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Assessing the Possibility of Medupi and Kusile Providing Enough Electricity Running at Full Capacity in South Africa

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ABSTRACT

This study assesses the possibility of Kusile and Medupi power plants with providing enough electricity to the South African economy when generating at full capacity. The study utilised time series data spanning from 1980 to 2021 collected from secondary sources such as the International Energy Agency and the World Bank. The study employed DF-GLS and PP unit root tests, ARDL Bounds test, ARDL ECM model and Granger causality tests to assess the possibility. The results revealed that there is a positive relationship between electricity generation, economic growth, and population growth on electricity consumption while electricity loss and trade openness were negatively related to electricity consumption. The granger causality results revealed unidirectional causality running from electricity consumption to economic growth and from trade openness to electricity consumption. The study recommended that Eskom and South African government should speed up the completion of Medupi and Kusile power plants, limit electricity loss and investing in new electricity infrastructure to match the gap between demand and supply and limit loadshedding in South Africa.

Keywords: Electricity Consumption, Electricity Generation, Medupi and Kusile, ARDL Model, South Africa
JEL Classifications: C1, C29, Q43, Q44, P18

1. INTRODUCTION

South Africa has been facing challenges of loadshedding since 2007 until present day. Loadshedding refers to when there is not enough supply capacity to meet electricity demand it becomes necessary to interrupt power supply at certain times to certain areas (Eskom, 2023). Among other factors, loadshedding is caused by coal supply issues at power stations, shortage of generator fuel, failure of units, demand prediction errors, weather-related issues, and supply import issues. The significance of this study is to access the possibility of Medupi and Kusile providing enough electricity when they are generating at full capacity in South Africa. Hlongwane and Daw (2022) alludes that electricity is the backbone of the South African economy, and it is a crucial industry that generates employment and value by extracting, processing, and delivering energy commodities and services across the country.

Scholars such as Lenoke (2017) analysed the impact of loadshedding on economic growth in South Africa from 1984 to 2014 focusing mainly on the consumption of electricity. Lenoke (2017) found that loadshedding has a negative impact on economic growth in South Africa. Loadshedding is done to protect the national electricity network by balancing supply and demand. If this is not done, the national grid will shut down entirely and the entire country will be blacked out for days to weeks. In the wake to try resolve the challenge of loadshedding, the newly constructed Medupi and Kusile power plants were expected to bring a relief to the electricity challenge in South Africa. Hlongwane and Daw (2022) alludes that population has been increasing but electricity generation has not been increasing enough to match with the population. Ratshomo and Nembahe (2019), Modise and Mahotas (2020) and Gabrielle (2020) summarizes that residential sector was accountable for 8%, commerce and public services 14%, agriculture 6%, transport

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sector 19%, industrial sector 52% and 1% not specified in terms of electricity consumption in South Africa.

1.1. Medupi Power Plant

Medupi Power Station is a 4800-megawatt coal-fired power station in Lephalale, South Africa's Limpopo region. The project includes of six 800 megawatt units that is to offer 4800-megawatt full installed capacity. Eskom indicated in November 2007 that the first unit will be commissioned in 2012, with the last unit slated for service in 2015. Once completed, Medupi will be Eskom's first supercritical and the world's largest dry-cooled power station. The location was chosen because of its vicinity to the Waterberg Coalfields and an existing transmission infrastructure, as well as the availability of land, reasonable coal prices, and alternate ash disposal alternatives (Eskom, 2007).

Eskom purchased 883-hectare site from Kumba Coal which was later named Exxaro Coal. Due to rising costs, the plant was expected to be commissioned in April 2011 but was postponed to 2014 (Eskom, 2007). The first unit, Unit 6, has been put back to mid-2015, while Unit 5 has been pushed back to 2016. The remaining units are expected to be operational by 2019 (Creamer, 2015). Unit 6 was the first unit to generate power at the facility when it was synchronized in March 2015. It was reported in July 2016 that Unit 5 will begin commercial operations in March 2018, and Unit 1 in May 2020 (Yelland, 2016). Unit 5 was synchronized in September 2016 and is scheduled to generate and distribute electricity to the national grid for several months. Unit 5 began commercial operation on April 3, 2017, and Unit 4 on November 28, 2017. The first synchronization of Medupi Unit 3 occurred in April 2018, with commercial operation scheduled for December 2018 (Barradas, 2018). On the 28th of June 2018. On June 28, 2019, Eskom announced that Unit 3 had achieved Commercial Operating status. In October 2018, Unit 2 was synchronized. In August 2019, Unit 1 was synced to the grid. According to Eskom, the full plant operation was scheduled to begin in 2021.

6 years after the first unit began supplying electricity to the national grid, the sixth and last generating unit entered commercial operation in July 2021. Nonetheless, boiler issues remained, and repairs were scheduled to take place over the next 2 years. About 1 week after its last unit started up, Eskom stated that the power plant had an explosion on the Unit 4 generator, which caused Unit 5 to trip (Zyl, 2021). Following an inquiry, a report issued in May 2022 said that nine workers were suspended because of the occurrence, procedural non-compliance, and managerial failings (Diemen, 2022). Unit 4 was failed to restart, and the plant's overall performance was being hampered by the missing 720 MW. At this stage, barely half of the Medupi units were fully operational. The African Development Bank admitted in June 2022 that the plant will not generate a financial advantage throughout its lifespan, using the project's 70% load factor as the targeted load factor (Sguazzin, 2022). The units at Medupi Power Plant came to service as follows: Unit 1 in 2021, Unit 2 and 3 in 2019, Unit 4 in 2017, Unit 5 in 2017 and Unit 6 in 2015.

1.2. Kusile Power Plant

Kusile Power Station is a projected 900-megawatt coal-fired power plant with a total capacity of 5 400 megawatts. Construction began in August 2008, with a capacity of 4 800 megawatts, divided into six 800-megawatt units (Power-Technology, 2021). The first producing unit was set to enter the South African energy grid in the second half of 2015, with the next five units following at eight and then 12-month intervals. The final unit was scheduled to go into service in 2019. In 2015, it was announced that Unit 1 will open in 2016 and the last unit would open in 2021 (Creamer, 2015). Eskom appointed ABB South Africa to replace Alstom in the control and instrumentation of the Kusile power plant in March 2015 (News24, 2015). As of May 2016, Eskom reported that Kusile Unit 1 will be operational by the end of 2017. In July 2016, it was stated that Unit 1 will begin commercial operations in July 2018, followed by Unit 6 in September 2022 (Yelland, 2016). Unit 1 was synchronized with the grid in December 2016, and commercial operations with 800MW capacity commenced in August 2017. Unit 2 was synchronized in April 2018. Eskom estimated in February 2019 that R8 billion will be required to repair design faults at Medupi and Kusile. A routine inspection discovered some flaws in various areas of the plant, including Unit 1, the only operational unit with a planned return to service date of August 2019 (Tilburg, 2019).

