

Hlongwane, Nyiko Worship; Daw, Olebogeng David

Article

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Kontakt/Contact

ZBW – Leibniz-Informationszentrum Wirtschaft/Leibniz Information Centre for Economics
Düsternbrooker Weg 120
24105 Kiel (Germany)
E-Mail: [rights\[at\]zbw.eu](mailto:rights[at]zbw.eu)
<https://www.zbw.eu/econis-archiv/>

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The Challenges and Opportunities of Electricity Generation on Economic Growth in South Africa: An ARDL Approach

Nyiko Worship Hlongwane*, Olebogeng David Daw

School of Economics, North-West University, South Africa. *Email: nyikowh@gmail.com

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ABSTRACT

This study examines the challenges and opportunities of electricity generation from coal on growth of South African economy. The study utilizes the available annual time series data collected from secondary sources (World Bank) spanning for the period from 1971 to 2015. The study employs the Autoregressive Distributed Lag (ARDL) model and an Error Correction Model (ECM) to analyse the challenges and opportunities of coal-fired electricity generation on growth South African economy. Statistical results from revealed a positive statistically insignificant short run and positive statistically significant long run relationship between electricity generated from coal and economic growth in South Africa. Renewable electricity generation also contribute positively to economic growth both in the short and long run period. The policy implication from this study is that the policy makers need to acknowledge the positive contribution of coal-fired electricity generation, revise policies on decommissioning of these powerplants, implement policies that encourage coal-fired electricity generation in a way that is environmentally friendly and increase investment in renewable electricity generation to boosts economic growth in South Africa.

Keywords: Electricity Generation, Economic Growth, Autoregressive Distributed Lag (ARDL) Model, Renewable Electricity, South Africa

JEL Classifications: C1, C29, Q43, Q44, P18

1. INTRODUCTION

Electricity is one of the main components needed in all countries today for carrying daily activities. Almost all the household in South Africa whether in a formal or informal settlements use electricity on daily basis for cooking, light, food conservation and industrial services. The high demand for electricity in South Africa recently has been mate with a shortage of electricity supply that was evident with the continuous power cuts from time and again to balance the demand and avoid a day in the darkness.

Lenoke (2017) stresses that power cuts impact the economy negatively in South Africa. South Africa is known to be a water scarce country that cannot afford massive hydroelectricity generation units or powerplants. This has resulted in South African economy relying on electricity produced from coal, oil, and gas sources for a long period. Several scholars have been focusing on the supply and

demand of electricity but only a limited number of them have focused on the generation side of electricity in South Africa. Researchers such as Khobai (2018) focused on the electricity generation in South Africa but mainly focusing on the renewable sources.

1.1. Overview of the Study

Figure 1 above presents information or a highlight of sources of annual electricity generation in South Africa from 2010 to 2020. It is demonstrated that in Figure 1, coal is the main source of electricity, followed by nuclear and imported electricity in South Africa. Halsey et al. (2017) highlights that South Africa has vast coal reserves, lower-quality coal is utilized domestically, while higher-quality coal of about 30% is exported. For national usage, roughly 60% of the coal is used in power plants to generate electricity, while the remaining 25% is used in a coal-to-liquid conversion operation. In 2016, over 91% of South African households had access to electricity, nonetheless, 1.5 million households remained without electricity.

While majority of the households utilizing power are directly linked to the grid, around 3.6% use electricity through an illegal connection, and about 0.4% use electricity without paying for it.

The Table 1 provides the coal-fired powerplants, their location, capacity, date commissioned, planned date of decommissioning and the operator. As depicted in the Table 1, most of the powerplants are in Mpumalanga province the coal-rich province while a few are in Gauteng, Limpopo, and Free State. Ozonoh et al. (2018) highlights that South Africa has huge coal reserves and 95% of the electricity production is from coal. Most of these powerplants have are old and has been constructed from as back as 1952, a case with Pretoria West in powerplant.

According to StatSA (2018), South Africa has an estimated 256 years of available coal reserves left in 2014 that fell from 282 in 2005 and those hoping for cleaner energy it might be impossible to break the dominance of electricity from coal. Coal is not only the cheapest source of energy in South Africa, but it has abundant reserves that can be utilised in a manner aligned with the promotion of cleaner energy and coal value of sales increased by 199% from 2005 to 2014 (StatSA, 2018). However, Ratshomo and Nembahe (2019) alludes that at the present extraction rate, it estimated that there is over 50 years of coal left.

Eskom (2019) stresses that with a total nominal electricity capacity of 45 gigawatts, Eskom dominates generation and of this, 40 gigawatts come from coal-fired power plants. Backlogs in and inadequate maintenance, low reserve levels, and insufficient coal supplies and frequent usage of substandard coal are major difficulties for Eskom's generation capabilities. Eskom's coal-fired power plants are on average 37 years old, and therefore require extensive maintenance and retrofitting to ensure their ongoing functioning. Eskom's reserve capacity levels have been impacted by delays in the commercial operation of the Medupi and Kusile power plants.

Gabrielle (2020) contents that Eskom owns and manages 29 power plants, accounting for 89% of total generation capacity, the

majority of which are coal-fired, as well as the continent's lone nuclear power plant, Koeberg. Independent Power Producers and private industrial generators such as cogeneration plants at pulp and sugar refineries and solar PV projects hold around a tenth of installed capacity, whereas municipalities own only 1%. Solar PV systems and diesel generators are examples of distributed generation, which presently totals 1GW. Eskom's total electricity sales in 2019 were 208,319 GWh per hour (GWh), down from 208,319 GWh in 2007. Sales of electricity per capita have fallen by 7% in only the last 2 years.

According Mjambana (2021), South Africa's energy source has historically been dominated by coal. Coal now provides roughly 77% of South Africa's basic energy demand. Eskom has been building two new coal-fired power plants, the Medupi and Kusile power stations, during the last decade, each with a capacity of 4800 MW and a combined capacity of more than 9GW. The Medupi power plant was eventually finished on August 2, 2021, according to Eskom but sections of Kusile are still under development. By 2030, the IRP intends to decommission slightly over 10,000 MW of coal-fired power stations, replacing them with a combination of renewables and natural gas.

