Renewable electricity generation and government expenditure on economic growth of South Africa and Botswana

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Abstract: The study analysed renewable electricity generation and government expenditure on economic growth of South Africa and Botswana. The study utilizes time series data from 1980 to 2021 collected from the World Bank and International Energy. The study performed the DF-GLS and PP unit root test, ARDL Bounds tests and related diagnostics tests. Empirical evidence revealed that renewable electricity generation has a favourable impact in South Africa and a detrimental effect in Botswana on economic growth. The study only found long run relationship between the variables in South Africa with the aid of the bounds test results. Related policies were given in the study based on statistical evidence.

Keywords: Renewable electricity generation, Government Expenditure, Economic growth, South Africa, Botswana.

JEL Specification: C32, O13, O43, Q43

1. INTRODUCTION

Khobai *et al.* (2020) asserts that the importance of renewable energy consumption has significantly increased in the recent years with some of the benefits including improvement in the quality of the environment and economic growth. According to Bridle *et al.* (2022), the South African Energy fiscal policies were designed with distributive aims, especially in the post-Apartheid state. These policies are linked to promoting domestic energy production and increasing energy security with access to affordable energy, which will in turn ensure economic development and impact positively on the other sectors of economic growth in the country.

According to Banks and Schäffler (2005), South Africa relies on low-cost electricity and coal to power industries that rely greatly on energy such as mining and metals processing. The country also depends on cola and liquid fuels for chemical processing, heating, transport, and other activities. The country's overall energy mix is dominated by coal, followed by crude oil, renewables, and nuclear energy (Bridle *et al.*, 2022). The table below provides an overview of South Africa's energy supply.

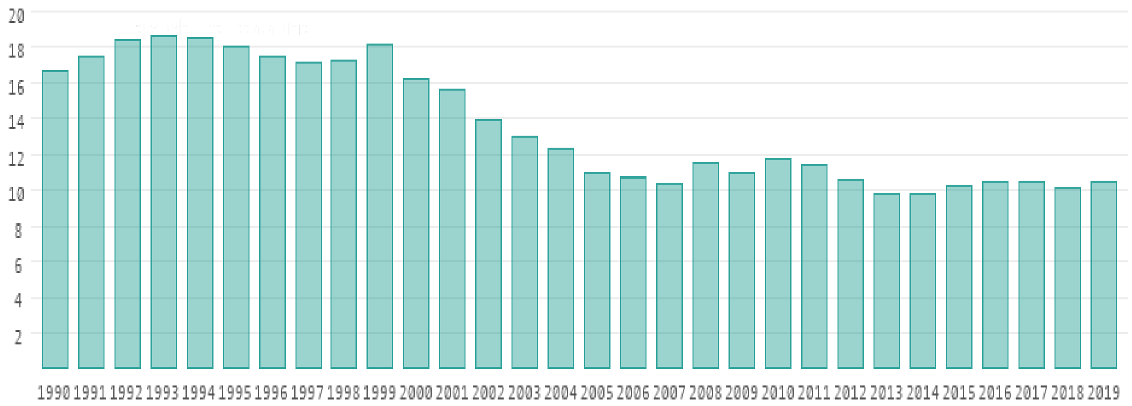
Energy source	total in South Africa	Percentage in South Africa	Percentage USA	per capita in South Africa	per capita USA
Fossil fuels	372.45 bn kWh	85,0 %	70,0 %	6,203.14 kWh	20,083.19 kWh
Nuclear power	17.53 bn kWh	4,0 %	9,0 %	291.91 kWh	2,582.12 kWh
Water power	4.38 bn kWh	1,0 %	7,0 %	72.98 kWh	2,008.32 kWh
Renewable energy	43.82 bn kWh	10,0 %	14,0 %	729.78 kWh	4,016.64 kWh
Total production capacity	438.18 bn kWh	100,0 %	100,0 %	7,297.81 kWh	28,690.27 kWh
Actual total production	234.50 bn kWh	53.5 %	43.0 %	3,905.60 kWh	12,338.29 kWh

Source: World-Data (2023)

According to Bridle *et al.* (2022) fossil fuels (coal) is the main source of energy in South Africa and contributes over 85 per cent of energy supply, followed by crude oil, used to generate energy through open-cycle gas turbines. Nuclear power supply contributes about 5 per cent of energy supply provided by Koeberg nuclear power station. Natural gas only contributes about 3 percent. The renewable energy supply is slowly increasing, provided by the Renewable Energy Independent Power Producer Program (REIPPP), with about 10 per cent in 2019.

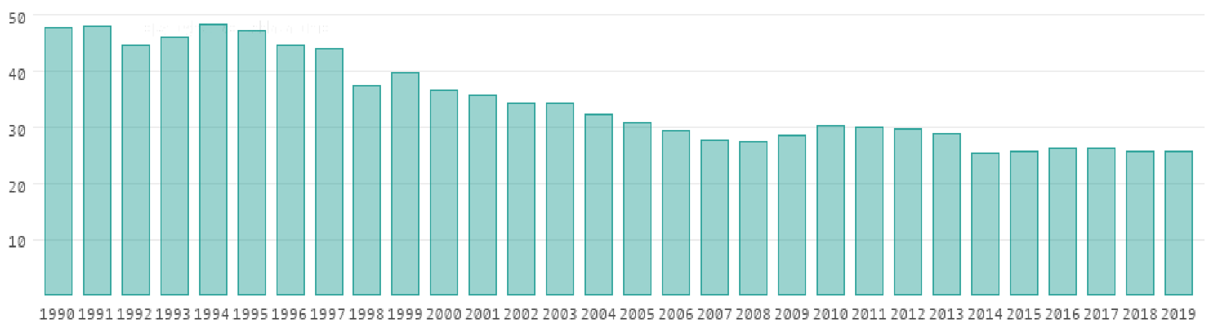
Banks and Banks and Schäffler (2005), argued that the contribution of renewable energy is relatively low in South Africa with biomass and hydropower as the main contributors of renewable energy. According to Khobai *et al.* (2020), other sources of renewable energy in

South Africa includes solar, wind and biofuels. The figure below shows the percentage share of renewable energy in South Africa from 1990 to 2019.