Unit 3 was synchronized to the national grid on March 16, 2019. While synchronized to the grid, units 2 and 3 were still undergoing testing and commissioning and were not yet in commercial service as of July 2019. According to Tilburg (2019), in the 1st week of July 2019, Unit 2 encountered a failure relating to the induced draft (ID) fans, necessitating minor repairs. Kusile's Unit 6 was being stripped for replacement parts for Units 1, 2, and 3. Unit 2 will begin commercial operations in October 2020. According to Eskom's 2020 Annual Report, the entire facility is expected to be operational by 2024 (Eskom, 2021). Contractor, financial, commercial, and contractual concerns reportedly caused delays from Unit 4 to Unit 6. Unit 4 was set to be online in January 2023, followed by Unit 5 in December 2023 and Unit 6 in May 2024. Tena (2021) highlights that in other publications, Eskom claimed that it expects the entire project to be finished by the end of 2023, which will give us the full 4,800 megawatts at that point. Due to a succession of outages and defects, Kusile was only producing a fraction of the power its three operable units were planned to produce in November 2021 (Cronje, 2021).

In June 2022, Eskom revealed in an official media announcement that Unit 4 had completed all testing and optimization and had been formally linked to the national grid. They also stated that units 5 and 6 were proceeding as planned. Construction-Review (2022) states that if the last two units are completed as planned, the station would be the world's fourth biggest coal plant. An air heater of the under-construction Kusile Power Plant's Unit 5 caught fire in October 2022, delaying commissioning until 2023/2024. Eskom had earlier claimed that the new 800MW Unit 6 at Kusile will assist to alleviate South Africa's persistent loadshedding crisis, but it is now scheduled to reopen in mid-2024. In November 2022, just 2 weeks after the air heater fire, a cement-like deposit build-up caused a flue gas duct of Unit 1 to collapse, with Eskom warning that the unit will be down for months, exacerbating South Africa's grid instability.

1.3. Electricity Generation Output, Peak Demand and Installed Capacity in South Africa 2022

The Figure 1 shows the monthly installed electricity generation capacity for South Africa in 2022. An addition of 720MW was added to the grid through the synchronization of a unit at Kusile Power Plant. South Africa holds 39824MW of installed electricity with coal dominating the generation of electricity.

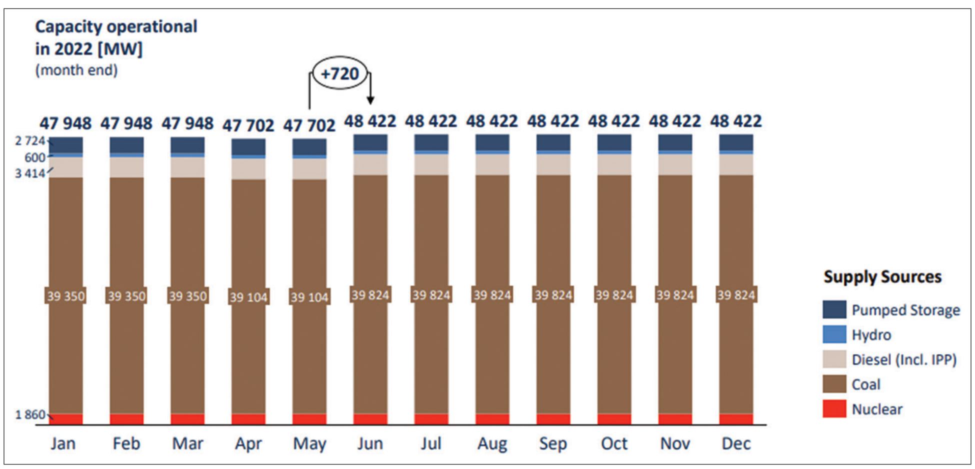
Figure 2 shows the monthly electricity output in South Africa from all sources. Coal's dominant effect of the generation of electricity slightly decreased through the year from 77% in January, 79% in August to 65% in December. Wind and solar has seen a significant increase in the generation of electricity per month from January to December. However, apart from local electricity generation, South Africa still relies on importing electricity from other countries as shown on the figure with a constant amount throughout the year.

Figure 3 shows electricity peak demand since 2010-2022 in gigawatt in South Africa. It can be noted that peak demand electricity has been decreasing from 2010 with 36.7GW, 35.8GW in 2017 to 34.6GW in 2022. The decrease in peak demand can be linked to the average increase in the generation of electricity from renewable sources and the existing non-renewable sources. The annual electricity generation for South Africa in 2022 was as follows: coal contributed 80.1% equivalent to 176.6TWh, nuclear contributed 4.6% equivalent to 10.1TWh, renewable energy contributed 13.7% equivalent to 30.2TWh and diesel contributed 1.6% equivalent to 3.6TWh. From the background above for Kusile and Medupi it is evident that South Africa is struggling with electricity generation. Loadshedding has been implemented to try balance the shortage in electricity demand and supply. This study investigates the possibility of having enough electricity if Kusile and Medupi power plants are running at full-generating capacity.