However, Eskom's plans to shift to renewables and achieve carbon neutrality by 2050 faces a huge criticism from trade unions and vested sectors in the coal sector. South Africa's coal mining players are exiting the market but it remains clear that coal will a significant role in the future of electricity generation as indicated in the South Africa's Integrated Resource Plan 2019 (Green, 2021).

2. LITERATURE REVIEW

2.1. Studies that Found Positive Relationship

Yoo and Kim (2006) investigated electricity generation and economic growth in Indonesia. The study borrowed time series data spanning from 1971 to 2002. The study employed an Engle-Granger model to analyse the relationship between

Table 1: South Africa's coal-fired power plants

Power Plant	Province	Capacity MW (planned)	Date commissioned	Planned date of decommissioning	Operator
Arnot	Mpumalanga	2 352	1971-1975	2025-2029	Eskom
Camden	Mpumalanga	1 561	1967-1969, 2005-2008	2020-2023	Eskom
Duvha	Mpumalanga	3 600	1980-1984	2030-2034	Eskom
Grootvlei	Mpumalanga	1 180	1969-1977, 2008-2011	2025-2028	Eskom
Hendrina	Mpumalanga	1 893	1970-1976	2021-2027	Eskom
Kelvin	Gauteng	214	1957		Aldwych International
Kendal	Mpumalanga	4 166	1988-1992	2038-2043	Eskom
Komati	Mpumalanga	990	1961-1966, 2009-2013	2024-2028	Eskom
Kriel	Mpumalanga	3 000	1976-1979	2026-2029	Eskom
Kusile	Mpumalanga	(4 800)	2017-2021		Eskom
Lethabo	Free State	3 708	1985-1990	2035-2040	Eskom
Majuba	Mpumalanga	4 110	1996-2001	2046-2050	Eskom
Matimba	Limpopo	3 990	1987-1991	2037-2041	Eskom
Matla	Mpumalanga	3 600	1979-1983	2029-2033	Eskom
Medupi	Limpopo	1 588 (4 764)	2015-2019		Eskom
Pretoria West	Gauteng	180	1952	2016	City of Tshwane
Rooival	Gauteng	300	1963	2025	City of Tshwane
Tutuka	Mpumalanga	3 654	1985-1990	2035-2040	Eskom
Total		40 036 (8770)			

Source: Author's own compilation

electricity generation and economic growth. The results from the study indicated a uni-directional causality running from economic growth to electricity generation. The researchers further recommend that policies to reduce electricity generation can be implemented without reducing economic growth in Indonesia.

Sarker and Alam (2010) investigated the nexus between electricity generation and economic growth in Bangladesh. The study borrowed time series data spanning from 1973 to 2006. The study employed a vector autoregressive (VAR) model and the Granger causality test to analyse the relationship between electricity generation and economic growth in Bangladesh. The empirical results reviewed a short run causal relationship running from electricity generation to economic growth. The study recommends that strategies and policies that increase electricity generation should be promoted as it boosts economic growth in Bangladesh.

Bayraktutan et al. (2011) investigated the relationship between electricity generation and economic growth in 30 OECD countries. The study borrowed time series data spanning from 1980 to 2007. The study employed panel data estimation techniques to analyse the relationship between OECD electricity generation and economic growth. The empirical results reviewed a long run positive relationship between electricity generation and economic growth. The researchers recommend that based on empirical results, the 30 OECD countries to implement policies that promote electricity generation so they can meet the electricity demand.

Altintas and Kum (2013) conducted a multivariate Granger causality between electricity generation, prices, exports, and economic growth in Turkey. The researchers borrowed annual time series data spanning from 1970 to 2010. The study employed Granger causality model and an error correction model to analyse the relationship between the variables. The long run results reviewed a causal relationship between the variables and the short run reviewed a bidirectional causality between the variables that runs from economic growth to electricity generation. The researcher recommends that reducing electricity production is detrimental to economic growth and Turkey should implement policies that increase electricity generation to meet an increasing electricity demand. The researchers also point out the need for Turkey to build new generation units to avoid electricity shortage on economic activities.

Ohler and Feters (2014) conducted a study on the causal relationship between renewable electricity generation and economic growth in 20 OECD countries. The borrowed panel data spanning from 1990 to 2008. The study employed a panel error correction model to analyse the relationship between the variables. The empirical results reviewed a bidirectional causality between electricity generation and economic growth. Other results reviewed a negative relationship of reviewed a positive relationship of biomass, hydroelectricity, waste, and wind energy on economic growth in the long run. The researchers recommend that it is important for policymakers to take into consideration environmentally friendly and or economically beneficial energy policies.

Marques et al. (2014) conducted a study on the interaction between electricity generation sources and economic growth in Greece. The study employed time series data from August 2004 to October 2013. The study employed a vector error correction model to analyse the relationship between the variables. The results reviewed a positive impact of convectional fossil sources on economic growth in the short run. Other results reviewed no causality between renewable energy source on economic growth both in the short and long run period. The study recommends the incorporation of Greek technology into renewable electricity generation to enhance economic growth.

Marques et al. (2016) investigated electricity generation mix and economic growth in France. The study borrowed monthly time series data spanning from January 2010 to November 2014. The study employed an autoregressive distributed lag model to analyse the relationship. Empirical results reviewed that nuclear energy boost economic growth in France while renewable energy was found to be detrimental for economic growth. The researchers recommend that policy makers in France should be aware of any reduction in nuclear sources is detrimental to economic growth.

Atems and Hotaling (2018) investigated the effect of non-renewable and renewable electricity generation on economic growth of the selected 174 countries. The study borrowed time series data spanning for the period from 1980 to 2012. The study employed Generalized Method of Moments (GMM) and the Granger causality approach to analyse the relationship between non-renewable and renewable electricity generation on economic growth. The empirical results from the study indicated a positive statistically significant relationship between non-renewable and renewable electricity generation on economic growth on the selected 174 panel. The researchers recommend that based on empirical results the importance of developing policies that increase investment in electricity to tackle the issue of power losses.

Khobai (2018) investigated causal linkages between renewable electricity generation and economic growth in South Africa. The study utilised quarterly time series data spanning from first quarter in 1997 to fourth quarter in 2012. The study employed a vector error correction model and granger causality tests to analyse the relationship between the variables. The empirical results reviewed a unidirectional causality running from electricity generation to economic growth and that electricity generation from renewable energy source enhances economic growth. The researchers recommend that the South African government should make appropriate effort to select energy policies that do not negatively affect economic growth.

