Electricity consumption and population growth in South Africa: A panel approach

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Electricity consumption and population growth in South Africa: A panel approach

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Abstract: This study investigates the relationship between population growth and electricity consumption in South Africa for the period from 2002 to 2021 collected from StatsSA. The study utilises Seemingly Unrelated Regression model and Dumitrescu and Hurlin (2012) causality tests to analyse the relationship between the variables. Empirical results revealed that there is a negative statistically significant relationship between population growth and electricity consumption in South Africa. The results further reveal one-way causality running from population growth to electricity consumption. The study recommends that the government and policy makers must implement policies aimed at increasing renewable electricity generation to match the gap between electricity demand and growing population thereby reducing constant loadshedding in South Africa.

Keywords: Electricity consumption, population growth, Seemingly Unrelated Regression (SUR) Model, Eskom, South Africa.

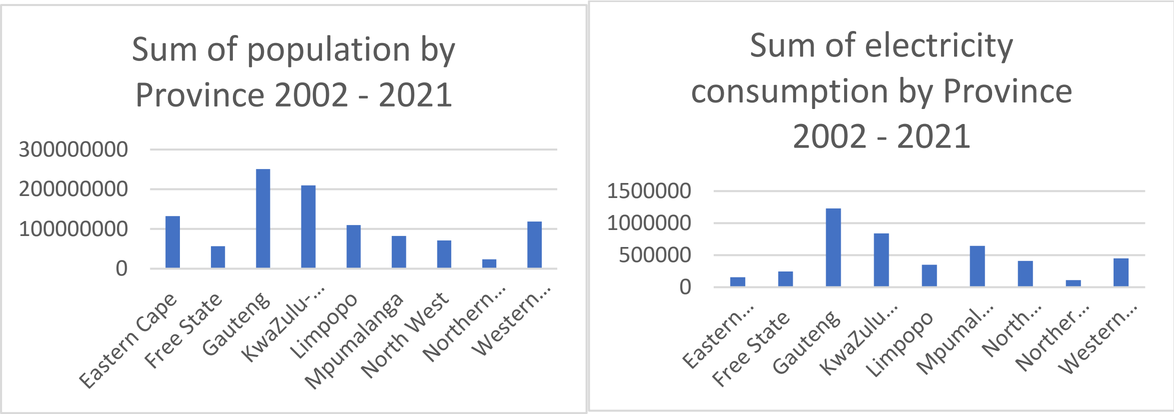
JEL Specification: C33, H20, O04, O25.

1. Introduction

Electricity is the backbone of an economy to grow in most societies today. South Africa has been marred with continuous loadshedding that has resulted from poor electricity generation that fails to meet the overgrowing electricity demand. The impact of loadshedding has resulted in some of the households having to find alternative sources of energy such as wood fuel in the rural areas, gas, and solar systems. This has also resulted in electricity consumption declining as people switch to alternative sources of energy. Lenoke (2017), Khobai and Le Roux (2017), Khobai (2018), Hlongwane and Daw (2021), Stungwa, Hlongwane et al. (2022) has conducted a study on electricity consumption but their studies was much focusing on the relationship between electricity consumption and economic growth. Electricity consumption is predicted to rise over next few decades. Increasing demand for electricity poses a problem to South Africa's administration because it relates to a significant reliance on expensive fuel imports. The study of primary factors of electricity consumption in South Africa will contribute to a better understanding and description of the nature of aggregate electricity consumption, as well as an endeavour to build a solid electricity policy.