2. LITERATURE REVIEW

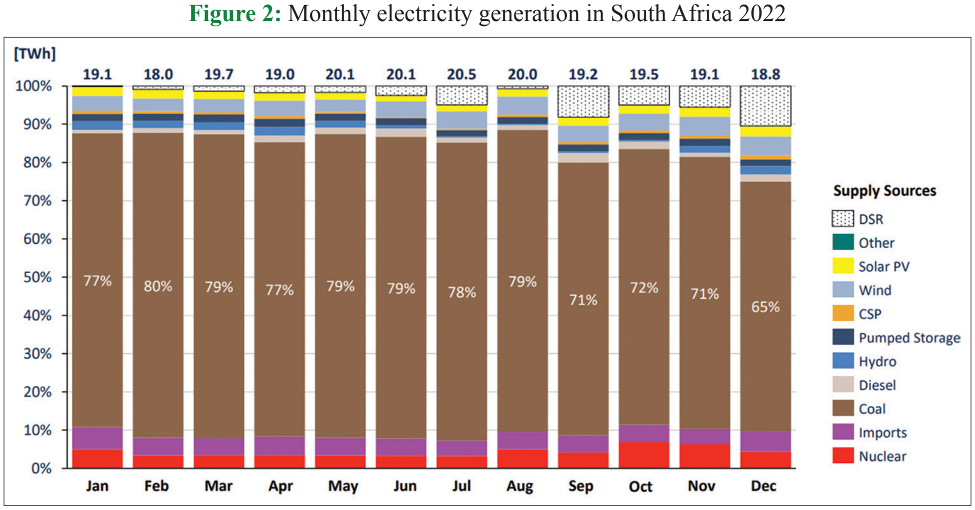
This section consists of empirical literature from developed countries, developing countries and South Africa as focus area. The study adopts studies that focuses on the determinants of electricity generation to achieve this study's objective. The following studies forms part of the literature from developed countries: Romero-Jordán et al. (2014) analyses the determinants of household electricity demand with data from 1998 to 2009 in Spain. The study employed a dynamic partial adjustment

Figure 1: Monthly installed capacity



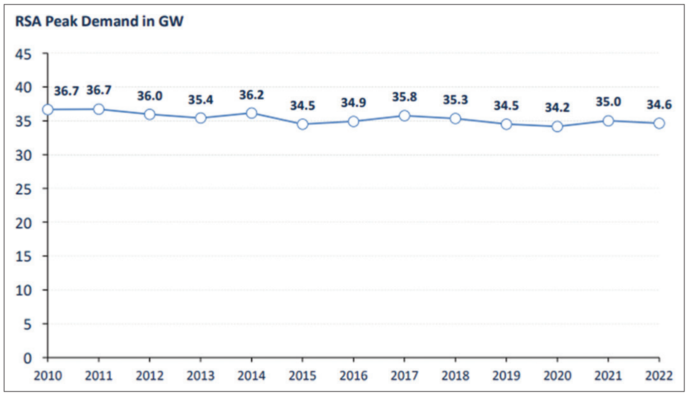
Source: CSIR (2022)

Figure 2: Monthly electricity generation in South Africa 2022



Source: CSIR (2022)

Figure 3: South Africa electricity peak demand from 2010 to 2022



Source: CSIR (2022)

model, and the results reveal that electricity demand is positively and significantly related to several variables such as electricity demand in previous year, income, temperature range, penetration of electric water heating in households and the number of heating and cooling degree days.

The following studies forms literature from developing countries: Ubi et al. (2012) conducted an econometric analysis of the determinants of electricity supply in Nigeria from 1970 to 2009. The study adopted parametric econometric methodology of ordinary least squares model and the results revealed that technology, government funding, and the level of electricity loss were statistically significant determinants of electricity supply in Nigeria and that average of 40% of electricity is lost in transmission per annum. The study recommends that the government should inject more funds into the electricity sector to complete electricity projects with state-of-the-art technology to enhance electricity supply.

Al-Bajjali and Shamayleh (2018) analyses the determinants of electricity consumption in Jordan during the period 1968-2015. The study borrowed Johansen Cointegration and VECM model to incorporate gross domestic product, electricity prices, population, urbanization, structure of economy and aggregate water consumption. The results revealed that GDP, urbanization, structure of the economy and aggregate water consumption is positive statistically significant while electricity prices are negatively related to electricity consumption. Population revealed short run positive statistically significant effect. The study recommends that there is a need to invest more in green energy projects, ban importing low efficiency electrical appliances and review refugee reception policy in place.

Cheng et al. (2019) analyses the determinants of changes in electricity generation intensity in China and further uncovers the reasons for the differences between the changes in electricity generation intensity in the thermal and sustainable power sectors. The study borrowed panel data spanning from 1997 to 2016 for Chinese provinces. The study developed a factorial-intertemporal nested decomposition model using the Laspeyres index, the results reveal that electricity consumption intensity is the main factor that reduces electricity generation intensity.

Zaman et al. (2012) investigates the determinants of electricity consumption function in Pakistan from 1975 to 2010. Study employed ARDL-VECM model to incorporate economic growth, foreign direct investment, and population growth. The results revealed that influx of foreign direct investment, income, and population growth is positively related to electricity consumption. The study recommends that Pakistan must liberalize its foreign direct investment to enhance energy policies to stimulate economic growth.

Kwakwa (2018a) examines the determinants of electricity power losses for Ghanaian economy from 1971 to 2013. The study employed fully modified ordinary least squares model and the results revealed that education, price of electricity, capital investment, income, manufacturing, and population have significantly influenced Ghanaian electricity loss. The study recommends the need to intensify capital investment in the power sector as well as public education to deal with electricity power loss.

Alawin et al. (2016) investigates the determinants of electricity demand in Jordan from 1985 to 2006. The study employed ARDL model, and the results revealed that electricity demand grows directly with economic growth and population. The study recommends that government should facilitate all procedures for economic units to adapt advanced means of production and consumption of energy to meet the increasing electricity demand.

Agyei-Sakyi et al. (2021) analysed the determinants of electricity consumption and volatility-driven innovative roadmaps to one hundred percent renewables for top consuming nations in Africa from 1990 to 2019. The study employed panel VECM model, and the results revealed that there exists a short-run unidirectional causal relationships from GDP to electricity consumption for Nigeria-South Africa can achieve 100% green electricity. The study recommends that for countries that aim to achieve 100% renewables is possible due to the radical transition pathways since it considers the volatility.

Bekhet and Harun (2017) investigates the elasticity and causality among electricity generation from renewable energy and its determinants in Malaysia from 1982 to 2015. The study employed VECM model, and the results revealed that long-run elasticity of capital and labour promotes renewable energy generation, while the responsiveness of economic growth and financial development undermine electricity generation from renewable energy. The study recommend that Malaysian government should pursue policies to enhance the utilization of renewable electricity sources toward national electricity supply security and sustainable socio-economic development.

Sharma and Kautish (2019a) investigates the dynamism between selected macroeconomic determinants and electricity consumption in India from 1980 to 2015. The study employed an NARDL and VECM models and the results revealed that positive and negative shocks in GDP and FDI have a positive and significant impact on electricity consumption. Further results reveal that the influence of the increased oil consumption on electricity demand is negative and statistically significant.