Source: World-Data (2023)

According to Mahachi *et al.* (2015), Botswana is also a developing country that relies mainly on fossil fuels for domestic, industrial, and business energy consumption, which has a negative impact on the environment. However, firms in Botswana recently have been approaching alternative forms of energy, such as solar, biogas and wind power that are ecologically sound. According to the World-Data (2023), the sources of renewable energy in Botswana includes wind, solar, biomass and geothermal. In 2019, renewable energy consumption accounted for about 25.6 percent. The figure below shows the percentage share of renewable energy consumption in Botswana between 1990 and 2019.



Source: World-Data (2023)

According to Banks and Schäffler (2005), renewable energy options are the most sustainable sources of energy, capable of reducing reliance of fossil fuels. Furthermore, using renewable energy can also reduce South Africa's economic vulnerability to the costs of imported fuels. The study aims to examine the relationship between government expenditure, renewable energy consumption and economic growth in South Africa and Botswana. The study emphasises the role of investing in renewable energy consumption by the governments of the two countries of interest and to bring forth the importance of government expenditure of renewable energy consumption as the most convenient and sustainable source of economic growth. The main objective of this study is to analyse renewable electricity generation and government expenditure on economic growth of South Africa and Botswana for the period from 1980 to 2021. This will help with electricity policy development and monitoring in both countries as they are facing problems of blackouts and unstable electricity supply that hampers economic growth.

2. LITERATURE REVIEW

The study by Menyah and Wolde-Rufael (2010) examined the long-run and causal relationship between economic growth, pollutant emissions and energy consumption in South Africa between 1965 and 2006. The study utilised the bound test approach to cointegration which revealed a short-run and a long-run relationship among the variables under study. The study also employed the modified version of the Granger causality test which revealed a unidirectional causal relationship coming from pollutant emissions to economic growth, from energy consumption to economic growth and lastly, from energy consumption to CO2 emissions. The results of the study suggest that South Africa can either sacrifice economic growth or reduce its energy consumption per unit of output, or both to reduce pollutant emissions. However, according to the study, in the long run there is a possibility to meet the energy needs of the country and reduce the pollutant emissions at the same time through the development of energy alternative to coal.

Can and Korkmaz (2019) studied the relationship between renewable energy and economic growth in Bulgaria using annual data from 1990-2016. The methods of analysis chosen in the study is the Toda-Yamamoto analysis and the Autoregressive Distributed Lag (ARDL) bound test. The variables used in the study include renewable energy consumption (REC, percentage of total final consumption), renewable electricity output (REO, percentage of total electricity output) and economic growth (GDP constant 2010 US$). The study showed three different results; first, the renewable energy consumption and renewable electricity output causes economic growth. The second results of the study showed that economic growth and renewable electricity output causes growth in renewable energy consumption. The last results showed that economic growth and renewable energy consumption do not cause growth in renewable electricity output. The study also found no long run relationship among the variables under study and concluded that there is no long-term relationship between renewable energy and economic growth.

The study by Shahbaz and Feridun (2012) explored the effects of financial development, economic growth, coal consumption and trade openness on environmental performance in South Africa using time series data for periods 1965-2008. The ARDL bounds test method was applied in the study to test the relationship among the variables under consideration and the error correction method ECM was used to test the short-run dynamics of the variables. The study results found a long run relationship among the variables under study. The study found that an increase in economic growth increases energy emissions, while financial development results in a decrease in energy emissions. The study further confirmed that coal consumption contributes towards environmental deterioration in South Africa while trade openness improves the quality of the environment through the reduction of growth in energy pollutants. Lastly, the study also verified the existence of environmental Kuznets curve and contributed new ideas on ways to sustain economic growth in South Africa by protecting the environment from degradation through efficient use of energy.

Marinaș *et al.* (2018) examined the correlation between economic growth and renewable energy consumption for ten European Union member countries from 1990-2014 from Central and Eastern Europe. The study used the Auto-regressive Distributed Lag (ARDL) method to test both the long run and the short run relationships between the variables of the study. The study showed the transition towards new energy paradigm in the short run and the long run on the other hand, corresponded to the long-term equilibrium of the variables under study. according to the study, the results revealed that GDP and Renewable energy consumption had a positive relationship in the short run in Romania and Bulgarian, whilst in Hungary, Lithuania, and Slovenia, increase in renewable energy consumption raised economic growth. Furthermore, the bi-directional relationship between renewable energy consumption and economic growth was confirmed in the long run for all countries under study. The study therefore investigated the feasibility of the Europe 2020 goals of increasing energy efficiency and proposed public policies to achieve these goals.

Yildirim *et al.* (2012) investigated the relationship between renewable energy consumption and economic growth in USA, using the Toda-Yamamoto approach and a bootstrap-correlated causality test. The variables included real GDP, employment, investment, and kinds of renewable energy consumption. The study found only one causal relationship from biomass-waste-derived energy consumption to real GDP. Furthermore, there was no evidence of a causal relationship between real GDP and all the other renewable energy kinds including total renewable energy consumption, geothermal energy consumption, hydro-electric energy consumption etc. In other words, using energy from waste solves the dumping problems and contributes to real GDP. The study, therefore, suggested that countries should focus on energy production from waste as an alternative resource of energy.