Oryani et al. (2020) conducted a study on the impact of electricity generation mix on economic growth and emission in Iran. The study utilised annual time series data spanning for the period from 1980 to 2016. The study borrowed a Structural Vector Autoregressive model to analyse the relationship between the variables through utilising Blanchard and Quah long run restrictions. The empirical results reviewed a positive impact of the increase in a share of renewable electricity on economic

growth. The researchers recommend an increase in the regulation of energy-intensive sectors like powerplants and transportation sectors to reduce the carbon emissions.

Azam et al. (2021) investigated the relationship between renewable electricity generation and economic growth in 25 developing countries. The study borrowed panel data spanning from 1990 to 2017. The study employed a panel Autoregressive Distributed Lag and Granger causality test to analyse the relationship between electricity generation and economic growth in 25 developing countries. The empirical results reviewed positive statistically significant long run relationship between renewable electricity generation and economic growth. The Granger causality results reviewed bidirectional causality that runs from electricity generation to economic growth both in the short and long run period. The researchers recommend the increase in investment in renewable electricity generation through tax credits, renewable energy portfolio standards and certification of renewable energy markets as it boosts economic growth. The researchers also advise the reduction on reliance on non-renewable energy sources.

2.2. Studies that Found an Inverse Relationship

Lean and Smyth (2010) conducted a multivariate Granger causality between electricity generation, exports, prices, and gross domestic product in Malaysia. The study employed time series data from 1970 to 2008. The study employed an autoregressive distributed lag model and granger causality test to analyse the relationship between the variables. The empirical results reviewed unidirectional causality running from economic growth to electricity generation. The researchers recommend that electricity conservation policies and strategies should be implemented in Malaysia and reduce electricity generation without affecting economic growth.

Maslyuk and Dharmaratna (2013) conducted a study on renewable electricity generation, carbon emissions and economic growth in Middle-Income countries in Asia. The study borrowed quarterly panel data spanning from 1980 to 2010. The study employed a structural vector autoregressive model to analyse the relationship between the variables. The empirical results reviewed a negative relationship between energy generation and economic growth in these countries. The researchers recommend that countries need to implement policies that will complement renewable energy generation and improving energy efficiency.

Hdom (2019) investigated carbon dioxide, fossil and renewable electricity generation and economic growth relationships in South American countries. The study borrowed panel data spanning from 1980 to 2010. The study employed a panel Autoregressive Distributed Lag model to analyse the relationship between the variables. The empirical results reviewed negative relationship between fossil electricity generation in the short and long run though in the long run the relationship to economic growth is insignificant. The researchers recommend that South American countries to maintain long term electricity generation from renewable sources.

2.3. Studies that Found No Relationship

Adeola (2019) investigated the relationship between structural breaks, electricity generation and economic growth in Nigeria.

The study borrowed quarterly time series data spanning from 1970 to 2016. The study employed a vector autoregressive model and structural breaks approach-rolling impulse response model to analyse the relationship between the variables. The empirical results reviewed that electricity generation does not granger cause economic growth in Nigeria. The researcher recommends that Nigeria requires a large-scale investment in the electricity sector and the need for renewable electricity to bridge the gap between electricity demand and supply.

3. METHODOLOGY

This study adopts an Autoregressive Distributed Lag (ARDL) model developed by Pesaran et al. (2001) and the Error Correction Model (ECM) to analyse the relationship between electricity generation and economic growth in South Africa. The data is tested for unit root by employing the Augmented Dickey-Fuller (ADF) test, Phillips Perron (PP) test and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test to ascertain stationarity of all variables. The study further employs an ARDL bounding test to determine cointegration among the variables. Diagnostic tests are performed to test for normality (Jarque-Bera), homoskedasticity, serial correlation and stability (CUSUM, RAMSEY). The annual time series data used in this study was collected from World Bank and South African Reserve Bank (SARB) from 1971 to 2015.

Dickey et al. (1984) proposed the three equations given below.

$$\Delta y_t = \gamma y_{t-1} + \sum_{i=2}^p \beta_i \Delta y_{t-i+1} + \varepsilon_t \quad (1)$$

$$\Delta y_t = a_0 + \gamma y_{t-1} + \sum_{i=2}^p \beta_i \Delta y_{t-i+1} + \varepsilon_t \quad (2)$$

$$\Delta y_t = a_0 + \gamma y_{t-1} + a_2 t + \sum_{i=2}^p \beta_i \Delta y_{t-i+1} + \varepsilon_t \quad (3)$$

The level of significance is at 10%, 5%, and 1%. Equation 3.1 does not have a deterministic trend and intercept, while equation 3.2 have a time trend and equation 3.3 is used the overall significance with a constant and a time trend. The rejection for the study is at 5%. If the probability of the ADF test exceed 5%, then the null hypothesis of unit root is rejected in favor of the alternate hypothesis and conclude that the variables are stationary.

Kwiatkowski et al. (1992) proposed a stationarity test for testing the null hypothesis that observable time series is stationary around deterministic trend against the alternative of a unit root as specified by the equation below:

$$x_t = r_t + \beta_t + \varepsilon_t \quad (4)$$

Where, x_t represents a random walk, β_t represents a deterministic trend and ε_t represents an error term. The null hypothesis $H(0)$ is that the data or series is stationary and the alternate hypothesis $H(1)$ is that the data or series is not stationary. The decision is to reject the null hypothesis $H(0)$ at 10%, 5% or 1% level of significance if the KPSS LM statistic is greater than the LM critical statistics and conclude that the series is not stationary.

3.1. Empirical Model Estimation

The ARDL model used in this study was also employed in the studies conducted by Lean and Smyth (2010) and Marques et al. (2016). The model starts with a simple multivariate framework represented as:

$$GDP_t = \beta_0 + \beta_1 ELG_t + \beta_2 GCF_t + \beta_3 CR_t + \beta_4 RELG_t + \beta_5 CO2_t + \varepsilon_t \quad (5)$$

Where:

GDP – Gross domestic product per capita (%)

ELG – Electricity production from coal sources (% of total)

GCF – Gross capital formation (as % of GDP)

CR – Coal Rents (as a % of GDP)

$RELG$ – Renewable electricity output (% of total electricity output)

$CO2$ – Carbon dioxide emissions from solid fuel consumption (% of total)

ε_t – represent the error term.