Adusah-Poku et al. (2022) investigates the determinants of electricity demand in Ghana from 1980 to 2018. The study employed ARDL, FMOLS, PAM and UECM models and the results revealed that power crisis have adverse effects on electricity demand in the long run. The study recommends that all efforts to eliminate power crisis should be made so that households, businesses, and industries will have the confidence to rely on electric power while firming up policies and incentives for other sustainable sources of power such as renewable energy.

Kwakwa (2018b) examines the determinants of electricity consumption for Benin using annual time series data from 1971 to 2014. The study employed ARDL, FMOLS and Canonical Co-integrating Regression and the results reveal that population, urbanization, education, and industrialisation positively affect electricity consumption for the country while income negatively affect. The study recommends the need to increase awareness on environmental-energy issues and the need for a policy to make new residential and non-residential buildings that would be constructed in the urban centres especially, to be energy efficiently designed.

Koranteng Nkansah et al. (2022) investigates the determinants of electricity demand in Cote D'Ivoire, Ghana, Nigeria, and Senegal from 1980 to 2018. The study employed pooled OLS model the results indicate that GDP, FDI, trade openness, industry output and population growth show a positive statistically significant relationship with electricity consumption while CPI reflects a negative effect. The study recommend that projects focused to increase electricity generation capacity in West Africa should be encouraged and energy from clean sources should be harnessed to provide electricity.

The following studies forms part of the literature focusing on South Africa: Sehlapelo and Inglesi□Lotz (2022) examines the determinants of electricity consumption in the nine South African provinces from 1995 to 2019. The study employed Fixed Effects and Pooled Mean Group estimators and the results of the fixed efforts demonstrated that population and electricity costs are main contributors of electricity demand. The study recommends that energy policymakers should consider differences when planning infrastructure development and changes in pricing structures.

Bohlmann and Inglesi-Lotz (2021) examines the determinants of the residential demand for electricity in South Africa including disposable income, electricity prices, food prices as well as the impact of the 2007/2008 load-shedding wave and the 2008 electricity pricing restructuring. The study utilized data from 1975 to 2016 and employed ARDL model to analyse the relationship between variables. Results reveal co-integration relationships among the variables and that disposable income has a positive impact on electricity consumption. The study recommends that there is a room to have policies designed to reduce electricity consumption by using prices as mechanism.

Hlongwane and Daw (2022) investigates electricity consumption and population growth in South Africa from 2002 to 2021. The study employed an SUR model and the results revealed that there is negative statistically significant relationship between population growth and electricity consumption in South Africa and that there is unidirectional causality running from population growth to electricity consumption. The study recommends that government and policymakers must implement policies aimed at increasing renewable electricity generation to match the gap between electricity demand and growing population thereby reducing constant loadshedding.

3. METHODOLOGY

3.1. Model Specification

The study analyses the possibility of Medupi and Kusile power plant to supply enough electricity in South Africa when generating at full capacity. The study utilises electricity consumption, electricity generation, gross domestic product, population growth, trade openness, and electricity loss to formulate a multivariate model. The variables are transformed into logarithms to have the same unit of measurement. The multivariate linear model utilised in this study can therefore be specified as given below:

$$LEC_t = \alpha_1 + \alpha_{LEG} LEG_t + \alpha_{LGDP} LGDP_t + \alpha_{LPOP} LPOP_t + \alpha_{LTO} LTO_t + \alpha_{LEL} LEL_t + \varepsilon_t \quad 3.1$$

Where LEC is the logged electricity consumption, LEG is the logged electricity generation, LGDP is the natural logarithm of gross domestic per capita representing economic growth, LPOP is the natural logarithm of population growth, LTO is the natural logarithm of trade openness, LEL is the logged electricity loss, α_1 is the constant and ε_t is the error term.

3.2. Data Sources

The study utilises annual time series data from 1980 to 2021 collected from secondary sources such as International Energy Agency (IEA) and the World Bank as shown in Table 1.

3.3. Data Analysis

The study employed Dickey-Fuller Generalised Least Square (DF-GLS) and Phillips-Perron (PP) unit root test to check for stationary of variables proposed by Elliott et al. (1992) and Phillips and Perron (1988) respectively. Elliott et al. (1996) emphasizes that the DF-GLS unit root test is has more power in the presence of an unknown trend or mean compared to the ADF and PP unit root tests. This will enable to avoid the problems of spurious regressions and help identify order of integration for appropriate lags selection. The study employed the VAR optimal lags length criterion to determine the appropriate number of lags to use in the model. The study employs the ARDL bounds test to check for cointegration relationships between the variables in the

Table 1: Data sources and description

Variable	Unit	Description	Source
LEC	GWh	Logged electricity consumption	IEA
LEG	GWh	Logged electricity generation	IEA
LGDP	%	GDP per capita annual growth rate	World Bank
LPOP	%	Population annual growth rate	World Bank
LTO	%	Trade openness	World Bank
LEL	GWh	Logged electricity loss	IEA

Source: Author's compilation

model. After evaluation of models, the study adopts the ARDL model proposed by Pesaran et al. (2001) utilised in the studies of Bohlmann and Inglesi-Lotz (2021) and Alawin et al. (2016). The study chose this model because majority of the studies on this topic utilised the VECM model. Therefore, the estimation of short run and long run relationships is given in the sections below based on the ARDL model.

