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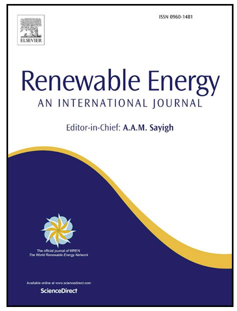

The asymmetric nexus of renewable energy consumption and economic growth: New evidence from Rwanda

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The asymmetric nexus of renewable energy consumption and economic growth: New evidence from Rwanda

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Abstract: Existing studies on the impact of renewable energy consumption on economic growth, which was conducted in either middle/ high-income countries or mixed sampled countries, produce the effect, but unfeasible in low-income countries. This study examines the asymmetric nexus of renewable energy consumption and economic growth, and the impact of agriculture and capital on economic growth by employing a non-linear autoregressive distributed lagged model (NARDL) and causality test from 1990 to 2015 in Rwanda. The results show evidence that renewable energy consumption affects economic growth. Asymmetric causality relationship, which is running from positive shocks renewable energy consumption to economic growth is noted. Furthermore, the unidirectional causality effect flowing from both agriculture and capital to economic growth for both positive and negative shocks is obtained. Therefore, the Government of Rwanda needs to realize positive economic growth from its investment in renewable energy consumption and agriculture as prior sectors of development.

Keywords: Renewable energy consumption; economic growth; asymmetric analysis; NARDL

1. Introduction

Renewable energy use is growing worldwide due to the availabilities of its resources, unstable energy prices, and reducing the negative effect of climate change. Its consumption contributed to about 22% of the World's final energy consumption by 2015 [1,2]. Due to the comprehensive benefits of using renewable energy, global demand for renewable energy is predicted to rise to 31% by 2035 [3]. On the same side, developed/developing countries are in advance to increase renewable energy. For example, Khoie et al [4] showed that renewable energy resources are planned to generate enough electricity in some states of the USA in the next two decades. In China, by Zhang et al [5], about 29% of major energy consumption in the next decades is predicted to rely on nuclear and renewable energy.

In West and Sub-Sahar Africa, there are insufficient renewable energy resources explored, such as solar energy, geothermal energy, hydro, and wind energy, which are all friendly with human health [6]. As an option result, wood biomass is highly prevalent in use but harming public health and the environment in this continent [7]. In the case of Rwanda, the energy production sector is facing critical circumstances. Although this country is a non-coastal with more than 12 million of the population occupying an area of 26,338 km^2 and it is among the top five heavily populated countries in the World, the produced energy is insufficient to the consumers. On the other hand, few studies showed that recently, there was a reasonable growth of social-economic development due to the increasing number of external and internal investors, which led to higher energy consumption [8,9]. Although, Rwanda is far behind its surrounding three east African countries (Kenya, Uganda, and Tanzania) for having sustainable development [10].

The World Bank reported that Rwanda significantly started using renewable energy in early 1990. Safari [11]indicated the description of renewable energy consumption in the last decade. About 10% of total energy consumption is renewable energy (agricultural residues, fuel, charcoal, grid and non-grid electricity, peat, gas, solar) in Rwanda. In 2010, about 90% of total energy was wood-fuel energy consumed in rural, while 10% consumed in urban areas. Biomass constituted 80.40% of total energy sources, whereas fuel and electricity constituted 6% and 0.90%, respectively. The households consumed 91% of the total energy, 4.5%, 2.7%, and 1.8% for the transport sector, industry sector, and public services, respectively [11].

In this sense, Munyaneza et al [12] referred to Rwanda's energy policy plans and predicted that 563 MW of electricity would be produced by 2018 merely on renewable energy, and cover about

70% of electricity demand. Due to the intensive effort to explore the available renewable energy resources (solar, geothermal, methane gas in Lake Kivu, biomass, biogas; and wind), the achievement intended to reduce the wood-fuel use from 86.3% to 50% by the end of 2020 [11,13].

On the other hand, Kadozi [14] showed that GDP per capita has significantly increased in this decade with a 10% yearly increase. Nevertheless, there was no evidence that this increment relied on renewable energy consumption. Rwanda's agriculture policy and strategy are dynamic, which leads to unstable improvement. This agriculture sector has low-frequency shocks as national droughts compared to the neighboring countries to affect agricultural dependence in the region [15]. In the last two decades, investing in the agriculture sector positively affected GDP, whereas, US$1 invested had generated US$4 of increase in GDP, and this lead to 26 % of poverty reduction [16,17]. Although, there is a lack of studies highlighted the link between economic growth and capital in Rwanda, Boyce et al [18] showed that capital contributed to boosting economic growth in Sub-Sahara Africa, including Rwanda. Thus, by implementing the second phase of the Economic Development and Poverty Reduction Strategy (EDPRS 2) and interest to use renewable energy technologies as it is applicable in developing countries [19], the plan of Rwanda energy policy may be achieved.

The comparative studies used middle and high-income countries showed that a low level of renewable energy consumption negatively affects economic growth. In contrast, the highest level has a strong positive impact, and again this effect varies according to the set of countries considered [20–22]. Although renewable energy plays a vibrant role in boosting the economy in middle and high-income countries, there was not yet evidence that it happened in the case of Rwanda, which is a low-income country. However, Rwanda may gain from knowing the impact of renewable energy consumption on its economic growth.

Various studies used several methodologies to test the link between renewable energy consumption and economic growth and provided trustable results. Some methods are Granger causality, panel co-integration, vector error correction model, Dynamic Ordinary Least Squares (DOLS), Fully Modified Ordinary Least Squares (FMOLS), Linear Autoregressive Distributed Lagged (ARDL), Non-linear ARDL, and Generalized Methods of Moments (GMM). Most of all approaches tested four prior hypotheses: conservative, feedback, growth, and neutral relationship hypotheses.

Through the previous studies, there is a lack of studies conducted in a single low-income country, whereas it is well known that renewable energy consumption is at a low level. This led to ignoring the little bit contribution of renewable energy consumption to economic growth. Furthermore, for the studies that used some low-income countries and compared with middle and high-income countries, findings did not explicitly show the impact of renewable energy consumption on economic growth in low-income countries. Last but not least, although various approaches used to investigate the effect of renewable energy consumption on economic growth provided reliable results, these methods were not applied in the case of Rwanda.

