at the 0.05 level
* denotes rejection of the hypothesis at the 0.05 level
**MacKinnon-Haug-Michelis (1999) p-values

Unrestricted Cointegration Rank Test (Maximum Eigenvalue)

Hypothesized No. of CE(s)	Eigenvalue	Max-Eigen Statistic	0.05 Critical Value	Prob.**
None *	0.914763	71.40731	40.07757	0.0000
At most 1 *	0.877777	60.95524	33.87687	0.0000
At most 2 *	0.782626	44.25796	27.58434	0.0002
At most 3 *	0.767619	42.32195	21.13162	0.0000
At most 4	0.313718	10.91752	14.26460	0.1584
At most 5 *	0.167620	5.320529	3.841466	0.0211

Max-eigenvalue test indicates 4 cointegrating eqn(s) at the 0.05 level

* denotes rejection of the hypothesis at the 0.05 level
**MacKinnon-Haug-Michelis (1999) p-values

Level form of variables should be used for the Cointegration test, not their first difference. Raw variables are also transformed using the logarithm. If the Trace and Max statistics have values more than the 5% critical threshold, the null hypothesis is rejected; otherwise, it is not.

Max-Eigen had found two co-integrating relationships at the 5% significant level, as can be seen in table 9. It is proposed that these six variables share a long-term trajectory and are connected by long-term equilibrium relationships.

Table 10: ARDR long run form and bounds test

Restricted Constant and No Trend

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LNEPC	0.668963	0.104149	6.662161	0.0167
LNACCEL	0.844441	0.463145	2.692580	0.0379
LNFDI	-0.282408	0.937507	-0.428855	0.6734
LNGDP	0.503298	0.321108	2.206280	0.0498
LNREGC	0.076847	0.029087	3.508661	0.0079
C	49.21385	26.19094	0.645928	0.5269

LNESD = 0.668*LNEPC +0.844*LNACCEL -0.282*LNFDI + 0.503
*LNGDP + 0.076*LNREGC +49.213

F-Bounds Test			Null Hypothesis: No levels relationship	
Test Statistic	Value	Signif.	I(0)	I(1)
			Asymptotic: n=1000	
F-statistic	20.64623	10%	2.08	3
k	5	5%	2.39	3.38
		2.5%	2.7	3.73
		1%	3.06	4.15
Actual Sample Size	30		Finite Sample: n=30	
		10%	2.407	3.517
		5%	2.91	4.193
		1%	4.134	5.761

According to table 5, Long Run and Bound Test results for the ARDL model in above table show that there is long-term linkage between energy per person and the deficit in energy supply because the probability is 0.01< 0.05 that if energy per person changes by one unit percent, the energy supply increases by 0.66 while all other variables remain constant. Access to power and the shortfall in the energy supply are linked over time, as evidenced by the p-value of 0.010<05.

Because a change in one unit percent of FDI results in a -0.28 decrease in energy supply deficit, if the likelihood of FDI is 0.06 or higher and the energy supply imbalance is present, there is no long-term relationship between the two. The p-value of 0.040<05 suggests that there is a long-term association between the gross domestic product and the lack of energy supplies. The outcomes demonstrated that there is a long-term link between REGC and ESD in Rwanda, with a probability of (0.00), which is less than 0.05.

F-statistic is most useful in determining whether or not a variable has an ongoing connection to the dependent variable. F-statistic for this model is 20.64623, which is more significant at the 5% level than the upper bound of 3.38, and lower bound of 2.39, showing that variables have a long term connection. In Rwanda in particular, renewable energy is essential for assisting rural areas since it increases energy supply, decreases reliance on imported fuels, and encourages employment in manufacturing and economic growth.

The findings indicated that renewable energy has a long-term relationship with Rwanda's energy supply deficit and total energy consumption. When energy supply is insufficient to meet energy demand, renewable energy is the solution, and it has the potential to meet demand while protecting the environment. It leads infrastructural development in terms of job creation and unemployment rate as a result of rural and urban electricity access.

Olz (2011) asserts that as renewable energy technologies have much lower CO_2 emissions than fossil fuels, they could reduce carbon dioxide emissions by displacing fossil fuels in the power production industry. In order to lower energy unit costs and make clean energy sources a competitive alternative to conventional energy sources due to the negative externalities associated with the production of conventional energy, it is essential to support renewable energy supply technologies and increase the power produced by clean energy sources.