Huang *et al.* (2008) examined the causal relationship between energy consumption and economic growth for 82 countries from 1972-2002. The study used data obtained from the World Bank and the data was divided into four, the low-income group, lower middle-income group, upper middle-income group and high-income group. Using the GMM-SYS approach for estimation of the panel VAR model, the study did confirm a causal relationship between energy consumption and economic growth. More specifically, the study found that the low-income group shows no causal relationship between energy consumption and economic. The middle-income group including both lower and upper middle-income groups showed a positive relationship between economic growth and energy consumption. The high-income group showed a negative relationship between the two variables. Further analysis of the data in the study showed that there is a great improvement in the environment in the high-income countries resulting from more efficient use of energy and a decrease in the release of CO2. The upper middle-income group on the other hand, saw a decrease in efficiency after the energy crisis which resulted in an increase in the release of CO2. The study therefore suggested a stronger energy conservation policy among all the four income groups since there was no sufficient evidence found to support that energy consumption leads economic growth.

Mehrara (2007) examined the causal relationship per capita energy consumption and per capita GDP in 11 oil exporting countries using a panel unit-root method of testing as well as panel cointegration analysis. The results of the study confirmed a unidirectional causal relationship from economic growth to energy consumption for the countries under study. The study suggested that policy makers in these countries must review their energy pricing policies to ensure energy conservation, as government policies in these countries normally keep domestic process bellow the free market level.

Namahoro *et al.* (2021) examined the impact of total and renewable energy consumption on economic growth at global and regional levels for low, lower, middle, and upper middle-income groups for 75 countries between 1980-2016. The study used the cross-sectional augmented Autoregressive Distributed lagged (CS-DL) method, and the common correlated effect means group (CCEMG) method. The study found that total energy affects economic growth positively in three income groups, and renewable energy consumption positively affects growth at the global level. At regional level, the effect of total and renewable energy consumption on economic growth was mixed across the income groups. The study therefore suggested that policy makers must reflect on the caused led negative effects and put policies in place to attract investors in renewable energy projects to ensure that renewable energy positively affect economic growth in all regions across the income groups.

The study by Sharmin and Khan (2016) examined the relationship between public health expenditures, logistics performance indices, renewable energy, and ecological sustainability in Association of Southeast Asian Nations member countries using secondary data to test the hypotheses with the structural equation modelling. The study results show that using renewable energy in logistics operations improves environmental and economic performance and reduces emissions. On the other hand, environmental performance showed a negative relationship with public health expenditures, indicating that greater environmental sustainability can improve human health and economic growth. The results further revealed that increased spending in public health and poor environmental performance lowers economic growth with less efficiency and low productivity of labour, thereby decreasing the economic activity speed. On the other hand, using renewable energy in logistics also creates better national image and promotes exports in environmentally friendly countries. The study therefore suggested that outcomes of the study will assist policy makers in making proper planning to their investments to achieve sustainable economic growth.

Chen *et al.* (2020) studied the renewable energy consumption and economic growth nexus using a threshold model from 103 countries between 1995-2015. The study found that relationship between the two variables is determined by the amount of renewable energy used. Furthermore, the results of the study demonstrated a positive relationship between renewable energy consumption and economic growth only if developing countries can exceed a certain threshold of renewable energy consumption. In other words, if developing countries use renewable energy below the threshold, the relationship between renewable energy consumption and economic growth would be negative. The results also confirmed no relationship between renewable energy consumption and economic growth in developed countries and a positive relationship in OEDC countries. the study results suggested that developing countries must exceed a certain threshold of renewable energy consumption to realise positive economic growth from their investment in renewable energy.

Fotourehchi (2017) studied the long run causality relationship between renewable energy consumption and economic growth for 42 developing countries using the Canning and Pedroni (2008) long-run causality test between 1990-2012. The finding of the study revealed a positive long run relationship between renewable energy consumption and economic growth. The causal relationship came from renewable energy consumption to GDP. The study suggested that policies encourage the development of renewable energy instead of polluted energy sector for environmental challenges and energy security.

Bernard and Obi (2016) examined the impact of sectoral consumption of non-renewable energy on economic growth in Nigeria using the Descriptive statistics pie chart and error correction model methods. The study used oil, gas, electricity, and coal consumed by the industry sector, agricultural sector, transport sector, commercial and residential sector as variables of analysis. The results found that all the variables under study contribute to economic growth significantly. The study also found that the residential sector consumed more energy than the other sectors and contributed greatly to economic growth. The study then recommended the formulation of policies aimed at encouraging the industrial sector to enhance economic growth and encourage energy consumption by the industrial sector in Nigeria.

Khobai *et al.* (2020) examined the relationship between renewable energy consumption and unemployment in South Africa between 1990-2014 using the Auto-Regressive Distribute Lag ARDL method to test the long-run and the short run effects of renewable energy consumption on unemployment. The results of the study revealed that renewable energy consumption has a negative impact of unemployment in South Africa in the long run. However, the short run showed a positive relationship between the variables. The study, therefore, promotes an increase in the production and the consumption of renewable energy to increase employment in South Africa.

Khobai (2021) examined the relationship between renewable energy consumption, poverty alleviation and economic growth in South Africa from 1990-2018 using quarterly data. The study employed the Auto-Regressive Distribute Lag (ARDL) method to explore the long run relationship between the variables. The study also used the Vector error Correction Model

(VECM) to test the causal direction between the variables. The results showed a long run relationship between renewable energy consumption, poverty, economic growth, financial development, and government expenditure. The results showed a negative impact of renewable energy consumption and economic growth on poverty in the long run and the short run. The results of the VECM suggested that renewable energy consumption causes economic growth and poverty in the long run. The study also found a bidirectional causal relationship between poverty and economic growth. In conclusion the study suggested to the energy policy makers the importance of policies that promote the implementation of clean technology to alleviate poverty in South Africa.