Therefore, in this study, we examine the asymmetric nexus of renewable energy consumption and economic growth within four existing hypotheses. First, the conservative hypothesis (one-way causality from economic growth to renewable energy consumption). Second, the feedback hypothesis (two-way causality between renewable energy consumption and economic growth). Third, the growth hypothesis (unidirectional causality flowing from renewable energy to economic growth). Lastly, the neutral hypothesis (no causational link between renewable energy consumption and economic growth). Non-linear Autoregressive Distributed lagged (NARDL) model implemented in R programming, and some important econometric tests are employed in this study.

Hatemi-j [23] proposed the asymmetric causality technique, and due to its efficiency, as shown by Tugcu [24] in the study to test the asymmetric relationship between energy consumption and economic growth, this test has also been applied in our study. Furthermore, we examine the impact of further covariates (agriculture and capital) to boost economic growth by adding them to our considered production function. Due to the low descriptive influence, the unit root test proposed by Kim and Perron [25] is used to examine the co-integration order and a single unknown structural break in the data recorded from 1990 to 2015. Nevertheless, two drawbacks of the NARDL model were identified by Nguyen et al [26], and in this study, we tested the first drawback, which is the conventional threshold method (variables simply decompose into positive and negative). To the best of our knowledge, this study is the first attempt to explore the asymmetric nexus of renewable energy consumption and economic growth in the case of Rwanda by employing NARDL approach.

The study is organized as follows: Section 2 is the literature review, methodology and data are in section 3, and results and discussion are in section 4. Section 5 concludes and provides renewable energy policy implications and suggests future studies.

2. Literature review

There are several existing literature on the effect of renewable energy consumption on economic growth in developed/ developing countries [27] and comparative studies which combined a set of similar income countries, such as G7 countries [26], and others, see ([28–32]). The highest prevalence of these studies merely on four hypotheses: the conservative, feedback, growth, and the neutral hypothesis. These hypotheses were empirically tested, and most of the findings support the feedback hypothesis when the entire panel data set is applied, see, for example, [28,33,34], except the results obtained by Menegaki [29] supported the neutral hypothesis for the European countries.

Chen et al ([20] and references therein) showed the neutral, negative, and positive effects of renewable energy consumption on economic growth, and some effects contradict others. Isik et al.[35] indicated that there was no significant relationship between renewable energy consumption and economic growth in Indonesia. Chen et al again demonstrated that the causal relationship between those two variables could be significantly positive when developing countries exceed a certain confident threshold of renewable energy consumed [20]. In the same sense, a neutral effect between renewable energy and economic growth has been found in Spain for a panel dataset from 1995 to 2012, and the long-run causality and short-run nexus growth of energy consumption for the economies of West African States [2,7]. On the other hand, some literature showed that the increment of renewable energy consumption negatively affects economic growth because of high investment costs, for example, in Turkey [36], European countries [37], and in India, Ukraine, the US, and Israel [28]. Beyond the impact of renewable energy consumption, some studies highlight the further effect of agriculture and capital on economic growth, and again renewable energy consumption contributes to the increase of these variables (agriculture and capital) [20,38,39].

Based on the economic growth standard of a particular country and reporting time, different methodologies have been applied to describe the effect between renewable energy consumption and economic growth. Several studies employed various panel data methods (FMOLS, DOLS, ARDL, GMM, NARDL, and others) employed to compute the long-run elasticities between renewable energy and economic growth [24,28,34,36,40]. Moreover, some of these methods applied also to the link between renewable energy consumption and other variables, including trade and financial [41,42]. Most of these approaches provided the symmetric and the non-symmetric relationship between renewable energy consumption and economic growth, and fewer indicated no connection between those two main variables, for detail, see [20,43].

Through the existing studies, we found that renewable energy consumption has a negative or neutral effect on economic growth. These studies focused on the low and middle-income countries, which consume low levels of renewable energy, but no studies were conducted in a single low-income country. Moreover, due to the availability of costless data for several countries, which are sometimes not normally distributed, non-linear asymmetric analysis through the NARDL approach is appropriate for this condition. Therefore, employing the NARDL approach to examine the asymmetric nexus of renewable energy consumption and economic growth in the case of Rwanda increases the impact of this study. This non-linear relationship between renewable energy consumption and economic growth can vary based on the other variables that can be added in the considered production function, however, the impact of agriculture and capital on economic growth will be examined in our study. In the next section, we present the methodology, including the NARDL specification.

3. Methodology and data

3.1. Methodology

Recently, Shin et al [44] improved the NARDL approach as an asymmetric postponement to the famous ARDL model [45] to detect both short run and long run asymmetries in the variables. The advantages of using the improved NARDL model is efficient, sensible to small sample size data, and able to be used for variables co-integrated at one or zero [I (1) or I (0)], and a combination of these orders. Despite traditional mathematical models, such as the exponential growth model can be simply used to show the direct relationship between renewable energy consumption on economic growth, NARDL can deeply examine the positive and negative relationship between those variables [44]. The steps of the methodological approach are illustrated in fig.1.

3.1.1. Correlation and unit root test

The most important issue in economic models is checking the dependence among variables. The Bivariate correlation is preferably used to test this dependence [46]. In the fact that our variables are time-varying series, the next step is to test the cross-sectional dependence between the current and previous values of similar variables. The unit root test proposed by Dickey and Fuller [47] is used under the null hypothesis that the series has the unit root and its alternative that series has no unit root. There are some cases, where the series presents unit root and certain breakpoints, which can cause inaccuracies in econometric prediction, and the stationarity hypothesis can sometimes fail to be rejected. However, Kim and Perron proposed a potential approach to eliminating unknown changes in the series [25]. The results obtained from Dickey and Fuller tests are usually compared with those estimated using the test proposed by Kwiatkowski, Phillips, Schmidt, and Shin (KPSS) [48] to see whether the results can provide the same conclusion. These tests rely on the following equation:

$$\Delta y_t = \psi y_{t-1} + \sum_{i=1}^{p} \phi_i \Delta y_{t-i} + \varepsilon_t \qquad (1)$$

For $\psi = 1$(null hypothesis by using DF test), $\phi_i = 1, i = 1,2,..., p$ unit root at maximum lags (p) by using Augmented Dickey and Fuller test, Δ indicates the differencing operator, and ε the error term.