Since the variables comes in natural logarithm, therefore there is no need to transform them into logarithms. The study continues to specify the short run and long run equations as shown below.

3.2. Estimation of Long Run Relationship

Once cointegration has been established among the variables, the ARDL model that can be specified as given below for long run estimations:

$$GDP_t = \beta_{01} + \sum_{i=1}^p k_{11} GDP_{t-i} + \sum_{i=0}^q k_{21} ELG_{t-i} + \sum_{i=0}^q k_{31} GCF_{t-i} + \sum_{i=0}^q k_{41} CR_{t-i} + \sum_{i=0}^q k_{51} RELG_{t-i} + \sum_{i=0}^q k_{61} CO2_{t-i} + \varepsilon_t \quad (6)$$

$$ELG_t = \beta_{02} + \sum_{i=1}^p k_{12} ELG_{t-i} + \sum_{i=0}^q k_{22} GCF_{t-i} + \sum_{i=0}^q k_{32} GDP_{t-i} + \sum_{i=0}^q k_{42} CR_{t-i} + \sum_{i=0}^q k_{52} RELG_{t-i} + \sum_{i=0}^q k_{62} CO2_{t-i} + \varepsilon_t \quad (7)$$

$$GCF_t = \beta_{03} + \sum_{i=1}^p k_{13} GCF_{t-i} + \sum_{i=0}^q k_{23} ELG_{t-i} + \sum_{i=0}^q k_{33} GDP_{t-i} + \sum_{i=0}^q k_{43} CR_{t-i} + \sum_{i=0}^q k_{53} RELG_{t-i} + \sum_{i=0}^q k_{63} CO2_{t-i} + \varepsilon_t \quad (8)$$

$$CR_t = \beta_{04} + \sum_{i=1}^p k_{14} CR_{t-i} + \sum_{i=0}^q k_{24} ELG_{t-i} + \sum_{i=0}^q k_{34} GCF_{t-i} + \sum_{i=0}^q k_{44} GDP_{t-i} + \sum_{i=0}^q k_{54} RELG_{t-i} + \sum_{i=0}^q k_{64} CO2_{t-i} + \varepsilon_t \quad (9)$$

$$RELG_t = \beta_{05} + \sum_{i=1}^p k_{15} RELG_{t-i} + \sum_{i=0}^q k_{25} CR_{t-i} + \sum_{i=0}^q k_{35} GCF_{t-i} + \sum_{i=0}^q k_{45} ELG_{t-i} + \sum_{i=0}^q k_{55} GDP_{t-i} + \sum_{i=0}^q k_{65} CO2_{t-i} + \varepsilon_t \quad (10)$$

$$CO2_t = \beta_{06} + \sum_{i=1}^p k_{16} CO2_{t-i} + \sum_{i=0}^q k_{26} RELG_{t-i} + \sum_{i=0}^q k_{36} CR_{t-i} + \sum_{i=0}^q k_{46} GCF_{t-i} + \sum_{i=0}^q k_{56} ELG_{t-i} + \sum_{i=0}^q k_{66} GDP_{t-i} + \varepsilon_t \quad (11)$$

3.3. Short Run Relationships

The short run dynamic error correction model can therefore be derived from an ARDL model through a simple linear transformation. The dynamic short run with long run equilibrium is therefore incorporated by an unrestricted ECM with ECM_{t-1} that is an error correction term that should be negative and statistically significant. Δ represents a differenced variable.

$$\Delta GDP_t = \beta_{01} + \sum_{i=1}^p \alpha_{1i} \Delta GDP_{t-i} + \sum_{i=0}^q \alpha_{2i} \Delta ELG_{t-i} + \sum_{i=0}^q \alpha_{3i} \Delta GCF_{t-i} + \sum_{i=0}^q \alpha_{4i} \Delta CR_{t-i} + \sum_{i=0}^q \alpha_{5i} \Delta RELG_{t-i} + \sum_{i=0}^q \alpha_{6i} \Delta CO2_{t-i} + \lambda ECM_{t-1} + \varepsilon_t \quad (12)$$

$$\Delta ELG_t = \beta_{02} + \sum_{i=1}^p \alpha_{1i} \Delta ELG_{t-i} + \sum_{i=0}^q \alpha_{2i} \Delta GDP_{t-i} + \sum_{i=0}^q \alpha_{3i} \Delta GCF_{t-i} + \sum_{i=0}^q \alpha_{4i} \Delta CR_{t-i} + \sum_{i=0}^q \alpha_{5i} \Delta RELG_{t-i} + \sum_{i=0}^q \alpha_{6i} \Delta CO2_{t-i} + \lambda ECM_{t-1} + \varepsilon_t \quad (13)$$

$$\Delta GCF_t = \beta_{03} + \sum_{i=1}^p \alpha_{1i} \Delta GCF_{t-i} + \sum_{i=0}^q \alpha_{2i} \Delta ELG_{t-i} + \sum_{i=0}^q \alpha_{3i} \Delta GDP_{t-i} + \sum_{i=0}^q \alpha_{4i} \Delta CR_{t-i} + \sum_{i=0}^q \alpha_{5i} \Delta RELG_{t-i} + \sum_{i=0}^q \alpha_{6i} \Delta CO2_{t-i} + \lambda ECM_{t-1} + \varepsilon_t \quad (14)$$

$$\Delta CR_t = \beta_{04} + \sum_{i=1}^p \alpha_{1i} \Delta CR_{t-i} + \sum_{i=0}^q \alpha_{2i} \Delta GCF_{t-i} + \sum_{i=0}^q \alpha_{3i} \Delta ELG_{t-i} + \sum_{i=0}^q \alpha_{4i} \Delta GDP_{t-i} + \sum_{i=0}^q \alpha_{5i} \Delta RELG_{t-i} + \sum_{i=0}^q \alpha_{6i} \Delta CO2_{t-i} + \lambda ECM_{t-1} + \varepsilon_t \quad (15)$$