Overview of the study: There are insufficient studies focusing on the relationship between population growth and electricity consumption in South Africa and the significance of this study is to investigate on that nexus. Electricity infrastructure is divided into three sub-sectors: generation, transmission, and distribution. In terms of generation, Eskom is the market leader in the production of power. Eskom generates, transmits, and distributes electricity in South Africa to industrial, mining, commercial, agricultural, mining, commercial, agricultural, and residential clients, as well as municipalities, which redistribute electricity to companies and homes within their jurisdictions (Ratshomo and Nembahe 2019). In addition, the utility acquires power from Independent Power Producers (IPPs) under different agreement schemes, as well as electricity generating facilities located outside of the country's boundaries. Electricity is the backbone of the South African economy, and it is a critical industry that generates employment and value by extracting, processing, and delivering energy commodities and services across the country. South Africa's consistent economic expansion, along with an increased emphasis on industrialisation and a mass electrification initiative to provide power to deep rural regions, has resulted in a sharp increase in electricity consumption in recent years. Ratshomo and Nembahe (2019), Modise and Mahotas (2020) and Gabrielle (2020) summarizes that residential was accountable for 8%, commerce and public services 14%, agriculture 6%, transport sector 19%, industry sector 52% and 1% was not specified in terms of electricity consumption in South Africa in 2016. Residential sector accounted for 72% of electricity consumption in South Africa according Ratshomo and Nembahe (2019). Population has been increasing but electricity consumption has not been increasing enough to match with the population. Figure 1 below shows the sum of population growth and electricity consumption in nine provinces in South Africa.

Figure 1: Sum of population and electricity consumption by province from 2002 to 2021



Source: Author's own compilation using data from StatsSA

Figure 1 above shows the sum of population growth and electricity consumption by province from 2002 to 2021. According to Figure 1, Gauteng has the highest electricity consumption followed by KwaZulu-Natal, Mpumalanga, and Western Cape province in terms of total gigawatt hours consumed. This is because Gauteng is the main tertiary and industrial hub of South Africa and holds a lot of population as compared to other provinces. In terms of the sum of population, Gauteng has the highest number, followed by KwaZulu-Natal, Eastern Cape, Western Cape, and Limpopo province. In South Africa we have a problem of high electricity consumption and high population growth, hence the significance of this study is to investigate the relationship between population growth and electricity consumption in South Africa. This will enable the policy makers, government, and Eskom to know how much electricity they should generate to meet the increasing consumption from the growing population.

2. Literature

Theoretical literature: The theoretical that underpins the investigation is presented in this section of the study. This study focuses on the growth theories in greater depth. Malthus (1798) believed that population increase will outpace the earth's ability to produce food, resulting in humanity's destitution. Solow (1956) underlined in a research that contributed to economic growth theory that a country with faster population growth rates will have lower levels of capital and income per worker in the long run. According to Kremer (1993), population expansion leads to economic growth. More people in the country equals more geniuses, scientists, and engineers, which lead to quicker technical advancement (Stungwa and Daw 2021). This study, however, tries modifying the growth theories by making electricity consumption depend on population growth and economic growth in South Africa to investigate the nature of relationship that exists among the variables.

A review of developing countries: Mohanty and Chaturvedi (2015) examine the weather electricity energy consumption on economic growth in Indian using the annual data spanning 1970-1971 to 2011-2012. Using granger causality test and Engle-Granger technique, their study suggested that electricity energy consumption has a positive relationship on economic growth in the short run and long run.

Athukorala and Wilson (2010) investigate it the short run dynamics and long run equilibrium relationship between the residential electricity demand and the factors influencing demand, like capita income, price of electricity, price of kerosene oil and price of liquefied petroleum gas using an onion data for Sri Lanka for the period of 1960 to 2007. The main findings of the paper were that increasing the price of electricity is not the most effective tool to reduce electricity consumption. Niu, Jia et al. (2013) analyzed the causality between electricity consumption and human development and assesses the changing trend of electricity consumption. they have started employed panel data from 1990 to 2009 for 50 countries divided into four groups according to the income. For human development indicator, per capita GDP, consumption expenditure, urbanization rate, life expectancy at birth and the adult literacy rate was selected. The result from the study demonstrated long run bidirectional causality existing between electricity consumption and five indicators. The study further suggested, to enhance human development, the electricity should be incorporated into the basic public services construction to improve the availability of electricity for low-income residents.