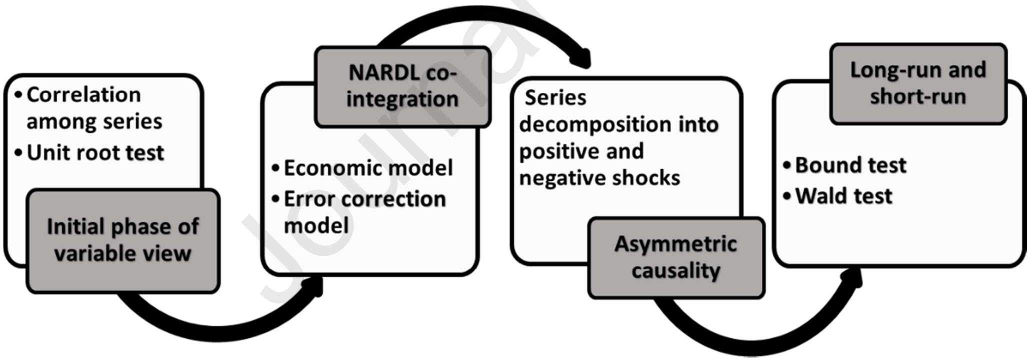

Fig.1: The steps of the methodological process

3.1.2. The NARDL co-integration testing approach

Non-linear and asymmetric co-integration analysis of the relationship between the variables has been not yet employed in similar studies in Rwanda. To detect this relationship together with NARDL approach, the multivariate economic model, considered as a production function, has been constructed. The model is written as follows:

$$\ln Y_t = \rho_0 + \rho_1 \ln REC_t + \rho_2 \ln A_t + \rho_3 \ln K_t + \varepsilon_t \qquad (2)$$

where $\rho_i \;\; i = 0,1,2,3$ is the effect of explanatory variables on the exogenous variable. *REC*, *A*, and *K* are renewable energy consumption, agriculture, and capital over time t, respectively, and ε_t is a disturbance term. For panel co-integration, an appropriate approach is a panel error correction model, which is a dynamic model and represented as:

$$\begin{aligned}\Delta \ln y_t &= \beta_0 + \sum_{i=1}^{p} \beta_{1,l} \Delta \ln y_{t-l} + \sum_{i=0}^{q} \beta_{2,l} \Delta \ln REC_{t-l} + \sum_{i=o}^{q} \beta_{3,l} \ln A_{t-l} + \sum_{i=0}^{q} \beta_{4,l} \Delta \ln K_{t-l} \\ &+ \beta_5 (\ln y_{t-1} - \rho_0 - \rho_1 \ln REC_{t-1} - \rho_2 \ln A_{t-1} - \rho_3 \ln K_{t-1}) + \varepsilon_t \end{aligned} \qquad (3)$$

Where Δ denotes the first difference, p, and q lags length selected by AIC selection criteria. To estimate (3) in one-step, examined by multiplying the error correction term out in the following model:

$$\begin{aligned}\Delta \ln y_t &= \beta_0 + \sum_{i=1}^{p} \beta_{1,l} \Delta \ln y_{t-l} + \sum_{i=0}^{q} \beta_{2,l} \Delta \ln REC_{t-l} + \sum_{i=o}^{q} \beta_{3,l} \ln A_{t-l} + \sum_{i=0}^{q} \beta_{4,l} \Delta \ln K_{t-l} \\ &+ \beta_5 \ln y_{t-1} - \beta_5 \rho_1 \ln REC_{t-1} - \beta_5 \rho_2 \ln A_{t-1} - \beta_5 \rho_3 \ln K_{t-1} + \varepsilon_t \end{aligned} \qquad (4)$$

The one-step estimated results of the intercept and each error correction coefficient of equation (4) are the combinations of long-run coefficients and long-run adjustment rates.

3.1.3. Asymmetric causality approach

The asymmetric causality test was recently employed to identify the direction of the asymmetric causal relationship between variables [23]. In the case of checking non-linear effects and differentiate positive and negative shocks in the variables, the test based on statistical inference in VAR [49] can be employed, and then variables can be a random walk process. To represent the positive and negative shocks of the variables, and random walk process in an asymmetric structure, and by Hatemi-j [23] test, variables can be decomposed as follow:

$$REC_t^+ = \sum_{j=1}^{t} \Delta REC_j^+ = \sum_{j=1}^{t} \max\left(\Delta REC_j, 0\right) \quad , \quad REC_t^- = \sum_{j=1}^{t} \Delta REC_j^- = \sum_{j-1}^{t} \min\left(\Delta REC_j, 0\right) \quad ,$$

$$A_t^+ = \sum_{j=1}^{t} \Delta A_j^+ = \sum_{j=1}^{t} \max\left(\Delta A_j, 0\right) \quad , \quad A_t^- = \sum_{j=1}^{t} \Delta A_j^- = \sum_{j-1}^{t} \min\left(\Delta A_j, 0\right) \quad ,$$

$$K_t^+ = \sum_{j=1}^{t} \Delta K_j^+ = \sum_{j=1}^{t} \max\left(\Delta K_j, 0\right), \quad K_t^- = \sum_{j=1}^{t} \Delta K_j^- = \sum_{j-1}^{t} \min\left(\Delta K_j, 0\right), \; y_t^+ = \sum_{j=1}^{t} \Delta y_j^+ = \sum_{j=1}^{t} \max\left(\Delta y_j, 0\right),$$

$$y_t^- = \sum_{j=1}^{t} \Delta y_j^- = \sum_{j-1}^{t} \min\left(\Delta y_j, 0\right) \; (5)$$