$$\Delta RELG_t = \beta_{05} + \sum_{i=1}^p \alpha_{1i} \Delta RELG_{t-i} + \sum_{i=0}^q \alpha_{2i} \Delta CR_{t-i} + \sum_{i=0}^q \alpha_{3i} \Delta GCF_{t-i} + \sum_{i=0}^q \alpha_{4i} \Delta ELG_{t-i} + \sum_{i=0}^q \alpha_{5i} \Delta GDP_{t-i} + \sum_{i=0}^q \alpha_{6i} \Delta CO2_{t-i} + \lambda ECM_{t-1} + \varepsilon_t \quad (16)$$

$$\Delta CO2_t = \beta_{06} + \sum_{i=1}^p \alpha_{1i} \Delta CO2_{t-i} + \sum_{i=0}^q \alpha_{2i} \Delta RELG_{t-i} + \sum_{i=0}^q \alpha_{3i} \Delta CR_{t-i} + \sum_{i=0}^q \alpha_{4i} \Delta GCF_{t-i} + \sum_{i=0}^q \alpha_{5i} \Delta ELG_{t-i} + \sum_{i=0}^q \alpha_{6i} \Delta GDP_{t-i} + \lambda ECM_{t-1} + \varepsilon_t \quad (17)$$

4. RESULTS

The results of the ADF and PP unit root test are given in the Table 2 and they indicate that all the variables are significant at first difference except for GDP that is significant at both level and first difference. This implies that we fail to reject the null hypothesis (H_0) at the level for GDP and at first difference for ELG, GCF, CR, RELG and CO2 implying that the variables do not have a unit root. Furthermore, this indicates that the variables are integrated of order one or $I(1)$. This means that the ARDL is suitable to be employed in the model since it requires variables to be stationary at level $I(0)$ or first difference $I(1)$ or a mixture of $I(0)$ and $I(1)$ but no variable should be stationary at second difference $I(2)$ as this violates the assumption of the ARDL model.

The study also further performs the KPSS stationarity test to confirm the results that are given by the ADF, and PP unit root test as given in Table 3.

The study therefore continues to perform the lag length criterion to determine optimal number of lags to be used in the study as shown in the Table 4.

The results in Table 4 show that majority of the lag selection order criteria, that is, the LR, FPE, SC and HQ selected 1 lag for the model except for AIC that selected 4 lags. Since the best selected lags is 1, the model the study will utilise 1 lag in the model to analyse the challenges and opportunities of coal-fired electricity generation on the growth of South African economy.

The results in Table 5 indicates the results of the ARDL bounding test to cointegration. The value of the F-statistic (4.076614) is greater than the critical value of the lower bound $I(0)$ and upper bound $I(1)$ at 5% and 10% level of significance. This implies the rejection of the null hypothesis (H_0) of no long run relationship between our variables and we can conclude that there indeed exists a long run relationship between the variables in the model.

The results of the t-Bound test have a t-statistic of -5.329615 that is smaller than the critical values at $I(0)$ and $I(1)$ implying the rejection of the null hypothesis $H(0)$ of no long run relationships. Considering both the results of the F-bound and t-bound test, we can therefore conclude that there indeed exist long run relationship among the variables in the model. The results of the short run relationship between the variables in the model are given in Table 6.

4.1. Cointegrating Equation

$$D(\text{GDP}) = -63.358309494501 - 0.679391447890 * (\text{GDP}(-1) - (1.22367188 * \text{ELG}(-1) - 0.67258825 * \text{GCF}(-1) - 0.45395472 * \text{CR}(-1) + 0.08950797 * \text{RELG} - 0.06646964 * \text{CO2}))$$

From Table 6, the results depict a positive statistically insignificant short run relationship between electricity generated from coal and economic growth in South Africa. This implies that in the short run, a 1% increase in electricity generated from coal will insignificantly result in economic growth increasing by 0.19%, *ceteris paribus*. These results are consistent with the study carried by Marques et al. (2014) that found a positive relationship between electricity generated from fossil fuels and contradicts the study carried by Hdom (2019) that found a negative short run relationship between electricity produced from fossil fuels and economic growth in Southern American countries. This means that policies that increase coal electricity generation must be promoted as this has a positive impact on the growth of South African economy.

Furthermore, there is a positive statistically significant short run relationship between gross capital formation and economic growth in South Africa. This implies that a 1% increase in gross capital formation in the short run, will significantly result in economic growth increasing by 0.42%, *ceteris paribus*. These results confirms that gross capital formation boost economic growth in South Africa in the short run. These results means that policies that favours gross capital formation must be prioritized as this results in economic growth increasing.

There is a negative statistically significant short run relationship between coal rents and economic growth in South Africa. This means that a 1% increase in coal rents in the short run, will significantly result in economic growth declining by 0.49%, *ceteris paribus*. This means that coal rents are not good for economic growth in the short run as they contribute negatively to the growth of the South African economy. These results means that policies that reduces coal rents in the short run must be promoted as this will result in economic growth increasing.

There is a positive statistically insignificant short run relationship between renewable electricity generation and economic growth in South Africa. A 1% increase in renewable electricity generation in the short run, will insignificantly result in economic growth increasing by 0.06% in South Africa, *ceteris paribus*. These results are consistent with the study carried by Khobai (2018) that found a positive impact of renewable electricity generation on the growth of South African economy. This means that in the

Table 2: ADF and PP unit root tests

Variables	ADF				PP			
	Constant		Trend & Constant		Constant		Trend & Constant	
	Level	Δ	Level	Δ	Level	Δ	Level	Δ
GDP	-4.1604***	-6.7202***	-4.3053***	-6.6335***	-4.1522***	-20.8995***	-4.2424***	-21.0584***
ELG	-2.0873	-8.4445***	-2.4608	-8.3639***	-2.0618	-8.3046***	-2.5654	-8.2373***
GCF	-1.5983	-6.7871***	-2.2796	-6.6682***	-1.4043	-6.8467***	-2.2636	-6.6973***
CR	-3.6948***	-7.5464***	-3.6699**	-7.6606***	-3.6166***	-9.7235***	-3.5051*	-9.9414***
RELG	0.0363	-6.1693***	-4.7162***	-6.1820	-1.0166	-6.6356***	-1.6469	-7.6109***
CO2	-1.5448	-6.2441***	-1.1560	-6.3130***	-1.5253	-6.2451***	-1.1018	-6.3129***

Source: Author's own computation (*) Significance at 10%, (**) significance at 5%, (***) significance at 1%

short run renewable electricity generation is important for the growth of South African economy in the short run. These results means that policies that favours renewable electricity generation in the short run must be promoted as this will increase economic growth in South Africa.