3.3.1. Estimation of long run relationships

Once the study discover cointegration relationships between the variables from ARDL bounds test, the long run equations can therefore be specified as follows:

$$LEC_t = \beta_{01} + \sum_{i=1}^{p} k_{11} LEC_{t-i} + \sum_{i=1}^{q} k_{21} LEG_{t-i} + \sum_{i=1}^{q} k_{31} LGDP_{t-i} + \sum_{i=1}^{q} k_{41} LPOP_{t-i} + \sum_{i=1}^{q} k_{51} LTO_{t-i} + \sum_{i=1}^{q} k_{61} LEL_{t-i} + \varepsilon_t \quad 3.2$$

$$LEG_t = \beta_{02} + \sum_{i=1}^{p} k_{12} LEG_{t-i} + \sum_{i=1}^{q} k_{22} LEC_{t-i} + \sum_{i=1}^{q} k_{32} LGDP_{t-i} + \sum_{i=1}^{q} k_{42} LPOP_{t-i} + \sum_{i=1}^{q} k_{52} LTO_{t-i} + \sum_{i=1}^{q} k_{62} LEL_{t-i} + \varepsilon_t \quad 3.3$$

$$LGDP_t = \beta_{03} + \sum_{i=1}^{p} k_{13} LGDP_{t-i} + \sum_{i=1}^{q} k_{23} LEG_{t-i} + \sum_{i=1}^{q} k_{33} LEC_{t-i} + \sum_{i=1}^{q} k_{43} LPOP_{t-i} + \sum_{i=1}^{q} k_{53} LTO_{t-i} + \sum_{i=1}^{q} k_{63} LEL_{t-i} + \varepsilon_t \quad 3.4$$

$$LPOP_t = \beta_{04} + \sum_{i=1}^{p} k_{14} LPOP_{t-i} + \sum_{i=1}^{q} k_{24} LGDP_{t-i} + \sum_{i=1}^{q} k_{34} LEG_{t-i} + \sum_{i=1}^{q} k_{44} LEC_{t-i} + \sum_{i=1}^{q} k_{54} LTO_{t-i} + \sum_{i=1}^{q} k_{64} LEL_{t-i} + \varepsilon_t \quad 3.5$$

$$LTO_t = \beta_{05} + \sum_{i=1}^{p} k_{15} LTO_{t-i} + \sum_{i=1}^{q} k_{25} LPOP_{t-i} + \sum_{i=1}^{q} k_{35} LGDP_{t-i} + \sum_{i=1}^{q} k_{45} LEG_{t-i} + \sum_{i=1}^{q} k_{55} LEC_{t-i} + \sum_{i=1}^{q} k_{65} LEL_{t-i} + \varepsilon_t \quad 3.6$$

$$LEL_t = \beta_{06} + \sum_{i=1}^{p} k_{16} LEL_{t-i} + \sum_{i=1}^{q} k_{26} LTO_{t-i} + \sum_{i=1}^{q} k_{36} LPOP_{t-i} + \sum_{i=1}^{q} k_{46} LGDP_{t-i} + \sum_{i=1}^{q} k_{56} LEG_{t-i} + \sum_{i=1}^{q} k_{66} LEC_{t-i} + \varepsilon_t \quad 3.7$$

3.3.2. Short run relationships

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

$$\Delta LEC_t = \beta_{01} + \sum_{i=1}^{p} \alpha_{1i} \Delta LEC_{t-i} + \sum_{i=1}^{q} \alpha_{2i} \Delta LEG_{t-i} + \sum_{i=1}^{q} \alpha_{3i} \Delta LGDP_{t-i} + \sum_{i=1}^{q} \alpha_{4i} \Delta LPOP_{t-i} + \sum_{i=1}^{q} \alpha_{5i} \Delta LTO_{t-i} + \sum_{i=1}^{q} \alpha_{6i} \Delta LEL_{t-i} + \lambda ECT_{t-1} + \varepsilon_t \quad (3.8)$$

$$\Delta LEG_t = \beta_{02} + \sum_{i=1}^{p} \alpha_{1i} \Delta LEG_{t-i} + \sum_{i=1}^{q} \alpha_{2i} \Delta LEC_{t-i} + \sum_{i=1}^{q} \alpha_{3i} \Delta LGDP_{t-i} + \sum_{i=1}^{q} \alpha_{4i} \Delta LPOP_{t-i} + \sum_{i=1}^{q} \alpha_{5i} \Delta LTO_{t-i} + \sum_{i=1}^{q} \alpha_{6i} \Delta LEL_{t-i} + \lambda ECT_{t-1} + \varepsilon_t \quad (3.9)$$

$$\Delta LGDP_t = \beta_{03} + \sum_{i=1}^{p} \alpha_{1i} \Delta LGDP_{t-i} + \sum_{i=1}^{q} \alpha_{2i} \Delta LEG_{t-i} + \sum_{i=1}^{q} \alpha_{3i} \Delta LEC_{t-i} + \sum_{i=1}^{q} \alpha_{4i} \Delta LPOP_{t-i} + \sum_{i=1}^{q} \alpha_{5i} \Delta LTO_{t-i} + \sum_{i=1}^{q} \alpha_{6i} \Delta LEL_{t-i} + \lambda ECT_{t-1} + \varepsilon_t \quad (3.10)$$

$$\Delta LPOP_t = \beta_{04} + \sum_{i=1}^{p} \alpha_{1i} \Delta LPOP_{t-i} + \sum_{i=1}^{q} \alpha_{2i} \Delta LGDP_{t-i} + \sum_{i=1}^{q} \alpha_{3i} \Delta LEG_{t-i} + \sum_{i=1}^{q} \alpha_{4i} \Delta LEC_{t-i} + \sum_{i=1}^{q} \alpha_{5i} \Delta LTO_{t-i} + \sum_{i=1}^{q} \alpha_{6i} \Delta LEL_{t-i} + \lambda ECT_{t-1} + \varepsilon_t \quad (3.11)$$

$$\Delta LTO_t = \beta_{05} + \sum_{i=1}^{p} \alpha_{1i} \Delta LTO_{t-i} + \sum_{i=1}^{q} \alpha_{2i} \Delta LPOP_{t-i} + \sum_{i=1}^{q} \alpha_{3i} \Delta LGDP_{t-i} + \sum_{i=1}^{q} \alpha_{4i} \Delta LEG_{t-i} + \sum_{i=1}^{q} \alpha_{5i} \Delta LEC_{t-i} + \sum_{i=1}^{q} \alpha_{6i} \Delta LEL_{t-i} + \lambda ECT_{t-1} + \varepsilon_t \quad (3.12)$$

$$\Delta LEL_t = \beta_{06} + \sum_{i=1}^{p} \alpha_{1i} \Delta LEL_{t-i} + \sum_{i=1}^{q} \alpha_{2i} \Delta LTO_{t-i} + \sum_{i=1}^{q} \alpha_{3i} \Delta LPOP_{t-i} + \sum_{i=1}^{q} \alpha_{4i} \Delta LGDP_{t-i} + \sum_{i=1}^{q} \alpha_{5i} \Delta LEC_{t-i} + \sum_{i=1}^{q} \alpha_{6i} \Delta LEG_{t-i} + \lambda ECT_{t-1} + \varepsilon_t \quad (3.13)$$

3.3.3. Residual Diagnostics

The study will perform the Breusch-Godfrey serial correlation test to check for any presence of serial correlation in the model. The study will perform Breusch-Pagan-Godfrey test to find out if the conditions of homoskedasticity is present or not in the model. The study will perform Jarque-Bera test to check for normality of residuals in the model. The study will also perform stability tests of CUSUM and Ramsey to check for stability of residuals from the model.