Adebayo *et al.* (2021) examined the nexus between coal energy consumption, economic growth, renewable energy consumption and CO2 emission between 1980-2017 using variety of econometric techniques to examine the relationship between variables under study. The ARDL bounds test along with the Kripfganz and Schneider (2018) critical approximation p-value tests both showed a long-run relationship between the study variables. The study also provided evidence of growth-induced pollution emission in South Africa, which shows South Africa is on an unclean growth path. This is also supported with the results of coal consumption with also reduces the quality of the environment. However, financial development shows great ability to improve the environment quality. The study, therefore, suggested to the policy makers the need to transition from conventional energy based on fossil fuel to renewable energy mix which is environmentally friendly.

Nyoni (2020) investigated the short-run and long-run effects of renewable energy on economic growth in South Africa using linear and nonlinear autoregressive distributed lag (ARDL) models between 1991-2016. The study results found no evidence of a linear and nonlinear cointegration effects of consumption and production of renewable energy consumption on economic growth in South Africa. The study explained the absence of cointegration as a sign of inefficient usage of renewable energy in promoting economic growth in South Africa. The study, therefore, suggested that policy makers need to accelerate the establishment of renewable energy infrastructure supporting the energy requirements in the future.

Molefe and Choga (2017) examined the relationship between government expenditure and economic growth in South Africa between 1990-2015 using the Vector Error Correction Model and Granger Causality Test methods. The study used Gross Domestic Product, government expenditure, national savings, government debt and consumer price index or inflation as variables of the study. The results of the study showed a negative relationship between government expenditure and economic growth in the long run. Furthermore, the results of the study revealed a causal relationship from economic growth to government expenditure, implying that economic growth affects government expenditure in South Africa.

Mahachi *et al.* (2015) examined the factors influencing the adoption of renewable energy technology in two Botswana hotels, Gaborone Sun, and Cumberland Hotel through interviews with the key informants from the hotels. The study used the general conceptual model design and the barriers of corporate greening as well as the narrative analysis to present the results. The results of the study revealed the driving forces behind the adoption of renewable energy in the hotels, as the availability of the biogas and technology in Botswana, political leadership, financial benefits, availability of a comprehensive environmental sustainability program and strong environmental management values. The Cumberland Hotel highlighted lack of financial resources as one of the barriers against the adoption of biogas and Gaborone Sun indicated the lack of space for further expansion as the problem with solar energy adoption. The study results suggested that environmental management strategies and values should drive the exploitation of renewable energy by local hotels and at national level, government should take a responsive approach in facilitating the adoption of renewable energy plans.

Sekantsi and Timuno (2017) studied the main drivers of increasing electricity demand in Botswana using the Autoregressive Distributive Lag (ARDL) bounds testing method and the Error Correction Model (ECM) between 1981-2011. The study examined the role of financial development, industrialisation, and urbanisation in Botswana’s energy. The results of the study revealed that economic growth, financial development, and industrialisation have a positive impact on electricity consumption, whilst urbanisation only increase electricity consumption in the long run. The results of the study suggested that policy makers should consider the increase in electricity demand arising from financial development, urbanisation, and industrialisation in their energy consumption planning in the economy to avoid energy crisis. Furthermore, policy makers must invest in renewable energy source to access affordable energy source.

3. METHODOLOGY

The study utilises borrowed time series data spanning for the period from 1980 to 2021 sourced from the World Bank and International Energy Agency to analyse renewable electricity generation and government expenditure on economic growth of South Africa and Botswana utilising renewable electricity consumption, CO2 emissions, government expenditure and trade as control variables. shown in the growth function below adopted from Khobai and Le Roux (2017).

LGDP = f(LREG, LCO2, LGOV, LTR)……………………..…………………………..… (3.1)

Table 3.1 Data Sources and Description

Symbol	Variable	Description	Unit	Source
LGDP	Economic growth	Gross domestic product per capita growth	Annual %	World Bank
LREG	Renewable electricity generation	Renewable electricity generation is the share of renewable electricity in total final electricity generation.	Gigawatt Hours	IEA
LCO2	Carbon dioxide emissions	Carbon dioxide emissions from all sources	Total metric tonnes	IEA
LGOV	Government Expenditure	Annual percentage growth of general government final consumption expenditure based on constant local currency. Aggregates are based on constant 2015 prices, expressed in U.S. dollars. General government final consumption expenditure (general government consumption) includes all government current expenditures for purchases of goods and services (including compensation of employees). It also includes most expenditures on national defence and security but excludes government military expenditures that are part of government capital formation.	Annual % growth	World Bank
LTR	Trade	Merchandise trade as a share of GDP is the sum of merchandise exports and imports divided by the value of GDP, all in current U.S. dollars.	% Of GDP	World Bank

Source: Authors owns compilation

The empirical model estimation utilised in the study was adopted from the studies of Khobai and Le Roux (2017), Stungwa *et al.* (2022), Hlongwane and Daw (2021b), Hlongwane and Daw (2021a) and Hlongwane and Daw (2022b). The study modifies this model to suit the study's main objective. The linear econometric model can be specified as follows:

$$LGDP_t = \beta_0 + \beta_1 LREG_t + \beta_2 LCO2_t + \beta_3 LGOV_t + \beta_4 LTR_t + \varepsilon_t \ldots\ldots\ldots\ldots\ldots\ldots.\ldots\ldots\ldots. (3.2)$$

Whereby,

LGDP = natural logarithm of gross domestic product per capita

LREG = logged renewable electricity generation

LCO2 = logged CO2 emissions

LGOV = natural logarithm of government expenditure

LTR = natural logarithm of trade

ε_t = is the error term

t = refers to the period

β_{0_4} = refers to the constants

3.2 Unit root

Tests of unit root are estimated at first before estimating Autoregressive Distributed Lags (ARDL) model. This is done to determine the level of integration of variables and avoid problems of spurious regressions if the variables are found to be stationary. The study employs the Dickey-Fuller Generalised Least Squares (DF-GLS) and Phillips-Perron (PP) unit root test proposed by Elliott *et al.* (1992) and Phillips and Perron (1988). Elliott *et al.* (1996) argues that the DF-GLS test has more power in the presence of an unknown trend or mean compared to the ADF and PP unit root test. The null hypothesis of unit root is tested against the alternative hypothesis of stationarity in all tests. If the computed DF-GLS test statistic is greater than the critical values at 1%, 5% and 10% level of significance, the null hypothesis of unit root is rejected and conclude that the series is stationary. This study is used to determine the long-time properties of the variables employed in the model. If a time series is found to be stationary, it means that its variance, mean, and covariance remain constant over time, and that the result of their analysis is reliable and can be used to forecast future economic activities. The study also employs the VAR lags criterion to determine the optimal number of lags to use in the estimation.