5. CONCLUSION AND RECOMMENDATION

The goal of the study was to determine how a shortage in the energy supply would be affected by renewable energy. In order to lower energy unit costs and make clean energy sources a competitive alternative to conventional energy sources, it is essential to promote renewable energy supply technologies. Clean energy sources need also have their power output improved. A variety of factors influence demand for renewable energy, including technological innovation, energy price, efficiency, and judicious use of available funds, not to mention the impact that policy can have on demand by changing pricing. Political change has an impact on energy demand since it disturbs a country's energy supply market and predicts price unpredictability. At the macro level, technology and economic structure both have a significant impact on energy demand. Energy intensity, or the quantity of energy used per unit of economic production, is influenced by each of these variables. Renewable energy has the capacity to meet demand while also safeguarding the environment. It drives infrastructure development by increasing employment and lowering the unemployment rate as a result of the availability of energy in both rural areas and urban. According to the study, renewable energy is essential for filling the gap in energy supply that needs to be bridged in order to fulfill demand. According to this study, in order to increase the value of environmental goods and services, the government should promote the effective use of renewable energy sources. Production of renewable energy aids in closing the energy deficit and cutting greenhouse gas emissions from fossil fuels.

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Appendices

Appendix 1: Data for model one

YEARS	TEC	GDP	FDI	ACCEL
1990	3.521	2550185618	7660000	0.9873875
1991	3.386	1911600970	4580000	1.165
1992	3.603	2029026704	5500000	2.3
1993	3.298	1971525999	5839999.9	3.5611031
1994	3.371	753636370.5	1000	2.11105211
1995	3.432	1293535011	2000000	1.431211021
1996	3.394	1382334879	2220000	1.125600021
1997	3.441	1851558302	2589999.9	1.027835965
1998	3.942	1989343495	7099999.9	2.174127579
1999	3.385	2155659413	1740000	3.31557703
2000	2.902	2067528500	8099999.9	6.199999809
2001	2.854	1965444515	18500000	4.57231617
2002	2.918	1964779921	1500000	5.93285799
2003	2.904	2137093489	4700000	7.288164616
2004	2.799	2375281627	7700000	8.640584946
2005	2.715	2932213575	7960000	4.800000191
2006	2.632	3317951468	30643966.4	11.34622574
2007	2.692	4068065929	82283165.8	12.70450306
2008	2.832	5177015141	102289999.9	6
2009	2.984	5671332138	118670000	15.44546127
2010	3.35	6121234529	216192556.8	9.699999809
2011	3.724	6881038270	112127535.8	10.80000019
2012	4.085	7650300320	269615550.4	17.5
2013	4.355	7815599503	233763793.6	15.19999981
2014	4.587	8241332517	313997162.8	19.79999924
2015	5.079	8539048448	162083821	22.79999924
2016	5.279	8690485823	279747327.6	29.37000084
2017	5.459	9253098954	274025990.7	34.09999847
2018	5.678	9640280084	366192315.5	36.96815109
2019	6.308	10355974217	263172335.2	40.36860657
2020	6.405	10333991456	99915133.32	46.59999847
2021	7.119	91927038022	898792325.6	48.92347022

Appendix 2: Data for model two

YEARS	CEC(ESD)	REGC	ACCEL	GDP	EPC
1990	4.604	2.11	0.98739	2550185618	483.129
1991	1.823	3.67	1.165	1911600970	506.167
1992	0.478	4.18	2.3	2029026704	537.55
1993	-8.459	3.63	3.5611	1971525999	526.527
1994	2.226	4.87	2.11105	753636370.5	567.945
1995	1.781	3.22	1.43121	1293535011	587.942
1996	-1.084	3.91	1.1256	1382334879	564.489
1997	1.372	3.23	1.02784	1851558302	535.977
1998	1.489	4.03	2.17413	1989343495	501.546
1999	-3.079	4.12	3.31558	2155659413	451.209
2000	-14.25	5.18	6.2	2067528500	365.81
2001	-1.655	4.99	4.57232	1965444515	346.755
2002	2.243	4.88	5.93286	1964779921	346.29
2003	-0.482	4.8	7.28816	2137093489	339.382
2004	-3.633	4.74	8.64058	2375281627	322.403
2005	-3.006	4.65	4.8	2932213575	307.063
2006	-3.022	4.51	11.3462	3317951468	291.095
2007	2.243	4.44	12.7045	4068065929	290.231
2008	5.223	4.32	6	5177015141	297.35
2009	5.35	4.23	15.4455	5671332138	304.988
2010	9.271	5.05	9.7	6121234529	333.673
2011	10.181	5.48	10.8	6881038270	361.837
2012	9.692	5.48	17.5	7650300320	387.261
2013	6.099	5.73	15.2	7815599503	400.929
2014	5.83	6.96	19.8	8241332517	413.887
2015	8.713	9.6	22.8	8539048448	446.723
2016	3.937	10.14	29.37	8690485823	452.381
2017	3.415	10.59	34.1	9253098954	455.64
2018	4.012	10.61	36.9682	9640280084	461.556
2019	9.09	11.2	40.3686	10355974217	499.546
2020	7.213	10.92	46.6	10333991456	501.121
2021	6.897	10.31	45.9	91927038022	5.15