4. RESULTS AND INTERPRETATIONS

The study performed DF-GLS and PP unit root as shown in Table 2. The results of both the DF-GLS and PP unit root indicate that the variables are stationary at first difference. This means that we fail to accept the null hypothesis that the variables have a unit root and we conclude that the variable are integrated of high order one, I(1). This makes it possible to employ the ARDL model adopted in this study since it requires the variables to be stationary at level form I(0) or first difference I(1) or a mixture of I(0) and I(1). The study continues to perform the optimal number of lags to be utilised in the study as shown in Table 3 below.

The study performed the VAR optimal lag length criterion at shown in Table 3 to check the recommended number of lags to utilise in the study. According to the LR, FPE and AIC criterion only 1 lag is recommended while the SC and HQ indicate zero lags to be utilised. The study therefore will utilise one lag even though the ARDL model has an advantage of selecting lags automatically. The study continues check for cointegration relationships as shown in Table 4.

The study employed the ARDL Bounds tests to check for cointegration relationships between the variables in the model as shown in Table 4. The results of the F-Bounds test has an f-statistic of 13.66909 that is above the critical statistics at I(0) and I(1). The results of the t-Bounds test indicate a t-statistic of -9.805866 that is lower than all the critical statistics at I(0) and I(1). These results of F-bound and t-Bound test entail that we fail to accept the null hypothesis of no cointegration and conclude that there exist long run relationships between the variables in the model. The study will estimate both short and long run relationships between the variables utilising equations 3.2 to 3.13 in Section 3 above.

The results of the Unrestricted Error Correction Model are shown in Table 5 displaying short run relationships between variables in the model. The results show a positive statistically significant relationship between electricity generation and electricity consumption in South Africa for the period understudy. A 1% increase in electricity generation in South Africa in the short run significantly result in electricity consumption rising by 1.04%, ceteris paribus. This entail that electricity generation is very important for electricity consumption in South Africa. This result calls for policy makers to review the actual performance of Kusile and Medupi power plant to limit breakdowns and accidents so that South Africa has enough power when these two power plants are running at full generating capacity.

Furthermore, the results shows that there is a positive statistically significant relationship between economic growth and electricity consumption in the short run. A 1% increase in economic growth in South Africa in the short run significantly result in electricity consumption rising by 0.0005%, ceteris paribus. This entails that economic growth rises electricity demand in South Africa. These results are consistent with the studies of Al-Bajjali and Shamayleh (2018), Alawin et al. (2016) and Sharma and Kautish (2019b). This calls for Eskom and the South African government to revise the electricity policies so that they are constituent with the demand from economic growth.

Moreso, there is a negative statistically significant short run relationship between electricity loss and electricity consumption in South Africa. A 1% increase in electricity loss in the short run in South Africa significantly result in electricity consumption declining by 0.09%, ceteris paribus. These results are consistent with the study of Ubi et al. (2012). This entails that Eskom and the South African government need to revise their distribution

Table 2: Unit root tests

Variable	Dickey-Fuller GLS				Phillips-Perron			
	Constant		Trend and Intercept		Constant		Trend & Intercept	
	Level	Δ	Level	Δ	Level	Δ	Level	Δ
LEC	−0.5339	0.0208	−0.6822	−5.4188***	−5.2871***	−5.6788****	−1.8355	−7.7004***
LEG	0.1233	−0.0710	−0.2407	−5.0479***	−5.3478***	−5.3843***	−1.7044	−7.0844***
LGDP	−3.4872***	−7.5013***	−4.1252***	−6.5075***	−4.2547***	−9.7253***	−4.3897***	−8.6762***
LPOP	−0.8445	−5.4929***	−1.6929	−5.5077***	−1.1829	−5.1011***	−1.8118	−5.0198***
LTO	−1.7266*	−5.8792***	−2.4606	−6.3081***	−1.9431	−6.8002***	−3.3500*	−7.1343***
LEL	−0.5730	−6.9683***	−2.7188	−7.0186***	−1.3532	−6.9973***	−2.6668	−6.9267***

Source: Author's own computation

Table 3: Optimal lag length

Lag	LogL	LR	FPE	AIC	SC	HQ
0	46.02383	NA	4.90e-09	−2.106517	−1.847951*	−2.014521*
1	87.07169	66.97283*	3.85e-09*	−2.372194*	−0.562231	−1.728223
2	114.2731	35.79130	7.09e-09	−1.909109	1.452252	−0.713163
3	153.9358	39.66275	8.90e-09	−2.101886	2.810873	−0.353964

Source: Author's own computation

and transmission infrastructure to minimize electricity loss. This is constant with economic expectations that if electricity loss increases, the available electricity for consumption falls.

Moreover, there is a positive statistically insignificant short run relationship between population growth and electricity consumption in South Africa. A 1% increase in population growth in South Africa in the short run insignificantly result in electricity consumption rising by 0.0003%, ceteris paribus. The magnitude of effect is not that worrisome but the positive effect of population on electricity consumption calls for the government to review their electricity consumption policies to be consistent with the growing population. These results are consistent with the studies of Bohlmann and Inglesi-Lotz (2021), Zaman et al. (2012) and Koranteng Nkansah et al. (2022) while inconsistent with the study of Hlongwane and Daw (2022).

There is a negative statistically significant short run relationship between trade openness and electricity consumption in South Africa. A 1% increase in trade openness in South Africa in the short run significantly result in electricity consumption declining by 0.0002%, ceteris paribus. This entail that the increase in trade openness plays a detrimental effect on electricity consumption in the South Africa. These results are inconsistent with the study of Koranteng Nkansah et al. (2022). This calls for the government to revise policies on electricity so they can save energy. The ECT term is −1.217169, which means that 127% of the errors in electricity consumption are corrected annually towards long run equilibrium. The long run relationships are given in the section below.