3.3 ARDL Model and long run relationships

The study adopts the Autoregressive Distributed Lags model proposed by Pesaran *et al.* (2001) to analyse renewable electricity generation and government expenditure on economic growth of South Africa and Botswana. Studies that make the literature review shows that majority of the studies has been focusing on a single country analysis and limited studies has carried a comparative analysis on the topic. This study, however, utilises the ARDL model to show the short run and long run relationships between the variables and to reveal if the results found by majority of the studies in the literature section is the same in South Africa and Botswana. The ARDL model for long run relationships can be specified as given in Equations 3.3 to 3.7 below:

$$LGDP_t = \beta_{01} + \sum_{i=1}^{p} k_{11}\, LGDP_{t-i} + \sum_{i=1}^{q} k_{21}\, LREG_{t-i} + \sum_{i=1}^{q} k_{31}\, LCO2_{t-i} + \sum_{i=1}^{q} k_{41}\, LGOV_{t-i} + \sum_{i=1}^{q} k_{51}\, LTR_{t-i} + \varepsilon_t \quad \text{(3.3)}$$

$$LREG_t = \beta_{02} + \sum_{i=1}^{p} k_{12}\, LREG_{t-i} + \sum_{i=1}^{q} k_{22}\, LGDP_{t-i} + \sum_{i=1}^{q} k_{32}\, LCO2_{t-i} + \sum_{i=1}^{q} k_{42}\, LGOV_{t-i} + \sum_{i=1}^{q} k_{52}\, LTR_{t-i} + \varepsilon_t \quad \text{(3.4)}$$

$$LCO2_t = \beta_{03} + \sum_{i=1}^{p} k_{13}\, LCO2_{t-i} + \sum_{i=1}^{q} k_{23}\, LREG_{t-i} + \sum_{i=1}^{q} k_{33}\, LGDP_{t-i} + \sum_{i=1}^{q} k_{43}\, LGOV_{t-i} + \sum_{i=1}^{q} k_{53}\, LTR_{t-i} + \varepsilon_t \quad \text{(3.5)}$$

$$LGOV_t = \beta_{04} + \sum_{i=1}^{p} k_{14}\, LGOV_{t-i} + \sum_{i=1}^{q} k_{24}\, LCO2_{t-i} + \sum_{i=1}^{q} k_{34}\, LREG_{t-i} + \sum_{i=1}^{q} k_{44}\, LGDP_{t-i} + \sum_{i=1}^{q} k_{54}\, LTR_{t-i} + \varepsilon_t \quad \text{(3.6)}$$

$$LTR_t = \beta_{05} + \sum_{i=1}^{p} k_{15}\, LTR_{t-i} + \sum_{i=1}^{q} k_{25}\, LGOV_{t-i} + \sum_{i=1}^{q} k_{35}\, LCO2_{t-i} + \sum_{i=1}^{q} k_{45}\, LREG_{t-i} + \sum_{i=1}^{q} k_{55}\, LGDP_{t-i} + \varepsilon_t \quad \text{(3.7)}$$

3.4 ARDL-Error Correction Model and short run relationships

After confirmation of long run relationships existing between renewable electricity generation, economic growth, trade, CO2 emissions, and government expenditure using the ARDL-Bounding tests to cointegration, the study employs the ARDL-ECM model to determine the short run relationships between the variables. Short run dynamic error correction model can be derived from the ARDL long run estimations models made through a simple linear transformation. Equations 3.8 to 3.12 below shows the ARDL-ECM model whereby, ECT_{t-1}

is an error correction term that should be negative and statistically significant, Δ represents the differenced short run variables while λ shows the coefficient of the speed of adjustment to long run equilibrium:

$$\Delta LGDP_t = \beta_{01} + \sum_{i=1}^{p} \alpha_{11} \Delta LGDP_{t-i} + \sum_{i=1}^{q} \alpha_{21} \Delta LREG_{t-i} + \sum_{i=1}^{q} \alpha_{31} \Delta LCO2_{t-i} + \sum_{i=1}^{q} \alpha_{41} \Delta LGOV_{t-i} + \sum_{i=1}^{q} \alpha_{51} \Delta LTR_{t-i} + \lambda ECT_{t-1} + \varepsilon_t \quad (3.8)$$

$$\Delta LREG_t = \beta_{02} + \sum_{i=1}^{p} \alpha_{12} \Delta LREG_{t-i} + \sum_{i=1}^{q} \alpha_{22} \Delta LGDP_{t-i} + \sum_{i=1}^{q} \alpha_{32} \Delta LCO2_{t-i} + \sum_{i=1}^{q} \alpha_{42} \Delta LGOV_{t-i} + \sum_{i=1}^{q} \alpha_{52} \Delta LTR_{t-i} + \lambda ECT_{t-1} + \varepsilon_t \quad (3.9)$$

$$\Delta LCO2_t = \beta_{03} + \sum_{i=1}^{p} \alpha_{13} \Delta LCO2_{t-i} + \sum_{i=1}^{q} \alpha_{23} \Delta LREG_{t-i} + \sum_{i=1}^{q} \alpha_{33} \Delta LGDP_{t-i} + \sum_{i=1}^{q} \alpha_{43} \Delta LGOV_{t-i} + \sum_{i=1}^{q} \alpha_{53} \Delta LTR_{t-i} + \lambda ECT_{t-1} + \varepsilon_t \quad (3.10)$$