There is negative statistically insignificant short run relationship between CO₂ emissions from solid fuel consumption and economic growth in South Africa. A 1% increase in CO₂ emissions from solid fuel consumption will insignificantly result in the growth of South African economy declining by 0.05%, *ceteris paribus*. Though these results are insignificant, their negative contribution on the growth of South African economy is of interest as they are not good for economic growth. This means that policies that favours the reduction of CO₂ emissions from solid fuel consumption must be promoted and implemented to increase economic growth in South Africa.

The coefficient of the error correction model is negative (−0.679391) and statistically significant with a probability of 0.0000. This implies that the speed of adjustment is 67.94%, and if there is deviation from equilibrium then 67.94% economic growth is corrected within a year towards long run equilibrium.

The results of the bound test confirmed that there exist a long un relationship in among the variables. This study then continues to analyse the challenges and opportunities of coal-fired electricity generation on South African economic growth in the long run by estimate the long run ARDL model and the results are given in Table 7.

As given in Table 7, there is a positive statistically significant long run relationship between electricity produced from coal and economic growth in South Africa. This implies that in the long run, a 1% increase in in electricity generated from coal will result in economic growth increasing by 1.22%, *ceteris paribus*. These results are consistent with the studies carried by Atems

and Hotaling (2018) and Altintas and Kum (2013) that found a positive relationship between fossil fuel electricity generation and economic growth. These results mean coal electricity generation is important for the growth of South African economy. This means that policies that favours coal electricity generation must be promoted as this will result in the increase in growth of South African economy.

There is a negative statistically significant relationship between gross capital formation and economic growth in South Africa. A 1% increase in gross capital formation in the long run, will significantly result in economic growth decreasing by 0.67%, *ceteris paribus*. This means that gross capital formation is not good for the growth of South African economy in the long run. These results means that policies that reduces gross capital formation in the long run must be promoted as this will result in increase in the growth of South African economy.

Furthermore, there is a negative statistically insignificant relationship between coal rents and economic growth in the long run in South Africa. A 1% increase in coal rents in the long run in South Africa, will insignificantly result in economic growth decreasing by 0.45%, *ceteris paribus*. This means that coal rents are not good for the growth of South African economy in the long run. These results means that policies that reduces coal rents in the long run must be promoted and implemented as this will result in increase in the growth of the South African economy.

There is a positive 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, will insignificantly result in economic growth increasing by 0.09%, *ceteris paribus*. These results contradicts the results found by Lean and Smyth (2010) and Maslyuk and Dharmaratna (2013) that found the negative relationship between electricity generation and economic growth. These results means that renewable electricity generation is important for the growth of South African economy in the long run. Therefore, policies that favours the implementation and increase in renewable electricity generation must be promoted and implemented to increase economic growth in South Africa.

There is a negative statistically insignificant relationship between CO₂ emissions from solid fuel consumption and economic growth in South Africa. A 1% increase in CO₂ emissions from solid fuel consumption in the long run in South Africa, will insignificantly result in economic growth declining by 0.07%, *ceteris paribus*. This means that CO₂ emissions from solid fuel consumption is not good for the growth of South African

Table 3: KPSS stationarity test

Variables	KPSS stationarity test			
	Intercept		Trend and Intercept	
	Level	Δ	Level	Δ
GDP	0.2757	0.5000**	0.1243*	0.5000***
ELG	0.5759**	0.0915	0.1557**	0.0508
GCF	0.6258**	0.1066	0.1788**	0.1063
CR	0.0993	0.1523	0.0922	0.0977
RELG	0.9363	0.4242*	0.0711***	0.2742
CO ₂	0.4050**	0.1994***	0.1680***	0.0800***

Source: Author's own computation (*) Significance at 10%, (**) significance at 5%, (***) significance at 1%

Table 4: Optimal lag length criteria

Lag	LogL	LR	FPE	AIC	SC	HQ
0	−519.8806	NA	5571.990	25.65271	25.90348	25.74403
1	−403.5881	192.8754*	113.1826*	21.73600	23.49137*	22.37521*
2	−370.9848	44.53127	149.9399	21.90170	25.16166	23.22951
3	−326.6376	47.59207	137.8400	21.49452	26.25909	23.22951
4	−2.89.9284	28.65113	275.3331	21.45992*	27.72909	23.74281

Source: Author's own computation

Table 5: ARDL bounding test to cointegration

F-Bounds test				
Null hypothesis: No levels relationship				
Test Statistic	Value	Signif.	I (0)	I (1)
F-statistic	4.076614	10%	2.26	3.35
k	3	5%	2.62	3.79
		2.5%	2.96	4.18
		1%	3.41	4.68
t-Bounds Test				
Value	Signif.	I (0)	I (1)	
t-statistic	-5.329615	10%	-2.57	-3.86
		5%	-2.86	-4.19
		2.5%	-3.13	-4.46
		1%	-3.43	-4.79

Source: Author's own computation

Table 6: Error correction model and short run relationship

ARDL ECM Regression				
Case 3: Unrestricted Constant and No Trend				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-63.35831	11.89160	-5.327988	0.0000
D (ELG)	0.190833	0.243644	0.783244	0.4394
D (GCF(-1))	0.422154	0.149305	2.827458	0.0081
D (CR(-1))	-0.492334	0.213574	-2.305215	0.0280
D (RELG(-1))	0.060811	0.702385	0.086578	0.9316
D (CO2(-1))	-0.045159	0.036234	-1.246296	0.2220
CointEq(-1)*	-0.679391	0.127475	-5.329615	0.0000
R-squared		0.675833		
Adjusted R-squared		0.621805		
Durbin-Watson stat		1.894351		

Source: Author's own computation

Table 7: ARDL and long run relationships

ARDL levels equation				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
ELG	1.223672	0.522222	2.343201	0.0257
GCF	-0.672588	0.275727	-2.439329	0.0206
CR	-0.453955	0.464241	-0.977842	0.3357
RELG	0.089508	1.023947	0.087415	0.9309
CO2	-0.066470	0.050944	-1.304752	0.2016

Source: Author's own computation

economy in the long run. These results therefore means that policies that promotes the reduction in CO2 emissions from solid fuel consumption in South Africa must be prioritised and implemented as this will result in an increase in the growth of the economy.