Table 4: Co-integration tests

Null Hypothesis: No levels relationship				
F-Bounds Test				
Test statistic	**Value**	**Signif (%)**	**I (0)**	**I (1)**
F-statistic	13.66909	10	2.26	3.35
K	5	5	2.62	3.79
		2.5	2.96	4.18
		1	3.41	4.68
	t-bounds test			
t-statistic	−9.805866	10	−2.57	−3.86
		5	−2.86	−4.19
		2.5	−3.13	−4.46
		1	−3.43	−4.79

Source: Author's computation

The study estimated long run relationships utilizing an ARDL levels equations as shown in Table 6. There is a positive statistically significant long run relationship between electricity generation and electricity consumption in South Africa. A 1% increase in electricity generation in the long run in South Africa significantly result electricity consumption rising by 1.07%, ceteris paribus. This entails that electricity generation plays an important role electricity consumption and energy sector in South Africa. These results are the same with the short run results meaning that Eskom and the South Africa government must implement policies that leads to Medupi and Kusile power plants generating at their full capacity so that there is enough electricity to meet the demand.

Moreso, there is a positive statistically significant long run relationship between economic growth and electricity consumption in South Africa. A 1% increase in economic growth in the long run significantly result in electricity consumption increasing by 0.001%, ceteris paribus. These results entail that economic growth is a prominent determinant of electricity demand in South Africa. These results are consistent with the studies of Al-Bajjali and Shamayleh (2018), Alawin et al. (2016) and Sharma and Kautish (2019b). This calls for policy makers, Eskom, and the South African government to speed up economic growth policies that are consistent with electricity demand to limit loadshedding. This entails speeding up investment in finishing the construction of Medupi and Kusile power plants to perform at full scale.

There is a negative statistically significant long run relationship between electricity loss and electricity consumption in South Africa. A 1% increase in electricity loss in the long run significantly result in electricity consumption declining by 0.10%, ceteris paribus. These results are consistent with the short run results implying that the effect of electricity loss is the same in both periods. These results are the same with the results from the study of Ubi et al. (2012). These results entail that Eskom, and the South Africa government must focus on minimizing electricity losses between their transmission and distribution infrastructure.

Furthermore, there is a positive statistically insignificant long run relationship between population growth and electricity

Table 5: Short run relationships

Unrestricted ARDL error correction regression				
Selected model: ARDL (1,1,1,1,0,1)				
Case 3: Unrestricted constant and no trend				
Variable	**Coefficient**	**Standard error**	**t-Statistic**	**Probability**
C	0.000468	0.000540	0.867381	0.3929
D (LEG(−1))	1.037160	0.019255	53.86437	0.0000
D (LGDP(−1))	0.000534	0.000167	3.188189	0.0034
D (LEL(−1))	−0.093773	0.002511	−37.33869	0.0000
D (LPOP(−1))	0.000312	0.002122	0.146813	0.8843
D (LTO(−1))	−0.000245	9.59E-05	−2.554629	0.0161
CointEq(−1)*	−1.217169	0.124127	−9.805866	0.0000
R-squared		0.995240		
Adjusted R-squared		0.994540		
Durbin-Watson stat		1.623288		

Source: Author's computation

consumption in South Africa. A 1% increase in population growth in the long run in South Africa significantly result in electricity consumption rising by 0.0003%, ceteris paribus. These results entail that though the magnitude of effect is not that worrisome, the positive effect is eminent as population growth is directly related to electricity consumption. These results are consistent with the studies of Bohlmann and Inglesi-Lotz (2021), Zaman et al. (2012) and Koranteng Nkansah et al. (2022). This calls for the government and Eskom need to generate enough electricity to balance the gap between demand and supply and solve loadshedding in South Africa.

There is a negative statistically significant long run relationship between trade openness and electricity consumption in South Africa. A 1% increase in trade openness in the long run significantly result in electricity consumption declining by 0.0002%, ceteris paribus. These results are the same with the short run relationships. This entails that trade openness plays an important role on saving electricity in South Africa in both short and long run period. These results are inconsistent with the study of Koranteng Nkansah et al. (2022). This calls for policy makers and the government to initiate campaigns that promote energy saving. The study continues to perform residual diagnostics to check for reliability of the results and policies from the study as shown in the section below.

The study performed the Granger causality test to check for causal relationships as shown by the results in Table 7. The results reveal a unidirectional causality running from electricity consumption to economic growth at 5% level of significance. These results are inconsistent with the results of Agyei-Sakyi et al. (2021) that found unidirectional causality running from economic growth to electricity consumption. This means that it is electricity consumption that causes economic growth in South Africa. Furthermore, the results reveal a unidirectional causality running from trade openness to electricity consumption at 10% level of significance. This means that trade openness indeed has a causal relationship with electricity consumption. Trade openness policies implemented will have causal effect on electricity consumption in South Africa. The study continues to perform diagnostics tests as shown in Table 8 to check for reliability of the results and policies from the study.

The study performed the residual diagnostics test as shown in Table 8. The Breusch-Godfrey-Pagan heteroskedasticity have a probability of 0.3712 that is greater than 0.05 implying the failure to reject null hypothesis (Ho) and conclude that the residuals are homoscedastic. The probability value of the Jarque-Bera is 0.5345 that is above the 0.05 critical value implying that we fail to reject the null hypothesis (Ho) that the residuals are normally distributed. The study performed the Breusch-Godfrey serial correlation test utilising 1 lag, and the probability value is 0.0767 that is above the 0.05 critical value implying that we fail to reject the null hypothesis (Ho) and conclude that the model does not suffer from any serial correlation.