$$\Delta LGOV_t = \beta_{04} + \sum_{i=1}^{p} \alpha_{14} \Delta LGOV_{t-i} + \sum_{i=1}^{q} \alpha_{24} \Delta LCO2_{t-i} + \sum_{i=1}^{q} \alpha_{34} \Delta LREG_{t-i} + \sum_{i=1}^{q} \alpha_{44} \Delta LGDP_{t-i} + \sum_{i=1}^{q} \alpha_{54} \Delta LTR_{t-i} + \lambda ECT_{t-1} + \varepsilon_t \quad (3.11)$$

$$\Delta LTR_t = \beta_{05} + \sum_{i=1}^{p} \alpha_{15} \Delta LTR_{t-i} + \sum_{i=1}^{q} \alpha_{25} \Delta LGOV_{t-i} + \sum_{i=1}^{q} \alpha_{35} \Delta LCO2_{t-i} + \sum_{i=1}^{q} \alpha_{45} \Delta LREG_{t-i} + \sum_{i=1}^{q} \alpha_{55} \Delta LGDP_{t-i} + \lambda ECT_{t-1} + \varepsilon_t \quad (3.12)$$

3.5 Diagnostics Tests

3.5.1 Serial Correlation: The study will utilise the Breusch-Godfrey Serial Correlation LM test to determine serial correlation in the model.

3.5.2 Heteroskedasticity: The study will utilise the Breusch-Pagan-Godfrey test to find out if the condition of homoscedasticity is found or not in the estimated model.

3.5.3 Normality test: The study will employ the Jarque-Berra histogram normality test to check if the estimated model's residuals are normally distributed and ascertain no violation of the normality rule of linear models.

3.5.4 Stability tests: The study will rely on the CUSUM SUM, CUSUMSQ and Ramsey RESET tests to ensure the stability of the estimated parameter.

4. RESULTS AND INTEPRETATIONS

Table 4.1: Unit root test South Africa

Variables	**Dickey-Fuller GLS**		**Phillips-Perron**	
	Constant	Trend & Intercept	Constant	Trend & Intercept

	Level	Δ	Level	Δ	Level	Δ	Level	Δ
LGDP	-3.4872 ***	-7.5013 ***	-4.1252 ***	-6.5075 ***	-4.2547 ***	-9.7253 ***	-4.3897 **	-8.6762 ***
LREG	-1.7045 *	-7.5047 ***	-3.2273 ***	-8.1538 ***	-1.5002	-8.5365 ***	-3.0926	-9.5849 ***
LCO2	-0.1993	-5.1016 ***	-1.1654	-6.3023 ***	-1.9971	-5.9872 ***	-0.9321	-6.2618 ***
LGOV	-3.2729 ***	-0.0570	-4.6776 ***	-8.0373 ***	-5.6190 ***	-25.663 ***	-5.6066 ***	-25.136 ***
LTR	-1.4788	-6.5259 ***	-2.3916	-7.0117 ***	-1.4046	-7.2456 ***	-3.2396 *	-9.9684 ***

Source: Author's own computation

Table 4.2: Unit root test Botswana

Variables	**Dickey-Fuller GLS**				**Phillips-Perron**			
	Constant		Trend & Intercept		Constant		Trend & Intercept	
	Level	Δ	Level	Δ	Level	Δ	Level	Δ
LGDP	-5.5431 ***	-8.2669 ***	-6.9107 ***	-8.6904 ***	-6.0805 ***	-22.857 ***	-7.1390 ***	-22.778 ***
LREG	-2.5913 **	-3.1095 ***	-2.5614	-4.4247 ***	-6.7934 ***	-3.1928 *	-2.8701	-11.570 ***
LCO2	0.0403	-5.6986 ***	-2.1221	-6.5119 ***	-1.6728	-6.5237 ***	-2.3661	-6.5220 ***
LGOV	-2.7627 ***	-7.8574 ***	-4.2688 ***	-5.9367 ***	-3.3986 **	-15.919 ***	-4.1824 **	-19.187 ***
LTR	-1.8380 *	-7.3450 ***	-2.5856	-7.2347 ***	-2.1849	-7.2991 ***	-2.5072	-7.2293 ***

Source: Author's own computation

The study performed the DF-GLS and PP unit root test as shown in Tables 4.1 and 4.2 above for South Africa and Botswana, respectively. The results of both DF-GLS and PP unit root tests reveal that variables are mainly stationary at first difference when the constant as well as the constant and trend are incorporated. The study, however, will estimate the relationships utilising the variables at first difference I(1) for better analysis and this makes it suitable to deploy the ARDL model proposed by Pesaran *et al.* (2001).

Table 4.3: Bounding test to cointegration

Country	F-statistic	Critical Values					
		1%		5%		10%	
		I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
South Africa	9.622042 ***	3.29	4.37	2.56	3.49	2.2	3.09
Botswana	2.436079	3.29	4.37	2.56	3.49	2.2	3.09

Source: Author's own computation. Note: (***) indicates 1% level of significance

The study performed the ARDL-Bounding test to cointegration as shown in Table 4.3 above. The results revealed that there are long run relationships between the variables in South Africa, whereas in Botswana there is only short run relationships. This is because the f-statistic (9.622042) for South Africa is greater than the critical values at 1%, 5% and 10% level of significance, whereas the f-statistic (2.436079) for Botswana is below the critical values at 1%, 5% and 10% level of significance. The study will estimate both short run and long run relationships for South Africa, whereas for Botswana it will estimate short run relationships only as shown in Tables 4.4 and 4.5 below.