Ouédraogo (2010) examined the direction of causality between electricity consumption and economic growth in Burkina Faso for the period of 1968 to 2003. The bounce test yields evidence of cointegration between electricity consumption GDP and capital formation when electricity consumption and GDP are used as dependent variables. The start argued that electricity is a significant factor in socio economic development in Burkina Faso, therefore energy policies must be implemented to ensure that electricity generates few potential negative impacts. Bangladesh one of the largest populous countries in the world is being overwhelmed by an access demand of energy from the households, hence, Debnath, Mourshed et al. (2015) investigated the bottom up approach towards modelling the aggregate energy demand of right households of Bangladesh from 2010 to 2015. The energy demand pathway model demonstrated a significant rise in energy demand. Lionel (2013) investigated the relationship between electricity supply and economic development in Nigeria using an annual time series data from 1970-2009. The paper employed error correction model for empirical analysis of the study. The results showed that per capita GDP, lagged electricity supply, Technology, cut it down at the significant variables that influence economic development in Nigeria. Electricity supply has an influence in economic development in Nigeria, but its impact is very low.

Jamil and Ahmad (2010) investigated the relationship between electricity consumption, electricity prices and economic growth in Pakistan. The study employed annual time series data spanning for the period from 1960 to 2008. The study employed a Vector Error Correction Model (VECM) and Granger causality test to analyse the relationship between the variables in Pakistan. Empirical results revealed short run positive relationship between electricity consumption and economic growth in Pakistan. Granger causality results revealed unidirectional causal relationship from economic growth to electricity consumption that indicates economic growth stimulates electricity consumption in the long run. The researchers recommend that it is essential for Pakistan policymakers to plan and increase infrastructure development to meet increasing electricity demand. The researchers also recommend that government should adopt policies to sustain electricity supply. Hussain, Rahman et al. (2016) forecasted electricity consumption in Pakistan. The study borrowed available annual time series data spanning for the period from 1980 to 2011. The study employed Holt-Winter and Autoregressive Integrated Moving Average (ARIMA) models to forecast electricity consumption in Pakistan. The empirical results revealed that electricity demand is higher in the household sector than in other sectors and that electricity generation would be lesser than the increase in electricity generation. The researchers recommend that policymakers should focus on short- and long-term projects such as renewable sources of electricity to balance the supply-demand gap in Pakistan.

da Silva, de Marchi Neto et al. (2016) investigated electricity supply security and the future role of renewable energy sources in Brazil. The researchers found that hydroelectricity generation is the backbone of electricity supply in Brazil. The recent drought exposed the exposed vulnerability of electricity supply and drew significant immediate attention to address power outages. The researchers highlight that Brazil faces considerable increases in electricity consumption and policy makers should focus on renewable energy sources to balance energy supply and reduce dependence on hydroelectric power. Osman, Gachino et al. (2016) conducted a study on electricity consumption and economic growth in the GCC countries. The study borrowed available annual panel data spanning from 1975 to 2012. The study employed panel estimation techniques to analyse the relationship between the variables. Empirical results revealed positive results between the variables both in the short and long run period. The researchers recommend that if these countries adopt or implement policies that conserve electricity, this will have negative impact on economic growth of these countries.

Salahuddin and Alam (2016) conducted a study on information and communication technology, electricity consumption and economic growth in OECD countries. The study borrowed available annual panel data spanning for the period from 1985 to 2012. The study employed panel estimation techniques to analyse the relationship between the variables. Empirical results revealed that electricity consumption boost economic growth. Based on empirical results, the researchers recommend the adaption of technologies that promotes efficiency electricity consumption to reduce hazards arising from electricity consumption. Zhang, Zhou et al. (2017) investigated electricity consumption and economic growth in China. The study utilises available literature spanning from 1978 to 2016 that focuses on electricity generation and economic growth. The study reveals that vector error correction model (VECM) and vector autoregressive (VAR) model are the most employed models in the analysis. The study revealed that there is interaction between electricity consumption and economic growth. The researchers stresses that due to employment of different models, the results are not the same. The researchers recommend that China should increase the renewable sources of electricity to balance the strain on electricity supply and maintain environmentally friendly status.