Table 6: Long run relationships

ARDL levels equation Selected Model: ARDL (1,1,1,1,0,1) Case 3: Unrestricted constant and no trend				
Variable	**Coefficient**	**Standard Error**	**t-Statistic**	**Probability**
LEG(−1)	1.070760	0.019423	55.12914	0.0000
LGDP(−1)	0.001082	0.000523	2.070247	0.0474
LEL(−1)	−0.099145	0.005449	−18.19394	0.0000
LPOP(−1)	0.000256	0.001747	0.146537	0.8845
LTO(−1)	−0.000417	0.000222	−1.880983	0.0700

Source: Author's computation

Table 7: Causality relationship

Pairwise granger causality test Lags: 1 Sample: 1980, 2021		
Null hypothesis	**F-statistic**	**Probability**
D (LEG) does not Granger Cause D (LEC)	0.61717	0.4371
D (LEC) does not Granger Cause D (LEG)	0.02845	0.8670
D (LGDP) does not Granger Cause D (LEC)	0.06138	0.8057
D (LEC) does not Granger Cause D (LGDP)	9.31637	0.0042
D (LEL) does not Granger Cause D (LEC)	0.72367	0.4004
D (LEC) does not Granger Cause D (LEL)	0.74673	0.3931
D (LPOP) does not Granger Cause D (LEC)	0.13031	0.7202
D (LEC) does not Granger Cause D (LPOP)	1.56376	0.2190
D (LTO) does not Granger Cause D (LEC)	3.69825	0.0622
D (LEC) does not Granger Cause D (LTO)	0.04455	0.8340

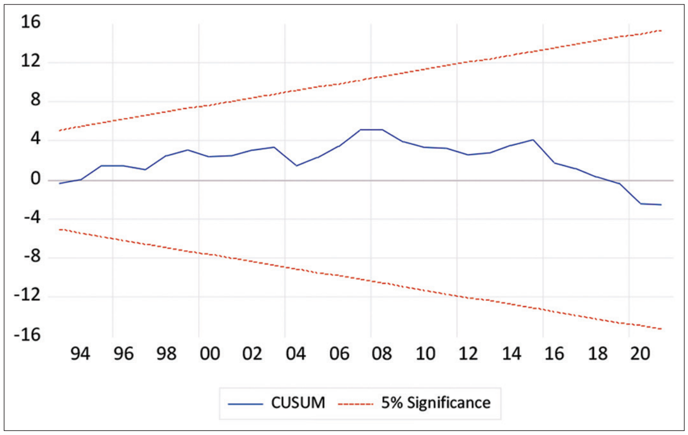
Source: Author's computation

Table 8: Residual diagnostics tests

Test	Probability	Decision
Breusch-Godfrey-Pagan heteroskedasticity test	0.3712	Accept Ho
Breusch-Godfrey serial correlation test	0.0767	Accept Ho
Jarque-Bera normality test	0.5345	Accept Ho
Ramsey reset test	0.1280	Accept Ho

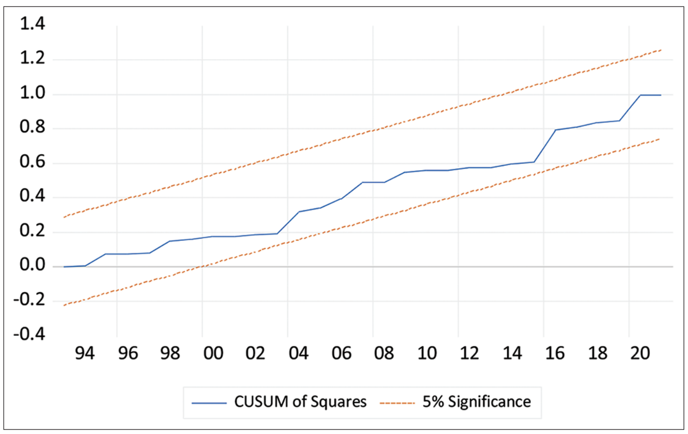
Source: Author's computation

Figure 4: CUSUM test



Source: Author's computation

Figure 5: CUSUM of Squares test



Source: Author's computation

The study 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 4 and 5. The blue line lies within the 5% critical region implying that the model is stable and reliable for policy recommendations. The study conducted the RAMSEY RESET test to check for model misspecification as shown in Table 8. The results have an F-statistical probability value of 0.1280 that is above 0.05 critical value implying that we fail to reject null hypothesis (Ho) and conclude that the chosen model 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 RECOMMENDATIONS

The major objective of this study was to investigate the possibility of Medupi and Kusile power plants providing the South African economy enough electricity when operating at full generating capacity for the period from 1980 to 2021. The goal was assured by employing the techniques of stationarity tests (DF-GLS and PP), cointegration tests (ARDL F-bound and t-Bound), long run relationships (ARDL levels equations), short run relationships (Unrestricted ARDL Error Correction Regression) and diagnostics tests (residual and stability tests). The unit root showed that variables are integrated of high order one I(1), and the bounds tests revealed cointegration relationships between variables, and one variable was utilised in the model. The results of the short and long run periods were found to be the same and the diagnostics test confirmed that the model does not suffer from any irregularities.

Based on the results from the study, the study therefore makes the following policy recommendation: Firstly, the positive relationship between electricity generation and consumption in South Africa both in the short and long run period calls for Eskom, policy makers and South African government to speed up the process of completing the construction of Kusile and Medupi Power Plants so they can operate at full generating capacity and provide enough electricity that is able to meet the gap between generation and consumption and eliminate loadshedding. This includes employing qualified technicians and engineers to limit the technical faults and accidents at these newly constructed power plants and all other power plants in South Africa.

Secondly, economic growth was found to have a positive effect on electricity consumption in both periods. However, the Granger causality results revealed that there is unidirectional causality running from electricity consumption to economic growth. This means that the government must revise policies on electricity consumption as they have the high chances of having causal effect on economic growth. This would entail enacting policies that boost electricity consumption so that economic growth can increase as it is direly needed in South Africa.

Thirdly, there is a negative relationship between electricity loss and electricity consumption in South Africa for the period understudy. This calls for Eskom, municipalities, and the South African government to invest in electricity infrastructure to limit the loss of electricity in the chain of transmission and distribution. This would include frequent visits to transformers and inspection on transmission lines to limit electricity theft by unpaying municipalities and illegally connected customers.

Fourthly, there is a positive relationship between population growth and electricity consumption for the period understudy. This calls for the government to consider building new electricity generating power stations that can be able to match the gap between population growth and electricity consumption. This would help minimizing loadshedding as the growing electricity demand from customers would be meet with growing electricity generation.

Fifthly, there is a negative relationship between trade openness and electricity consumption in South Africa. This calls for the government to revise its trade policies since it negatively impacts the consumption of electricity in the country. Less electricity consumed in the country is an indication of less productivity in the country due to trade. South Africa relies on many imports hence there is a negative effect between trade openness and electricity consumption.

In conclusion, the study assessed the possibility of Medupi and Kusile power plants providing the South Africa economy with enough electricity when generating at full capacity. This was achieved by utilising time series data from 1980 to 2021 and the positive relationship between electricity generation and electricity consumption. The studies in future should consider utilising the electricity generation data from Kusile and Medupi power plant to see their main impact on the electricity demand in South Africa.

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