Table 4.4: Short run relationships. Dependent variable: DLGDP

Variable	South Africa ARDL (3,4,1,1,2)	Botswana ARDL (1,0,0,0,0)
DLGDP(-1)	0.273773 (0.0559)	-0.776927 (0.4315)
DLREG	1.319019 (0.0032)	-10.69943 (0.7386)
DLCO2	51.31325 (0.0000)	26.97914 (0.6515)
DLGOV	-0.231927 (0.0202)	0.302747 (0.7253)
DLTR	0.206646 (0.0047)	0.005779 (0.9913)
ECT(-1)	-2.180168	-1.776927

	(0.0000) ***	(0.0046) **
R-Squared	0.916103	0.784622
Adj R-Squared	0.883835	0.784622
DW Stat	1.925270	2.223875

Source: Author's own computations, Note: Figure in parenthesis are p-values

The study employed the ARDL (3,4,1,1,2) for South Africa and ARDL (1,0,0,0,0) based on the available data spanning from 1980 to 2021 as shown in Table 4.4 above. The results reveal a positive statistically significant relationship between renewable electricity generation and economic growth for South Africa, whereas a negative statistically insignificant relationship between renewable electricity generation and economic growth for Botswana. A 1% increase in renewable electricity generation in the short run in South Africa significantly result in economic growth rising by 1.31%, ceteris paribus. Whereas a 1% increase in renewable electricity generation in Botswana in the short run insignificantly result in economic growth declining by 10.70%, ceteris paribus. This means that renewable electricity generation is good for the growth of South African economy whereas it has not been able to influence economic growth in Botswana as Botswana still lags with renewable electricity generation.

Moreover, there is a positive statistically significant relationship between CO2 emissions and economic growth in South Africa and positive statistically insignificant relationship between CO2 emissions and economic growth in Botswana in the short run. A 1% increase in CO2 emissions in the short run in South Africa significantly result in economic growth rising by 51.31%, ceteris paribus. Whereas a 1% rise in CO2 emissions in Botswana in the short run insignificantly result in economic growth rising by 26.98%, ceteris paribus. These results entail that CO2 emissions plays an important role in the growth of these two economies. These results are inconsistent with the study of Hlongwane and Daw (2022b). This also calls for the government of South Africa and Botswana to reveal their CO2 emissions to have an economic growth that is compliant with environmentally friendly.

Furthermore, there is a negative statistically significant relationship between government expenditure and economic growth in South Africa, whereas a positive statistically insignificant relationship between government expenditure and economic growth in the short run. A 1% increase in government expenditure in the short run in South Africa, significantly result in economic growth declining by 0.23%, ceteris paribus. These results are consistent with the study of Hlongwane *et al.* (2021) that found the negative relationship between government expenditure and economic growth. Whereas a 1% increase in government expenditure in the short run in Botswana insignificantly result in economic growth rising by 0.30%, ceteris paribus. These results entail that increase in government expenditure is good for the growth of Botswana economy and detrimental for the growth of South African economy. This calls for the governments of these countries to review fiscal policies so that they can be able to significantly boost economic growth.

Moreso, there is a positively statistically significant and insignificant relationship between merchandise trade and economic growth in South Africa and Botswana respectively. A 1% increase in trade in South Africa in the short run significantly result in economic growth rising by 0.20%, ceteris paribus. Whereas a 1% rise in trade in Botswana in the short run insignificantly result in economic growth rising by 0.01%, ceteris paribus. These results entail that increase in merchandise trade is imperative for the growth of these two economies. These results are consistent with the studies of Hlongwane and Daw (2022b) and Khobai and Le Roux (2017).

The R-squared for South Africa is 0.916103, meaning that 91.61% of the variation in economic growth is explained by the independent variables while the remaining 8.39% is explained by the error term. The R-squared for Botswana is 0.784622, meaning that 78.46% of the variation in economic growth is explained by the independent variables while 21.54% is explained by the error term. These results display the favourable goodness of fit for the model as it is highly recommended that it should be 70% and above for a reliable model (Hlongwane & Daw, 2022b).

Table 4.5: Long run relationships. Dependent variable: LGDP

Variable	South Africa ARDL (3,4,1,1,2)	Botswana
DLREG	-0.200676 (0.7820)	N/A
DLCO2	11.50118 (0.0759) *	N/A
DLGOV	-0.322541 (0.0848) *	N/A
DLTR	-0.057290 (0.5670)	N/A

C	-0.130432 (0.4447)	N/A

Source: Author's own computations, Note: Figure in parenthesis are p-values

The results performed the long run tests for South Africa only as guided by the results from the ARDL Bounding tests as shown in Table 4.5 above. There is a negative statistically insignificant long run relationship between renewable electricity generation and economic growth in South Africa. A 1% increase in renewable electricity generation in the long run in South Africa insignificantly result in economic growth declining by 0.20%, ceteris paribus. This entails that in the long run renewable electricity generation has not been able to boost economic growth. These results are inconsistent with the studies of Stungwa *et al.* (2022), Hlongwane and Daw (2021b) and Khobai and Le Roux (2017) that found a positive relationship, whilst consistent with the study of Hlongwane and Daw (2022b) that found negative relationship.

Moreover, there is a positive statistically significant relationship between CO2 emissions and economic growth in South Africa in the long run at 10% level of significance. A 1% increase in CO2 emissions in the long run in South Africa significantly result in economic growth rising by 11.50%, ceteris paribus. These results entail that CO2 emissions has been playing a significant role on the growth of the South African economy. These results are inconsistent with the studies of Hlongwane and Daw (2022b), while inconsistent with the studies of Stungwa *et al.* (2022), Khobai and Le Roux (2017) and Hlongwane and Daw (2022a).