Ouedraogo (2017) modelled sustainable long-term electricity supply-demand in Africa. The study employed the system-based approach developed by Schwartz in the context of Long-range alternative planning. The results revealed that despite the increase in the electricity generation, the demand for electricity will still be prevailing by 2030 and 2040 implying the insufficient in electricity supply. The researchers suggest that energy efficiency policies should be implemented to reduce the high energy consumption levels in Africa. Shahbaz, Sarwar et al. (2017) conducted a study on the dynamics of electricity consumption, oil price and economic growth on a panel global perspective. The study borrowed available annual panel data for 157 countries spanning from 1960 to 2014. The study employed panel estimation techniques to analyse the relationship between the variables. Empirical results revealed a short run positive relationship of electricity consumption on economic growth. The researchers reveals that more vigorous policies on electricity to be implemented to attain sustainable long run economic growth. The study recommends electricity conversion policies to trigger economic growth. Belaid and Youssef (2017) conducted a study on environmental degradation, renewable and non-renewable electricity consumption on economic growth in Algeria. The study borrowed annual time series data spanning from 1980 to 2012. The study employed an autoregressive distributed lad model and Granger causality test to analyse the relationship between the variables in Algeria. Empirical results revealed a unidirectional long run causality between the variables. The study recommends that investment in renewable electricity will boosts economic growth that will help fight unemployment in Algeria.

Dey and Tareque (2019) investigates the electricity consumption and gross domestic product nexus in Bangladesh. The study borrowed the available time series data spanning from 1971 to 2014. The study employs an autoregressive distributed lag model to analyse the relationship between Bangladesh's electricity consumption and economic growth. Empirical results revealed a positive relationship between electricity consumption and economic growth both in the short and long run period. The researchers recommend that electricity generation and conservation policy will be effective in Bangladesh. Shahbaz (2015) examined the impact of electricity shortage on sectoral GDP such as agriculture, industrial and service sectors in the case of Pakistan for the period of 1991 to 2013. the ordinary least squared (OLS) Was used for empirical analysis of the study. The results from the study demonstrated that electricity shortage is inversely linked with it agricultural sector output, and the result further showed that industrial the sector output is inversely affected by electricity shortage. Ha and Ngoc (2021) revisits the relationship between energy consumption and economic growth in Vietnam. The study borrowed available annual time series data spanning for the period from 1971 to 2017. The study employs an asymmetric autoregressive distributed lag model to analyse the relationship between the variables. The empirical results revealed that the negative impacts are greater than the positive impacts both in the short and long run of electricity consumption on economic growth in Vietnam. The researchers recommend that the government should encourage enterprises and people to use intelligent equipment and low electricity consumption machines while adopting renewable energy sources as an alternative.

A review of developed countries: Kahouli (2018) investigated the causal relationship between electricity consumption, CO2 emissions, research and development stocks and economic growth of Mediterranean countries. The study borrowed annual panel data spanning for the period from 1990 to 2016. The study employed panel estimation techniques to analyse the relationship between the variables. The empirical results revealed that electricity consumption boosts economic growth in the Mediterranean countries. The researchers recommend that policymakers should implement policies of electricity that are environmentally friendly. Bekhet and bt Othman (2011) investigated the relationship between electricity consumption, consumer price index, gross domestic product, and foreign indirect investment for period of 1971 to 2009. The vector error correction model was employed to estimate the causal relationship between electricity consumption with respective independent variables. The results demonstrated that electricity consumption what is the cointegrated with all their respective independent variables. The results further showed that there long-run causality from electricity consumption to FDI, GDP growth and inflation was found to be significant.