In our asymmetric analysis, the positive and negative shocks of variables are shown as follows:

$$y_t^+ = \sum_{i=0}^{t} e_{1i}^+, y_t^- = \sum_{i=0}^{t} e_{1i}^-, REC_t^+ = \sum_{i=0}^{t} e_{2i}^+, REC_t^- = \sum_{i=0}^{t} e_{2i}^-, A_t^+ = \sum_{i=0}^{t} e_{3i}^+, A_t^- = \sum_{i=0}^{t} e_{3i}^-,$$
$$K_t^+ = \sum_{i=0}^{t} e_{4i}^+, K_t^- = \sum_{i=0}^{t} e_{4i}^- \qquad (6)$$

3.1.4. Long-run and short-run multipliers estimation

The long-run and short-run effect changes of explanatory variables on response variables are the coefficients of the model obtained after using equation (6) in equation (4), and the effect of changes in these variables presented in the following equation:

$$\Delta \ln y_t = \beta_0 + \theta \ln y_{t-1} + \gamma_1^+ \ln REC_{t-1}^+ + \gamma_2^- \ln REC_{t-1}^- + \gamma_3^+ \ln A_{t-1}^+ + \gamma_4^- \ln A_{t-1}^- + \gamma_5^+ \ln K_{t-1}^+$$
$$+ \gamma_6^- \ln K_{t-1}^- + \sum_{i=0}^{p} \sigma_1 \Delta \ln y_{t-1} + \sum_{i=0}^{q} \sigma_2 \Delta \ln REC_{t-1}^+ + \sum_{i=0}^{q} \sigma_3 \Delta \ln REC_{t-1}^- + \sum_{i=0}^{q} \sigma_4 \Delta \ln A_{t-1}^+ \qquad (7)$$
$$+ \sum_{i=0}^{q} \sigma_5 \Delta \ln A_{t-1}^- + \sum_{i=0}^{q} \sigma_6 \Delta \ln K_{t-1}^+ + \sum_{i=0}^{q} \sigma_7 \Delta \ln K_{t-1}^- + Z_t + \eta_t$$

For $i = 1,...,8, \sigma_i$ and γ_i represent short-run and long-run coefficients, respectively, whereas short-run coefficients reveal the direct effect of explanatory variables on exogenous variables. On the other hand, long-run coefficients demonstrate the speed and reaction time of the change towards an equilibrium state. The null hypothesis for short-run asymmetry was analyzed by considering the equality of coefficients ($\sigma = \sigma^+ = \sigma^-$), and similar for long-run asymmetry ($\gamma = \gamma^+ = \gamma^-$). To test these hypotheses, the Wald test is used for variables $y_t, REC_t, A_t,$ and K_t, and Z_t is the dummy variable. β_0 and θ are the intercept and drift rate of the model, respectively. Besides, Shahbaz et al [50] confirmed that this approach is suitable to test co-integration for time series data among the variables in a single equation. The bound test suggested by Shin et al [44] showed the reliable estimate of asymmetric long-term co-integration, and it is used to test the effect of renewable energy consumption on economic growth in this study. This is a combined test for all repressors of all lagged levels, and the evaluation is based on two tests: F-statistic test with the null hypothesis $\gamma = \gamma^+ = \gamma^- = 0$, for first-order co-integration, and t-statistic with the null hypothesis $\gamma = 0$ against the alternative of $\gamma \prec 0$ for zero-order co-integration. To fail to reject the null hypothesis indicating that there is a long-run relationship among the variables. Thus, we have used $L^+ = -\gamma^+/\sigma$, and $L^- = -\gamma^-/\sigma$, to determine the long-run asymmetric coefficients, for L^+

and L^{-} are positive long-run and negative long-run coefficients. The fractions are the coefficients of the economic model at the new equilibrium state. These long-term coefficients indicate the positive and negative variations of the response variables and describe the long-term relationship between the variables.

3.2. Data

Currently, there is a lack of studies that investigated the effect of renewable energy consumption on economic growth in Rwanda. However, to examine this impact, the time-varying panel data mined from The World Bank, CIA World Factbook online database, and some historical reports of energy consumption in Rwanda under the ELECTROGAZ (former name of the Rwanda utility for production, transmission, and distribution of electricity and water) employed. Descriptive statistics of indicators used are presented in table.1. The renewable energy consumption measured in kWh, GDP (in constant 2010 U.S. dollars) used as economic growth, Gross fixed capital formation (in constant 2010 U.S. dollars), and agriculture, value-added (in constant 2010 U.S. dollars), from 1990 to 2016 period were obtained from The World Bank database. All variables were transformed into per capita units by dividing the total yearly population, and then to achieve accurate results, we have transformed all variables to a natural logarithm. Transformed variables are denoted as follows: GDP per capita is denoted by economic growth (y_t), and agriculture, value-added per capita is represented by agriculture (A_t), renewable energy consumption denoted as REC_t , and Gross fixed capital formation is denoted as capital (K_t), see table. a in the Appendix. Fig.2 shows the increasing trends of economic growth, renewable energy consumption, agriculture, and capital. All variables got to the lowest level in 1994 due to the well-known incidence, which devastated all sectors in Rwanda. Descriptive analysis indicates that economic growth, renewable energy consumption, and capital are positively skewed, while agriculture is negatively skewed. The kurtosis test revealed that all variables/distribution are leptokurtic since all values are greater than +1.0. The Jarque-Bera test indicates all variables are not normally distributed.