Furthermore, there is negative statistically significant long run relationship between government expenditure and economic growth in South Africa at 10% level of significance. A 1% increase in government expenditure in the long run significantly result in economic growth declining by 0.33%, ceteris paribus. These results entail that government expenditure has not been able to influence economic growth in the long run for the period understudy. These results are consistent with the studies of Hlongwane *et al.* (2021) and Oladele (2016).

Moreso, there is a negative statistically insignificant relationship between merchandise trade and economic growth in the long run in South Africa. A 1% increase in merchandise trade insignificantly result in economic growth declining by 0.06%, ceteris paribus. These results entail that merchandise trade has not been able influence economic growth for the period understudy. These results are consistent with the studies of Hlongwane and Daw (2022b). The study continues to perform diagnostics tests as shown in Table 4.6 below to check validity of the results.

Residual diagnostics test

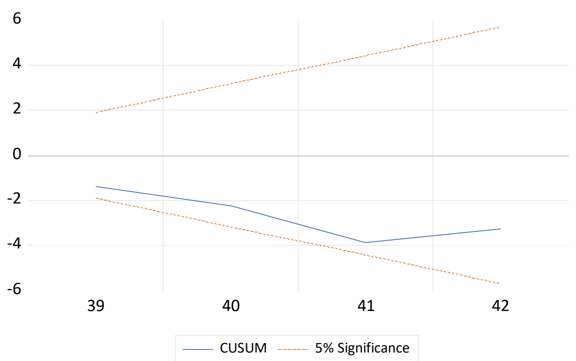
Table 4.6: Normality, heteroskedasticity, serial correlation and stability test

Country	Normality	Serial Correlation	Heteroskedasticity	Ramsey's RESET test
South Africa	1.0457 (0.5928)	0.0605 (0.8057)	17.159 (0.3095)	0.2400 (0.6297)
Botswana	0.9106 (0.3847)	0.4960 (0.4813)	3.4607 (0.6293)	0.7132 (0.4604)

Source: Author's own computation. Note: Figures in parenthesis are p-values

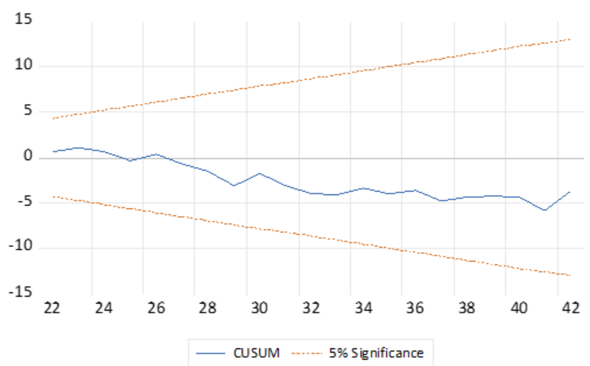
The study performed the diagnostics tests of normality, heteroskedasticity, serial correlation and model specification as shown in Table 4.6 above. The Jarque-Berra normality test was performed, and they revealed that the residuals are normally distributed for both South Africa and Botswana. Moreso, the study performed the Breusch-Godfrey LM serial correlation test and the results revealed that there is no serial correlation in the estimated models for both Botswana and South Africa. Furthermore, the study performed the Breusch-Pagan heteroskedasticity test and the results revealed that there is no heteroskedasticity in the selected model as the residuals are homoskedasticity. Lastly, there study checked the validity of model specification employing the Ramsey's RESET test and the results revealed the model is correctly specified.

Figure 4.1: CUSUM Botswana



Source: Authors' compilation

Figure 4.2: CUSUM South Africa



Source: Authors' compilation

Finally, the study performed the stability of the coefficients, the cumulative sum of recursive residuals (CUSUM) test for both South Africa and Botswana. The CUSUM graphs in Figures 4.1 and 4.2 above indicate model stability for both countries as the plots are within 5% confidence interval critical bands.

5. CONCLUSION AND RECOMMENDATIONS

The study analysed renewable electricity generation and government expenditure on economic growth in South Africa and Botswana for the period from 1980 to 2021. Dickey-Fuller Generalised Least Squares (DF-GLS) and Phillips-Perron (PP) unit root test were employed to determine the order of integration and avoid spurious regressions. The study performed the ARDL Bounds test and found only cointegration in South Africa and no cointegration for Botswana. The study employed the ARDL short and long run relationships for South Africa, whereas for Botswana it only performed short run relationships between the variables in the model. The study therefore provides the following recommendations based on statistical evidence:

Firstly, Eskom and Botswana Power Corporation needs to revise policies on renewable energy so it can significantly boost economic growth with a greater magnitude. Renewable electricity generation has managed to boost economic growth in the short run for South Africa while in the long run it was found to be detrimental. Botswana has adopted renewable electricity generation from five years back and the renewable electricity generation has not been able to influence economic growth as it was found to be detrimental.

Secondly, CO_2 emissions has been found to be boosting economic growth in South Africa both in the short run and long run period whereas for Botswana it was found to be detrimental. This calls for the respective policy makers in both countries to review policies on CO_2 emissions so they can achieve environmentally friendly economic growth. These two countries rely much on coal for electricity generation, and this is a contributing factor to their CO_2 emission levels.

Thirdly, government expenditure was found to boost economic growth in Botswana whereas it is detrimental for the growth of South African economy in both short and long run periods. This calls for the South African government and Botswana to review fiscal policies so they can increase their spending in funding renewable electricity generation and infrastructure. Finally, both countries need to promote trade as it boosts economic growth. This can be done through export promotion and import substitutions for both countries.

The main objective of this study was to analyse renewable electricity generation and government expenditure on economic growth in Botswana and South Africa from 1980 to 2021. By employing the ARDL model, the objective was achieved by revealing short and long run relationships for South Africa and only short run relationships for Botswana. In conclusion, renewable electricity generation was found to have a detrimental effect in Botswana and a favourable effect in South Africa in the short run. In the future, studies should consider using other models especially panel models to reveal new insights in the field.

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