In Greece, Marques, Fuinhas et al. (2014) investigated the relationship between electricity generation and economic growth. Data from August 2004 to October 2013 were used in the study. To examine the relationship between the variables, researchers used a vector error correction model. The findings showed that convectional fossil fuels have a short-term positive impact on economic growth. Other findings revealed that there is no link between renewable energy and economic growth in the short and long term. To boost economic growth, the study suggests that Greek technology be integrated into renewable electricity generation. Marques, Fuinhas et al. (2016) investigated the relationship between the mix of electricity generation and economic growth in France. From January 2010 to November 2014, the study used monthly time series data. The relationship was investigated using an autoregressive distributed lag model. According to empirical findings, nuclear energy promotes economic growth in France, whereas renewable energy is detrimental to economic growth. According to the researchers, policymakers in France should be aware that any reduction in nuclear power is harmful to economic growth.

Kirikkaleli, Adedoyin et al. (2021) conducted a study on nuclear energy consumption and economic growth in the United Kingdom. The study employed annual time series data spanning from 1998 to 2017. The study employed a Toda Yamamoto causality and wavelet coherence test to analyse the relationship between the variables. The empirical results revealed that there is a positive correlation between nuclear energy consumption and economic growth in the United Kingdom. Furthermore, the study highlight that it is critical for the United Kingdom policymakers to create development-focused techniques and processes to build the economy from environmentally sustainable sources. Al-Bajjali and Shamayleh (2018) investigated the determinants of electricity in Jordan for the period from 1986 to 2015. The study employed a VECM model and found that GDP, population growth, urbanization, structure of economy and aggregate water consumption are positive statistically significant determinants of electricity consumption. Zaman, Khan et al. (2012) conducted a study on the determinants of electricity consumption function in Pakistan for the period from 1975 to 2010. The study employed a VECM Granger causality test and found that population growth, income and investment have positive relationship with electricity consumption.

Huang (2015) investigated the determinants of household electricity consumption in Taiwan from 1981 to 2011. The study employed quantile regression and found that household income and household size have a positive significant relationship with electricity consumption. Bedir, Hasselaar et al. (2013) conducted a study on the determinants of electricity consumption among the Dutch dwellings and found that household activities such as household size, dwelling type, use of dryer, washing cycles and several showers explains the variation in electricity consumption. Kwakwa (2018) investigated the determinants of electricity consumption in Ghana for the period from 1971 to 2014. The study employed an ARDL model and found that population, urbanization, education, and industrialisation positively affect electricity consumption while income negative impact electricity consumption. Sharma and Kautish (2019) investigated the macroeconomic determinants and electricity consumption in India for the period from 1980 to 2015. The study employed an NARDL model and found that GDP has a positive impact on electricity consumption in India. Kwakwa (2017) conducted a study on electricity consumption in Egypt analysing the long-run effects. The study employed a fully modified OLS model on the data for the period from 1971 to 2012 and found that income, urbanisation, financial development, trade, and education positively impact electricity consumption. Ubi, Effiom et al. (2012) conducted an econometric analysis of the determinants of electricity supply in Nigeria for the period from 1970 to 2009. The study employed an ECM model and found that technology, government funding and the level of power loss were statistically significant determinants of electricity supply in Nigeria. Louw, Conradie et al. (2008) conducted a panel study on the determinants of electricity demand for newly electrified low-income African households. The results from the study found that income, wood fuel usage, iron ownership and credit obtained were significant in determining the consumption levels within these households.

A review of South Africa: Bekun, Emir et al. (2019) investigated the relationship between energy consumption, carbon emissions and economic growth in South Africa. The study borrowed available annual time series data spanning for the period from 1960 to 2016. The study employed Granger causality test to analyse the relationship between the variables in South Africa. The results revealed a positive relationship between electricity consumption and economic growth in South Africa. The researchers recommend that the electricity conservation policies harm economic growth. 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.