The short run and long run relationships has been thoroughly discussed in the study and their implications on the economy. The study therefore carries on performing diagnostic tests to show how serious the results from the study can be taken and for policy formulation as given below.

4.2. Diagnostic Tests

4.2.1. Residual diagnostic test

The results of the residual diagnostic tests (Breusch-Pagan-Godfrey, Harvey, Glesjer and ARCH) in Table 8 have a probability value of >5%. This imply the failure to reject the null hypothesis (Ho) and conclude that the residuals are homoscedastic. The probability value of the Jarque-Bera (0.3551) is greater than 5%

Table 8: Heteroskedasticity and serial tests

Test	Probability	Decision
Breusch-Pagan-Godfrey	0.9316	Fail to reject Ho
Harvey	0.4036	Fail to reject Ho
Glesjer	0.8744	Fail to reject Ho
ARCH	0.1575	Fail to reject Ho
Jarque-Bera	0.3551	Fail to reject Ho

Source: Author's own computation

Table 9: Serial correlation test

Breusch-Godfrey Serial Correlation LM Test:			
Null hypothesis: No serial correlation at up to 1 lag			
F-statistic	0.070310	Prob. F (1,32)	0.9323
Obs*R-squared	0.207499	Prob. Chi-square	0.9015

Source: Author's own computation

Table 10: RAMSEY RESET test

	Value	df	Probability
t-statistic	1.051468	30	0.3014
F-statistic	1.105585	(1, 30)	0.3014
Likelihood ratio	1.556170	1	0.2122

Source: Author's own computation

implying the failure to reject the null hypothesis (Ho) and conclude that the residuals are normally distributed.

Table 9 above shows the results of the Breusch-Godfrey serial correlation test. The study utilised 1 lag to check for serial correlation and the probability value (0.9015) of the Chi-square is >5%. This implies the failure to reject the null hypothesis and conclude that there's no serial correlation among the variables from the model. The study therefore carries on performing the stability diagnostic tests as shown by the CUSUM and CUSUM of squares shown in Figures 2 and 3 to check if the residuals are stable for the period from 1971 to 2015.

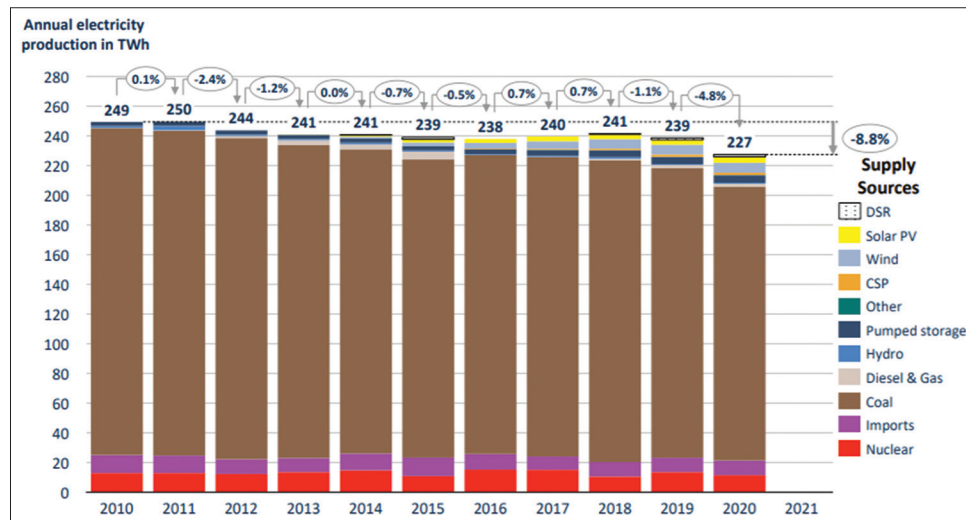
4.2.2. Stability diagnostic test

The study utilizes conducts a stability diagnostic test to ascertain that the model is stable. The study utilised the CUSUM and CUSUM of squares test as shown in Figures 2 and 3. The blue line lies within the 5% critical region implying that the model is stable and reliability of the chosen model. Since the blue line drifts within the red lines or the 5% critical region, this means that the model is stable for the period from 1971 to 2015 as by the CUSUM and CUSUM of squares.

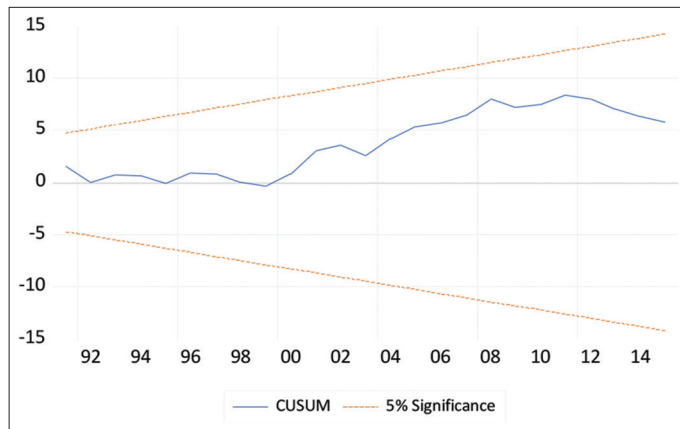
Table 10 above shows the results of the Ramsey Reset test to check for model misspecification The results of the RAMSEY RESET test have an F-statistical probability value (0.3014) that is >5%. This implies the failure to reject the null hypothesis (Ho) and conclude that the chosen model for the study does not suffer from misspecification. Therefore, it is safe to conclude that the model is correctly specified and reliable for policy decisions.