Sources: Our World in data, 2020; World Bank data, 2021**;** International Energy Agency, 2018

Appendix 3: Information from the result on model one

Dependent Variable: LNTEC
Method: ARDL
Date: 11/15/22 Time: 07:29
Sample (adjusted): 1992 2021
Included observations: 30 after adjustments
Maximum dependent lags: 2 (Automatic selection)
Model selection method: Akaike info criterion (AIC)
Dynamic regressors (2 lags, automatic): LNGDP LNP LNFDI LNACCEL
Fixed regressors: C
Number of models evalulated: 162
Selected Model: ARDL(1, 0, 0, 2, 0)

Variable	Coefficient	Std. Error	t-Statistic	Prob.*
LNTEC(-1)	0.766252	0.101763	7.529737	0.0000
LNGDP	1.86E-05	7.51E-06	2.471519	0.0217
LNP	1.477807	0.871374	1.695950	0.1040
LNFDI	-0.74E-07	7.45E-07	-1.038565	0.3103
LNFDI(-1)	1.56E-06	6.65E-07	2.349188	0.0282
LNFDI(-2)	1.21E-06	8.97E-07	1.349226	0.1910
LNACCEL	0.008341	0.012474	0.668681	0.5107
C	12.04389	9.341268	1.324210	0.0023

R-squared	0.981212	Mean dependent var	3.917533
Adjusted R-squared	0.975234	S.D. dependent var	1.256009
S.E. of regression	0.197659	Akaike info criterion	-0.181365
Sum squared resid	0.859523	Schwarz criterion	0.192288
Log likelihood	10.72048	Hannan-Quinn criter.	-0.061830
F-statistic	164.1398	Durbin-Watson stat	2.207728
Prob(F-statistic)	0.000000		

*Note: p-values and any subsequent tests do not account for model selection.

ARDL Long Run Form and Bounds Test
Dependent Variable: D(LNTEC)
Selected Model: ARDL(1, 0, 0, 2, 0)
Case 2: Restricted Constant and No Trend
Date: 11/15/22 Time: 07:32
Sample: 1990 2021
Included observations: 30

Conditional Error Correction Regression

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-0.042389	0.341268	-0.124210	0.9023
LNTEC(-1)*	-0.233748	0.101763	-2.296972	0.0315
LNGDP**	1.86E-05	7.51E-06	2.471519	0.0217
LNP**	1.477807	0.871374	1.695950	0.1040
LNFDI(-1)	2.00E-06	9.60E-07	2.082757	0.0491
LNACCEL**	0.008341	0.012474	0.668681	0.5107

D(LNFDI)	-7.74E-07	7.45E-07	-1.038565	0.3103
D(LNFDI(-1))	-1.21E-06	8.97E-07	-1.349226	0.1910

* p-value incompatible with t-Bounds distribution.
** Variable interpreted as Z = Z(-1) + D(Z).

Levels Equation
Case 2: Restricted Constant and No Trend

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LNGDP	0.941205	3.452205	2.304661	0.0310
LNP	0.322229	3.145796	2.029739	0.0569
LNFDI	0.053206	0.027106	2.506370	0.0494
LNACCEL	0.035684	0.014738	3.797614	0.0336
C	86.18145	1.476339	0.122834	0.0034

LNTEC = 0.94*LNGDP + 0.3222*LNP + 0.05*LNFDI + 0.0357
*LNACCEL +86.18

F-Bounds Test		Null Hypothesis: No levels relationship		
Test Statistic	Value	Signif.	I(0)	I(1)
			Asymptotic: n=1000	
F-statistic	6.282017	10%	2.2	3.09
k	4	5%	2.56	3.49
		2.5%	2.88	3.87
		1%	3.29	4.37
			Finite Sample:	
Actual Sample Size	30		n=30	
		10%	2.525	3.56
		5%	3.058	4.223
		1%	4.28	5.84