Bhattacharya, Paramati et al. (2016) analyses the relationship between renewable energy consumption on economic growth in 38 OECD countries. The study covered the period from 1991 to 2012 and employed a full modified ordinary least squares method to analyse the relationship between the variables. The results from the study revealed that renewable energy sources and non-renewable energy consumption had a negative effect on economic growth in South Africa. Menyah and Wolde-Rufael (2010) analysed the relationship between energy consumption, pollutant emissions and economic growth in South Africa. The study covered the period from 1965 to 2006 and employed a modified granger causality and ARDL model to analyse the relationship between the variables. The results revealed that energy consumption is negatively related to economic growth in South Africa. From the literature above, majority of the studies that were conducted focused on the relationship between electricity consumption and economic growth, and there is limited to insufficient studies that focuses on the relationship between population growth and electricity consumption in South Africa. This study therefore investigates the relationship between population growth and electricity consumption by utilising economic growth as an intermittent variable.

3. Methodology

Model Specification: The study investigates the relationship between population growth and electricity consumption in nine provinces in South Africa by utilising gross domestic expenditure as intermittent variable to formulate a multivariate model. The variables are transformed into logarithms to have the same unit of measurement and avoid problems of spurious regressions. These variables were adopted from the study conducted by Al-Bajjali and Shamayleh (2018) and Zaman, Khan et al. (2012) on the determinants of electricity consumption in Jordan. The study utilises a simple linear model given in the equation 1 below:

$$LELC_t = \alpha_0 + \alpha_{LPOP} LPOP_t + \alpha_{LGDP} LGDP_t + \varepsilon_t \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (1)$$

Whereby, LELC represents the logged electricity consumption, LPOP is the logarithm of population growth, LGDP is the logarithm of gross domestic product, ε_t *and* α_0 is the error term and constant.

Data Sources: The study utilises the annual time series data spanning for the period from 2002 to 2021 for electricity consumption, population and gross domestic product collected from Quantec and Statistics South Africa (StatsSA).

Data Analysis: The study employs a basic linear Seemingly Unrelated Regression (SUR) model developed by Moon and Perron (2006) to analyse the relationship between population growth and electricity consumption in South Africa. Suppose that y_{it} is a dependent variable, $x_{it} = (1, x_{it,1}, x_{it,2}, \dots, x_{it,Ki-1})'$ is a K_i – vector of explanatory variables observational unit i, and u_{it} is unobservable error term, where the double index it denotes the t^{th} observation of the i^{th} equation in the system, t denotes the time dimension. The classical linear SUR model is a system of linear regression equations as given below:

$$y_{it} = \beta'_1 x_{1t} + \mu_{1t} \dots \dots (1)$$

$$y_{Nt} = \beta'_N x_{Nt} + \mu_{Nt} \dots \dots (2)$$

Whereby, $i = 1, \dots, N$, and $t = 1, \dots, T$. Denote $L = K_1 + \cdots + K_N$. This study however modifies the simple SUR model to a multivariate regression with parameter restrictions since this study employs more variables as proposed by Moon and Perron (2006). In this modification, $X_t = [x'_{1t}, x'_{2t}, \dots, x'_{NT}]'$ and $A(\beta) = diag(\beta_1, \dots, \beta_N)$ to be (L×N) block diagonal matrix. The multivariate SUR model can therefore be rewritten as given below:

$$Y_t = A(\beta)' X_t + U_t \dots \dots (3)$$

Where the coefficient $A(\beta)$ satisfies:

$$vec(A(\beta)) = G\beta \dots \dots (4)$$

For some (NL×L) full rank matric G. In a special case where $K_1 = \cdots = K_N = K$, we have $G = diag(i_1, \dots, i_N) \otimes I_K$ where i_j denotes the j'th column of the $N \times N$ identity matrix I_N. In the errors of U_t are assumed to be iid overtime with mean zero and homoscedastic variance $\sum = E(\mu_t, \mu'_t|X)$. We assume that $\sum is$ positive definite and denote by σ_{ij} the $(i,j)^{th}$ element of $\sum$, that is $\sigma_{ij} = (\mu_t, \mu'_t|X)$.