Table 1: Descriptive statistics

	y_t	REC_t	A_t	K_t
Mean	2.653	1.346	2.074	1.800
Median	2.627	1.345	2.102	1.712
Maximum	2.885	1.961	2.227	2.359

Minimum	2.343	0.826	1.817	0.980
Std. Dev	0.134	0.295	0.105	0.324
Skewness	-0.020	0.170	-0.491	-0.201
Kurtosis	2.491	2.737	2.537	2.882
Jarque-Bera	0.282	0.200	1.279	0.189
Probability	0.868	0.904	0.527	0.909
Sum	68.998	35.012	53.939	46.820
Sum sq.dev	0.449	2.179	0.277	2.639
Observation	26	26	26	26

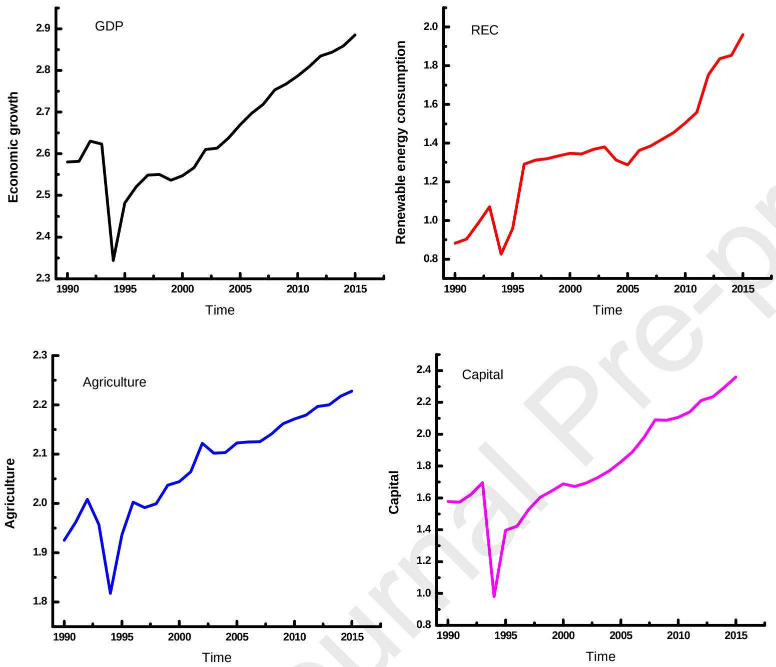

Fig.2: The increment trends of economic growth, renewable energy consumption, agriculture, and capital over time. All these variables reached their lowest values in 1994, corresponding with the greatest incidence, which ruined everything in Rwanda.

4. Results and discussion

This section represents the pair-wise correlation and unit root tests for all variables using the NARDL asymmetric co-integration test. We lastly, estimated the asymmetric causal relationship between the variables with the use of asymmetric causality tests. All findings of this study are obtained by using the R programming language, nardl-package contains a library (nardl) developed by Shin et al [44].

4.1. Pair-wise correlation and Unit root test of variables

The strong correlation amongst variables indicates that renewable energy consumption, agriculture, and capital positively contributed to boosting economic growth. The direct relationship between economic growth and other covariates is positive, and moving towards the increment of economic growth, see fig. a in the Appendix. The results in the table.2 reveal that the NARDL model of renewable energy consumption, agriculture, and capital highly explain economic growth, as the adjusted coefficient of determination R-square = 0.973 (97.3%) indicated. The explanatory variables are not auto-correlated with economic growth as the Durbin Watson test (DW=1.173) indicates. Besides, there is no serial correlation $\left(\mathrm{X}_{sc}^{2}=0.408\right)$and White heteroscedasticity $\left(\mathrm{X}_{hg}^{2}=0.789\right)$. The Wald test also indicates significant asymmetry co-integration for the long-run for renewable energy consumption, economic growth, agriculture, and capital for the period from 1990 to 2015 for Rwanda.

Table.2: Pair-wise correlation and model validation

	y_t	REC_t	A_t	K_t
y_t	1			
REC_t	0.859*	1		
A_t	0.921*	0.825*	1	
K_t	0.977*	0.926*	0.900*	1
R-square	0.977	Adj.R-square	0.973	
DW test	1.173			
X_{SC}^{2}	0.408	X_{HG}^{2}	0.789	

*, **, and *** indicate significance levels of 1%, 5%, and 10%, respectively. X_{sc}^{2}, and X_{HG}^{2} denote LM tests for serial correlation, and heteroscedasticity, respectively.

In the fact that the NARDL model is used when all variables are stationary and integrated at zero-order or I (1), the unit root test is used to confirm this assumption. The results in table.3 for without structural breaks and with structural breaks, reveals that all variables are stationary and integrated at the order I(0) and I(1), and allow us to examine co-integration between the variables. The change in variables determined by KPSS [51], and ADF [47] unit root tests. The output from these tests indicated that economic growth, renewable energy consumption, agriculture, and capital are stationary at levels and 1st difference with intercept and trend in the KPSS test. For the first difference by using the ADF test, all variables are either stationary or integrated at the order I(1). Perron [52] discovered an unexpected structural change in time-varying data, which can cause inaccuracies in econometric prediction, and the stationarity hypothesis can sometimes fail to be rejected, although the series has unknown structural breaks. Kim and Perron [25] proposed that the unit root test can estimate ambiguous results because of the small size of distribution and low degree of explanatory variables. However, to eliminate the unknown structural change, we used the breakpoint unit root test. The results of this test are obtained by considering both intercept and trend, and are presented in table.3 and indicate that all variables are stationary, and structural break exists in 2006, 2010, 2002, and 2008 for economic growth, renewable energy consumption, agriculture, and capital, respectively. On the other hand, considering only intercept, renewable energy consumption is stationary with a structural break in 2007, while economic growth, agriculture, and capital are non-stationary with the structural break in 2000, 2004, and 2014, respectively.

Table 3: Unit root analysis without/with a structural break

Without structural break	KPSS		ADF	
	Level	1st diff	Level	1st diff
y_t	0.186***	0.500*	-2.485[4]	-5.896*[0]
REC_t	0.150**	0.218*	1.417[0]	-0.899***[1]
A_t	0.067	0.281*	-3.294***[0]	-6.668*[1]
K_t	0.200**	0.665*	-0.273[0]	-6.053*[0]
With structural break	**Trend and intercept**		**With the only intercept**	
	Statistic	Break date	Statistic	Break date
y_t	-6.586*	2006	-3.983	2000
REC_t	-7.791*	2010	-8.054*	2007
A_t	-8.421*	2002	-4.108	2004
K_t	-6.742*	2008	-6.311	2014

*, **, and *** indicate significance levels of 1%, 5%, and 10%, respectively and [] indicates lag length.