Appendix 4: Information from the result on model two

Dependent Variable: LNESD
Method: ARDL
Date: 11/15/22 Time: 12:45
Sample (adjusted): 1992 2021
Included observations: 30 after adjustments
Maximum dependent lags: 2 (Automatic selection)
Model selection method: Akaike info criterion (AIC)
Dynamic regressors (2 lags, automatic): LNEPC LNACCEL LNFDI LNGDP LNREGC
Fixed regressors: C
Number of models evalulated: 486
Selected Model: ARDL(1, 2, 0, 2, 0, 2)

Variable	Coefficient	Std. Error	t-Statistic	Prob.*
LNESD(-1)	0.866188	0.169245	5.117967	0.0001
LNEPC	0.209728	0.022787	9.203700	0.0000
LNEPC(-1)	-0.385329	0.048624	-7.924650	0.0000
LNEPC(-2)	0.184829	0.031514	5.865043	0.0000
LNACCEL	-0.246808	0.149252	-1.653636	0.1165
LNFDI	-1.55E-08	6.18E-09	-2.500947	0.0229
LNFDI(-1)	-1.30E-08	9.00E-09	-1.440955	0.1678
LNFDI(-2)	1.73E-08	1.06E-08	1.634048	0.1206
LNGDP	1.34E-09	1.43E-10	9.353914	0.0000
LNREGC	-1.319863	0.614494	-2.147885	0.0464
LNREGC(-1)	0.073718	0.664714	0.110902	0.9130
LNREGC(-2)	1.657863	0.572765	2.894492	0.0101
C	-6.585392	2.735050	-2.407777	0.0277

R-squared	0.942387	Mean dependent var	8.269500
Adjusted R-squared	0.901718	S.D. dependent var	5.569734
S.E. of regression	1.746106	Akaike info criterion	4.251337
Sum squared resid	51.83109	Schwarz criterion	4.858522
Log likelihood	-50.77005	Hannan-Quinn criter.	4.445580
F-statistic	23.17252	Durbin-Watson stat	1.179358
Prob(F-statistic)	0.000000		

*Note: p-values and any subsequent tests do not account for model selection.

ARDL Long Run Form and Bounds Test
Dependent Variable: D(LNESD)
Selected Model: ARDL(1, 2, 0, 2, 0, 2)
Case 2: Restricted Constant and No Trend
Date: 11/15/22 Time: 12:48
Sample: 1990 2021
Included observations: 30

Conditional Error Correction Regression

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	6.585392	2.735050	2.407777	0.0277
LNESD(-1)*	-0.133812	0.169245	-0.790641	0.4400
LNEPC(-1)	0.009228	0.004771	2.534189	0.0599
LNACCEL**	-0.246808	0.149252	-1.653636	0.1165
LNFDI(-1)	-1.110108	1.440008	-0.767283	0.4534
LNGDP**	0.349909	1.432110	9.353914	0.0000
LNREGC(-1)	0.411718	0.694443	0.592875	0.5611
D(LNEPC)	0.209728	0.022787	9.203700	0.0000
D(LNEPC(-1))	0.184829	0.031514	5.865043	0.0000
D(LNFDI)	1.559308	6.181109	2.500947	0.0229
D(LNFDI(-1))	0.737308	1.067608	-1.634048	0.1206
D(LNREGC)	0.319863	0.614494	-2.147885	0.0464
D(LNREGC(-1))	-0.657863	0.572765	-2.894492	0.0101

* p-value incompatible with t-Bounds distribution.
** Variable interpreted as Z = Z(-1) + D(Z).

Levels Equation
Case 2: Restricted Constant and No Trend

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LNEPC	0.668963	0.104149	6.662161	0.0167
LNACCEL	0.844441	0.463145	2.692580	0.0379
LNFDI	-0.282408	0.937507	-0.428855	0.0634
LNGDP	0.503298	0.321108	2.206280	0.0498
LNREGC	0.076847	0.029087	3.508661	0.0079
C	49.21385	26.19094	0.645928	0.5269

LNESD = 0.668*LNEPC +0.844*LNACCEL -0.282*LNFDI + 0.503
*LNGDP + 0.076*LNREGC +49.213

F-Bounds Test — Null Hypothesis: No levels relationship

Test Statistic	Value	Signif.	I(0)	I(1)
			Asymptotic: n=1000	
F-statistic	20.64623	10%	2.08	3
k	5	5%	2.39	3.38
		2.5%	2.7	3.73
		1%	3.06	4.15

			Finite Sample:	
Actual Sample Size	30		n=30	
		10%	2.407	3.517
		5%	2.91	4.193
		1%	4.134	5.761