5. CONCLUSION AND RECOMMENDATION

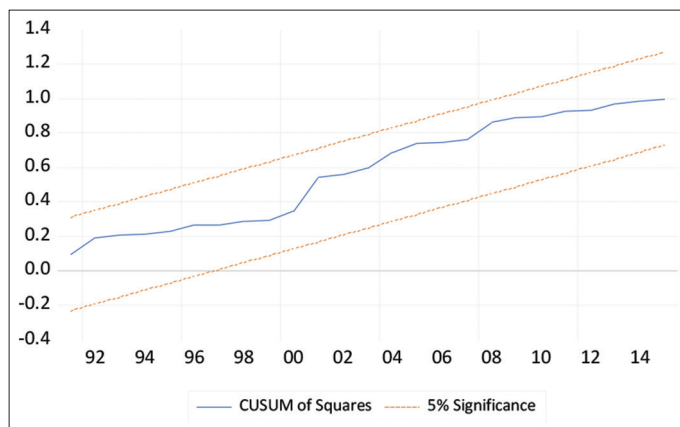
The major aim of the study was to analyse the challenges and opportunities of electricity generated from coal on economic growth in South Africa using available time series spanning from

Figure 1: Sources of electricity generation in South Africa

Source: Calitz and Wright (2021)

Figure 2: CUSUM

Source: Author's own computation

Figure 3: CUSUM of squares

Source: Author's own computation

1971 and 2015. The goal was assured by employing the techniques of stationarity tests (ADF, PP and KPSS), the ARDL bounding test for cointegration, Autoregressive Distributed Lag (ARDL) model, Error Correction Model (ECM) and diagnostic test (residual and stability diagnostic).

The unit root reviewed that the variables are stationary at level and first difference, in simplicity, they are integrated of $I(0)$ and $I(1)$ which is in line with the expectation of the ARDL model. The ECM revealed a short run statistically insignificant relationship between electricity generated from coal and economic growth in South Africa. The ARDL revealed that there is a positive statistically significant long run relationship between electricity generated from coal and economic growth in South Africa for the period understudy. The Error Correction Model revealed that the speed of adjustment is 67%, meaning and if there is deviation from equilibrium then 67% economic growth is corrected within a year.

The challenges identified are of old generating plants that include the likes of Arnot, Camden, Grootvlei, Hendrina, Kelvin, Komati, Kriel, Matla, Pretoria West and Rooival power plants. On average, Eskom's coal-fired powerplants are 37 years and they lack adequate maintenance to keep them functioning efficiently. Backlogs, insufficient coal supplies and substandard coal are some of the major challenges facing Eskom. Coal also must be transported for longer distance which also add a strain to financial capabilities on Eskom.

Eskom (2019) highlights that its long-term debt was R441 billion in 2019 and municipalities and individuals owed Eskom over R36.5 billion. Eskom (2019) reports that problems of deterioration of acute skills and erosion of capacity at both at governance and technical levels, deterioration in operational performance, coal shortages contributing to costly load shedding, outdated and unsustainable monopoly structure and climate change commitments are major challenges facing Eskom.

Eskom (2019) highlights that the opportunities to bring stability to the entity are a new business model of unbundling into three entities for generation, transmission and distribution. StatSA (2018) stresses that enough coal reserves that can last for approximately 256 years are left and the newly built Medupi and Kusile powerplants that will help the imbalance between electricity demand and supply in South Africa. Modise and Mahotas (2020) highlight another opportunity

that South Africa is committed to the use of clean coal through the employment of Clean Coal Technologies such as Carbon Capture Storage (CCS) and the stabilization of CO₂ emissions. The policy implications of the study are given below:

Firstly, the positive relationship of electricity generated from coal on economic growth in the short and long run reveals that electricity generated from coal must be given more attention as it boosts economic growth. The policy makers should propose and implement policies that encourage coal electricity generation in a way that is environmentally friendly to boost economic growth and help solve macroeconomic challenges. The abundance of coal cannot be ignored, it must be utilised in an environmentally friendly manner so that it can help balance the gap between increasing electricity demand and low electricity supply. The government must invest in retrofitting of coal powerplants in South Africa so they can reduce pollution levels and become environmentally friendly while not impacting negatively on economic growth. Eskom should revise policies on decommissioning of these powerplant as it might be detrimental for economic growth.

The second policy implementation is that the South African government must encourage people to apply for legal connection of electricity so that the producers can be able to forecast demand and help solve the problem of power outages. This will help Eskom to plan and produce electricity that will be adequate for the country to reduce unplanned power cuts to balance the overwhelming electricity demand.

Thirdly, there is a positive statistically significant short run relationship between gross capital formation and economic growth in the South Africa. This means that policy makers must create an environment that is favourable for the increase in gross capital formation in the short run as this will increase economic growth in South Africa. In the long run however, the policy makers must maintain a certain level of gross capital formation or reduce it as this will increase economic growth.

Fourthly, the study highlighted the problem of poor and untimely maintenance of the powerplants by Eskom. Therefore, the policy implication of this is that Eskom must service and maintain the generators on time so that they produce at their full capacity to maintain the balance between electricity supply and demand. Lack of maintenance is the hideous problem that is affecting the generators to produce electricity to their full capacity in South Africa that results in continuous power cuts.

Fifthly, the results displayed a negative relationship between coal rents and economic growth both in the short and long run period in South Africa. This means that policy makers must propose and implement policies that reduce coal rents as this will result in the growth of South African economy increasing. Adaptation of the methods or techniques that reduces the cost of coal production must be promoted since this will reduce the coal rents and increase economic growth.

Sixthly, the positive relationship between renewable electricity generation in both the short and long run in South Africa calls for

the government, private sector, and policymakers to speed up the process and investment in renewable electricity generation as this will result in an increase in electricity generated from renewable electricity generation thereby resulting in increase in economic growth in South Africa. The government must increase wind farms projects in the Eastern Cape, solar energy in the Karoo area in Northern Cape and tidal power on the coastal area as this will result in economic growth in South Africa as well as matching the gap between electricity demand and supply in South Africa.

Seventhly, there is a negative relationship between CO₂ emissions from solid fuel consumption and economic growth in both the short and long run period in South Africa. This means that the government must increase the carbon tax to reduce the levels of CO₂ emissions in South Africa. By reducing the level of CO₂ emissions in South Africa, it will result in an increase in growth of the South African economy.

The study analysed the challenges and opportunities of electricity generation in South Africa for the period from 1971 to 2019 and discussed them in detail in the analysis. This study would have liked to analyse the relationship until 2020 but the limitation was unavailability of the data for coal electricity generation from 2016 to 2020.

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