The above structural breaks followed the consequences that happened in Rwanda, which degraded all sectors over the last two decades. During the 1990s, Genocide and its consequences led to the loss of a massive population, and energy sources damaged, economic, and the crash of financial policies. Later, in 2000, the establishment was made in Rwanda energy sector, whereas the action Plan indicated the new economic development agenda included radical reforms in the energy sector, and the sustained economic growth generated a rapid increase in electricity demand. This agenda was well achieved [11]. Thus, the presence of structural break unit root in the series forced us to use the NARDL bound test to examine asymmetric co-integration among the variables.

To identify nonlinearity in variables, the BDS test [53] was employed, the results presented in table.4 agreed with non-linearities in economic growth, renewable energy consumption, agriculture, and capital. Furthermore, fig.3 also approves non-linearity and model parameters stability, which shows that the NARDL model is appropriate for economic growth, renewable energy consumption, agriculture, and capital in this study.

Table 4: Non-linearity BDS test

Variable	m = 2	m = 3	m = 4	m = 5	m = 6
y_t	0.1452*	0.2225*	0.2337*	0.1922*	0.1490*
REC_t	0.1241*	0.1430*	0.0614	-0.1717*	-0.2822*
A_t	0.1544*	0.238*	0.2866*	0.3050**	0.3375**
K_t	0.1275*	0.1779*	0.1656*	0.0758**	-0.0243

*, **, and *** indicate significance levels of 1%, 5%, and 10%, respectively.

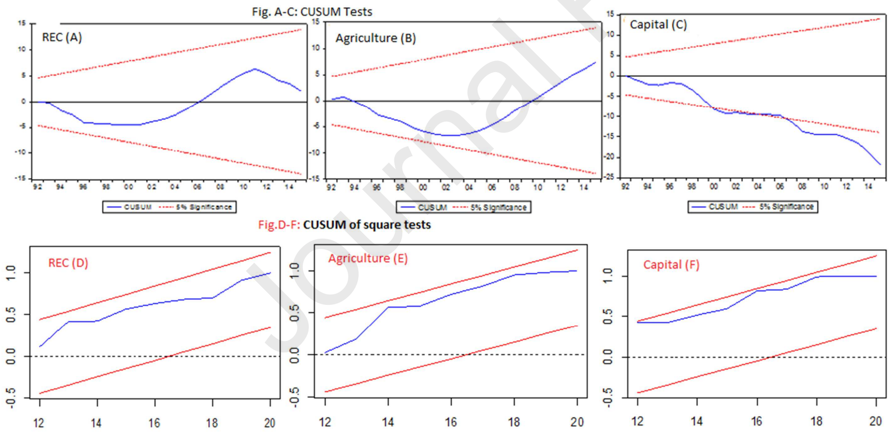

Fig.3: CUSUM tests and CUSUM squares tests NARDL model stability, REC (A), agriculture (B), and capital (C) are CUSUM tests, while REC (D), agriculture (E), and capital (F) are CUSUM of squares test for renewable energy consumption, agriculture and capital on economic growth at 5% significance level

4.2. Short-run and long-run asymmetric co-integration results

The results are presented in tables.5-6 show long- and short-term relationships among economic growth and renewable energy consumption, capital, and agriculture regarding positive and negative shocks. From table 5 positive shocks to renewable energy consumption have an insignificant positive effect on economic growth (coefficients of 0.0921, at 0.163 p-values), while negative shock has a significant negative effect (coefficient of -0.865 at 1%). This indicates that renewable energy consumption negatively impacts economic growth in the Rwanda economy in long term. This effect differs from those obtained from developed countries/developing countries, which use a high level of renewable energy [20]. The negative effect of renewable energy consumption may associate with the suggested reason that Rwanda had faced, including the lack of explored sufficient energy resources, especially renewable energy, since 1990. Recently, the insignificant positive effect of renewable energy consumption was associated with new policies, which have been introduced, and in 2019, about 34% of the population is using electricity (the World Bank report). As a result, Rwanda is exploring renewable energy resources in different dams so that a higher percentage of the population can easily use renewable energy in their daily services. This increases the trends of renewable energy use to boost economic growth.

The further covariates insignificantly contribute to either increase or decrease the economic growth in Rwanda. A positive shock to agriculture has an insignificant negative effect on economic growth with a long-run coefficient of -0.100 (0.653 p-values), while a negative shock has a significant negative effect with a long-rung coefficient of -2.361 at 1% significant). The results indicate that both positive and negative shocks to capital have an insignificant impact on economic growth. Furthermore, from table 6, positive and negative shocks to agriculture and renewable energy have a significant mixed effect on economic growth in the short-term.

Table.5: Long-run coefficients for co-integration results

Variables	Long-run (coefficient)	T-values	Probability
Constant	0.882*	4.654	0.001
y_{t-1}	-0.441*	-5.510	0.000
REC^{+}_{t-1}	0.0921	1.519	0.163
REC^{-}_{t-1}	-0.865*	-5.402	0.000
A^{+}_{t-1}	-0.100	-0.464	0.653
A^{-}_{t-1}	-2.361*	-5.437	0.000
K^{+}_{t-1}	0.053	0.247	0.810
K^{-}_{t-1}	-0.347	-1.419	0.190
Z_{t2000}	8.578*	6.662	0.000

*, **, and *** indicate significance levels of 1%, 5%, and 10%, respectively. “+”, and “-” denote positive and negative shocks, respectively, and Z_{2000} represents the dummy variable of the structural break for economic growth.

Table.6: Short-run coefficients from co-integration results

Variables	Short-run (coefficients)	T-value	Probability
ΔREC^{-}_{t-2}	*0.344***	*2.217*	*0.026*
ΔREC^{+}_{t-1}	*-0.183***	*-2.507*	*0.021*
ΔREC^{+}_{t-2}	*0.209**	*3.511*	*0.000*
ΔA^{+}_{t}	*0.998**	*0.0627*	*0.000*
ΔA^{-}_{t}	*0.987**	*0.021*	*0.000*
ΔA^{-}_{t-1}	*-1.291***	*-2.533*	*0.032*
ΔA^{-}_{t-2}	*1.504***	*2.529*	*0.032*

*, **, and *** indicate significance levels of 1%, 5%, and 10%, respectively. "+", and "-" denote positive and negative shocks, respectively.