The Dumitrescu-Hurlin Causality Test: Dumitrescu and Hurlin (2012) provide an extension of Granger (1969) causality test designed to detect causality in panel data. The underlying regression is:

$$y_{i,t} = \alpha_i + \sum_{k=1}^{K} \gamma_{ik}\, y_{i,t-k} + \sum_{k=1}^{K} \beta_{ik}\, x_{i,t-k} + \varepsilon_{i,t} \quad with\ i = 1, \dots, N\ and\ t = 1, \dots, T \dots \dots (5)$$

Whereby, $x_{i,t}$ and $y_{i,t}$ are the observations of two stationary variables for individual i period t. Coefficients are allowed to differ across individuals but are assumed to be time invariant. The lag order of K is assumed to be identical for all individuals, and the panel must be balanced. As given in Granger (1969), the procedure to determine the existence of causality is to test for significant effects of past values of x on the present value of y. The null hypothesis is therefore defined as:

$$H_0: \beta_{i1} = \cdots = \beta_{iK} = 0 \ \ \forall i = 1, \dots, N \dots \dots (6)$$

Which correspond to the absence of causality for all individuals to the panel. The DH test assumes there can be causality for some individuals but not necessarily for all. Thus, the alternate hypothesis is:

$$H_1: \beta_{i1} = \cdots = \beta_{iK} = 0 \;\; \forall i = 1, \ldots, N_1 \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots .. (7)$$

$$\beta_{i1} \neq 0 \; or \ldots \ldots .. or \; \beta_{iK} \neq 0 \; \forall i = N_1 + 1, \ldots, N$$

Where $N_1 \in (0, N-1)$ is unknown. If $N_1 = 0$, there is causality for all individuals in the panel. N_1 must be strictly smaller than N, otherwise, there is no causality for all individuals, and H_1 reduces to H_0. In opposition of the above notion, Dumitrescu and Hurlin (2012) proposes the following procedure: run the N individual regressions implicitly encloses in equation 5, perform F tests of the K linear hypothesis $\beta_{i1} = \cdots = \beta_{iK} = 0$ to retrieve the individual Wald statistic W_i, and finally compute the average Wald statistic $\overline{W}$:[1]:

$$\overline{W} = \frac{1}{N} \sum_{i=1}^{N} W_i \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots . (9)$$

Lopez and Weber (2017) emphasizes that the test is designed to detect causality at panel level and rejecting H_0 does not exclude noncausality for some individuals. Following Monte Carlo simulations, Dumitrescu and Hurlin (2012) show that $\overline{W}$ is asymptotically well behaved and can genuinely be used to investigate panel causality. Under the assumption that the Wald statistics W_i are independent and identically distributed across individuals, it can be shown that the standardized statistic $\bar{Z}$ when T→ ∞ first and then N → ∞ (sometimes interpreted as T should be large relative to N) follows a standard normal distribution:

$$\bar{Z} = \sqrt{\frac{N}{2K}} \times (\overline{W} - K) \; \xrightarrow[T, N \to \infty]{d} \; N(0,1) \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots . \ldots (10)$$

The testing procedure of the null hypothesis finally based on $\bar{Z}$ and $\tilde{Z}$. If these are larger than the standardized critical values, then Lopez and Weber (2017) highlight that the null hypothesis (Ho) must be rejected and conclude that Granger causality exists. For large N and T panel datasets, $\bar{Z}$ can be reasonably considered and for large N but relatively small T datasets, $\tilde{Z}$ should be favoured. The study therefore continues to provide the results and interpretations as shown in Section 4 below.

4. Results and Interpretation

Table 2: Unit root test

Variable	LLC		IPS		ADF-Fisher	
	Constant	Constant & Trend	Constant	Constant & Trend	Constant	Constant & Trend

LELC	-2.41460 ***	-2.76476 ***	-1.34980 *	-0.77465	24.6673	23.7009
LPOP	-8.60690 ***	7.21015	-5.13018 ***	6.15673	61.1092 ***	3.08208
LGDP	-5.24503 ***	8.69102	-0.96851	9.46007	27.3829 *	2.28978
DLELC	-7.00055 ***	-8.96537 ***	-6.13912 ***	-6.88326 ***	72.3898 ***	74.7454 ***
DLGDP	3.83358	5.50667	-3.35001 ***	-2.70020 ***	50.1112 ***	43.8120 ***

Source: Author's own computation

The study performed a panel unit root test as shown in Table 1 above by employing the Levin, Lin, and Chu test, Im, Pesaran, and Shin test and ADF-Fisher test. The results shows that LELC and LGDP are integrated of I(1) while LPOP is integrated of I(0). The study therefore continues to perform the panel cointegration test as shown in Table 2 below to determine long run relationships among the variables.