Table.7 represents the results from the Wald test, which are strengthing the asymmetric and symmetric relationships between economic growth and covariates presented in Tables 5 and 6. The results rejected the null-hypothesis of no co-integration relationships between renewable energy consumption and economic growth in the long-term with a coefficient of 0.0547 at a 5% significant level, and short-term with a coefficient of 5.922 at a 1% significant level. This confirms the long-term asymmetric relationships between both positive and negative shocks to renewable energy and growth. In the short-term, there is a significant positive impact for both positive shocks to renewable energy consumption at lag two on economic growth and negative effects at lag one, see table 6.

By employing the Wald test, the null-hypothesis for no co-integration relationships between growth and agriculture is rejected for both the long-term with coefficients of 4.803 at a 1% significant level, and the short-term with the coefficient of 0.051, at a 5% significant level. These effects of agriculture on economic growth are similar to those from the World Bank report [54]. Generally, the long-run asymmetric of all covariates are statistically significant (F-statistic > F-critical) by bound test suggested by Shin et al. [45] for co-integration at first order, see table. b in the Appendix.

Table.7: Wald test for long-run and short-run

Variables	Coefficient	Variables	Coefficient
$LREC_{t}^{+}$	*0.208**	$LREC_{t}^{-}$	*-1.961**
LA_{t}^{+}	*-4.390*	LA_{t}^{-}	*-102.823*
LK_{t}^{+}	*0.496*	LK_{t}^{-}	*-3.229*
Wald test	*3.139***		

$W_{LR}REC$	*5.922**	$W_{SR}REC$	*0.0547***
$W_{LR}A$	*4.803**	$W_{SR}A$	*0.051***
$W_{LR}K$	*2.414**	$W_{SR}K$	*0.022***

*, **, and *** indicate significance levels of 1%, 5%, and 10%, respectively. "+", and "-" denote positive and negative shocks, respectively. L^{+} and L^{-} are the computed long-run coefficients associated with positive and negative shocks, respectively. The Wald test for the null hypothesis of the long-run WLR bounds test is statistically significant.

Lastly, the figs.4 presents the results for employing the dynamic multiplier adjustments. They show that the economic growth adjustment is running towards the long- and short-run steady increment regarding positive and negative shocks in renewable energy, agriculture, and capital. These indicate the inequality effect of long- and short-term covariates on economic growth in various lengths of time. In fig.4-A, positive shock dominates negative shock to renewable energy consumption to affect economic growth, later, then positive and negative shocks moved symmetrically with economic growth. This finding is in the direction of those obtained by M. Luqman et al [55]. Fig.4-B shows that initially, negative shocks dominate positive shocks to capital to affect economic growth. Later, negative shock neutrally affects economic growth, while positive shock moved symmetrically with economic growth. On the other hand, fig.4-C indicates that negative shocks dominate positive shocks to capital to affect economic growth. These findings are almost similar to those that resulted in the studies used a similar methodology in Pakistan [38]. However, the negative shocks dominate positive shocks in renewable energy consumption, agriculture, and capital, and results indicate that a positive and negative relationship was noted between these covariates and economic growth.

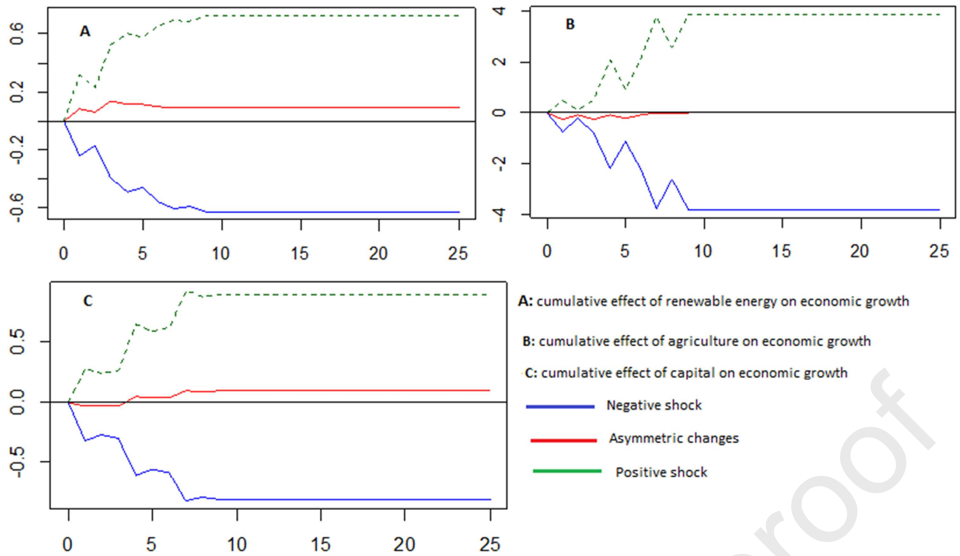

Fig.4: multiple plots that are showing the cumulative effect of renewable energy, agriculture, and capital on economic growth (blue lines show positive changes, red lines show negative changes, and green dotted lines show asymmetries in the selected variables.)

4.3. Asymmetric causalities between economic growth and covariates

In this study, we used the asymmetric causality test proposed by Hatemi-j [23] to compute the casual relationship among renewable energy consumption, agriculture, capital, and economic growth together with their cumulative coefficient. Table.8 represents the asymmetric causality results. Row-1(R-1) indicates the neutral causal effect between economic growth and renewable energy consumption. In R-2, there was a neutral effect between positive shocks to economic growth and positive shocks to renewable energy consumption, and similarly for negative shocks of economic growth and renewable energy consumption in R-3. These results are similar to those found in these studies [56–58]. In R-4, we found a significant symmetric causal effect runs from renewable energy consumption to economic growth. It is similar to that obtained in these references [57,59]. The significant asymmetric relationship between a positive shock of renewable energy consumption and a positive shock of economic growth are presented in R-5, and similar to that obtained by Luqman et al [41]. The neutral effect occurred between a negative shock to renewable energy consumption and economic growth (R-6). These findings are in the same direction as the Government of Rwanda's achievement, whereas it has made a dramatic improvement to attract new investors to build more renewable energy resources in a country to go faster in energy production and stabilize an energy supply for industries [11]. As a result, about 34% of the population are accessing electricity.

On the other hand, this study shows the neutral causal relationship between economic growth and agriculture (R-7), and between positive shock and negative shock to economic growth on both positive and negative shock to agriculture (R-8 and R-9). The asymmetric causal relationship that runs from agriculture to economic growth is presented in R-10, while there is no asymmetric relationship between positive shocks to agriculture and economic growth (R-11). We obtained a significant causal relationship between negative shocks to agriculture and economic growth, which is running from negative shocks in agriculture to economic growth (R-12). In the same sense, the results do not indicate an asymmetric feedback effect between positive shocks to agriculture and economic growth.

In the R-13, The neutral effect is noted for the symmetric relationship between capital and economic growth, which is moving from economic growth to capital. Similar findings were obtained for both positive and negative shocks to capital and economic growth (R-14 and R-15). The significant symmetric causality, which is running from capital to economic growth illustrated in R-16. Lastly, we found the asymmetric causal link between the negative shock to capital and negative shock to economic growth, moving from capital to economic growth (R-18). In (R-17) neutral effect between the positive shock to capital and positive shock to economic growth was noted. Therefore, all hypotheses of this study are similar to those tested by Tugcu and Topcu [24].

Table 8: Asymmetric and non-asymmetric causality test among variables

variables	F-test	P-value	Effect found
(1) $y_t \nRightarrow REC_t$	1.523	0.294	Neutral causal effect
(2) $y_t^+ \nRightarrow REC_t^+$	1.039	0.530	Neutral effect
(3) $y_t^- \nRightarrow REC_t^-$	0.970	0.556	Neutral effect
(4) $REC_t \Rightarrow y_t$	9.698*	0.004	Symmetric effect
(5) $REC_t^+ \Rightarrow y_t^+$	1.677***	0.081	Asymmetric effect
(6) $REC_t^- \nRightarrow y_t^-$	0.503	0.614	Neutral effect
(7) $y_t \nRightarrow A_t$	1.447	0.317	Neutral effect
(8) $y_t^+ \nRightarrow A_t^+$	1.039	0.530	Neutral effect
(9) $y_t^- \nRightarrow A_t^-$	0.970	0.556	Neutral effect

(10) $A_t \Rightarrow y_t$	9.205*	0.004	Asymmetric effect
(11) $A_t^+ \nRightarrow y_t^+$	0.472	0.800	No asymmetric effect
(12) $A_t^- \Rightarrow y_t^-$	0.122**	0.024	Asymmetric effect
(13) $y_t \nRightarrow K_t$	1.117	0.437	Neutral effect
(14) $y_t^+ \nRightarrow K_t^+$	0.550	0.755	Neutral effect
(15) $y_t^- \nRightarrow K_t^-$	1.548	0.386	Neutral effect
(16) $K_t \Rightarrow y_t$	0.282**	0.036	Symmetric effect
(17) $K_t^+ \nRightarrow y_t^+$	0.685	0.683	Neutral effect
(18) $K_t^- \Rightarrow y_t^-$	1.641***	0.072	Asymmetric effect

*, **, and *** indicate significance levels of 1%, 5%, and 10%, respectively. $\Rightarrow$, and $\nRightarrow$ represent unidirectional causality and no causality, respectively. R-1,2 …, represents rows.

5. Conclusions and policy implications

The existing studies that examined the impact of renewable energy consumption on economic growth were merely on the middle/high-income countries, and few compared these countries. In the fact that this relationship did not investigate in a single low-income country, there is imperceptible evidence that renewable energy can either positively or negatively affect economic growth. However, this study extends the literature on the asymmetric causality nexus of renewable energy consumption and economic growth by exploring this relationship in Rwanda as a low-income country. The Non-linear Autoregressive Distributed Lagged model (NARDL), and causality test which are suitable to examine long- and short-term relationships between variables have been employed in this study to establish the asymmetric impact of renewable energy consumption on economic growth. Furthermore, we investigated the link between agriculture and capital on economic growth in Rwanda for the period from 1990 to 2015.

The results confirmed a strong asymmetric co-integration relationship among variables. From these, there is a significant negative impact of long-term positive shock and an insignificant positive impact of a long-term negative shock to renewable energy consumption on economic growth. Besides, there is a long-term positive impact on both agriculture and capital on economic growth. Therefore, the findings confirm the evidence that renewable energy consumption affected either negative or positive economic growth. Due to instability in past decades, Rwanda faced a shortage of renewable energy, but currently, the government established energy policies so that about 70% of the population will access electricity. Among the economic sectors, agriculture has an outstanding contribution to Rwanda's economy. However, the findings suggest the Government of Rwanda realizes positive economic growth from investment to renewable energy and agriculture as primary sectors of development.

Based on the limitations and findings of this study, there are several avenues for future research. First, this study focused on the country-level impact of renewable energy consumption on economic growth without separating the effects of renewable energy utilization in different sectors. There is evidence that the effects of renewable energy consumption on economic growth vary across different sectors. The next study may examine this impact would make for a useful exploration. Second, our findings depend on yearly data, but the records of the consumed/ not consumed renewable energy prices can be counted in short-term periods. The next study can investigate the short-term responses of industries to renewable energy prices and their verdict with regard to renewable energy consumption, and the impact of these decisions on firm production.

Third, this study focused on the impact of renewable energy consumption on economic growth, but renewable energy is a combination of sub-energy types (wind energy, hydropower, etc.). The next study can investigate the effect of each energy type in several sectors all over the country.

Finally, the next study can investigate the effect of renewable energy on households' economic development. The upcoming study is discussing the effect of total energy consumption on economic growth. All these future and current studies may contribute to boosting national economic growth by considering the alternative energy resources and consumption capacity of different industries.

Declaration of competing interest

The authors declare that there is no conflict of interest and approve the submission to your reverence journal.

Data availability

The datasets used are available from the World Bank database [58], CIA World Factbook online database, and ELECTROGAZ. The combined dataset is available to the authors.

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