Table 2: Panel Cointegration test

Method	**Pedroni Residual Cointegration Test**		
		Statistic	**Probability**
H1: Common AR coefs. (Within-dimensions)	Panel v-Statistic	-0.342178	0.6339
	Panel rho-Statistic	-2.664407	0.0039
	Panel PP-Statistic	-9.403298	0.0000
	Panel ADF-Statistic	-8.329954	0.0000
H1: Individual AR coefs. (Between-dimension)	Group rho-Statistic	-1.416709	0.0783
	Group PP-Statistic	-10.30917	0.0000
	Group ADF-Statistic	-7.184155	0.0000
Ho: No cointegration	**Kao Residual Cointegration Test**		
		t-statistic	**Probability**
	ADF	-3.520705	0.0002
	Residual variance	0.000673	
	HAC variance	0.000116	

Source: Author's own computation

Table 2 above shows the cointegration results of Pedroni (1999) and Kao (1999). The results of Pedroni (1999) are separated into two sections: within the dimension and between dimensions. The null hypothesis of Pedroni (1999) stress that there is no cointegration between the variables. Within the dimension, Panel rho-statistic, PP-statistic and ADF-statistic are all significant at 1% level of significance. As a result, the null hypothesis cannot be accepted and the conclusion the conclusion that cointegration exists is reached. Because the four tests were a tie, the study cannot establish that there is cointegration without testing the between dimensions. The results of the between dimensions confirms presence of cointegration since the group rho-Statistic (0.0783) is statistically significant. The group PP-statistic and ADF-statistic are also significant at 1% level of significance. The results of Kao (1999) also confirms that there is cointegration within the variables in the model since the ADF probability value is significant at 1% implying the rejection of the null hypothesis of no cointegration. The study therefore continues to perform the Durbin-Watson test to detect autocorrelation as shown in Table 3 below.

Table 3: Durbin-Watson Test

Estimated models	**DW-statistics**	**Conclusion**
Fixed Effects Model	2.300624	No autocorrelation
Random Effects Model	2.099321	No autocorrelation
Seemingly Unrelated Regression	2.060358	No autocorrelation

Source: Author's own computation

The study begins by using the DW statistics to check for autocorrelation of the residuals sequence of fixed effects model (FEM), random effects model (REM) and Cross-section Seemingly Unrelated Regression (SUR). The results are presented in Table 3 above and the DW statistics for FEM, REM and SUR are greater than 2, implying that there is no presence of autocorrelation in the residuals when FEM, REM and SUR are used to investigate the relationship between total population, economic growth, and electricity consumption in the nine South Africa provinces. After some diagnostic tests, the results of the FEM and REM models cannot be accepted due to presence of heteroskedasticity and nonnormal residuals, therefore, the study will employ the Cross-section Seemingly Unrelated Regression to analyse the relationship between electricity consumption, total population, and economic growth in South Africa.

Table 4: Cross-section Seemingly Unrelated Regression on electricity consumption, population, and economic growth

Variables	**Coefficients**	**Std. Error**	**t-Statistics**	**Probability**
LPOP	-0.086142	0.211732	-3.963758	0.0001
LGDP	0.012592	0.005352	2.352653	0.0199
Intercept	0.578315	0.145299	3.980178	0.0001
R-squared Adjusted R-squared	0.449260 0.412787			

Durbin-Watson stat	2.060358
Prob(F-statistic)	0.000000

Source: Author's own computation

The study performed the SUR model to show long run relationship among the variables in the model as given in Table 4 above when LELC is a dependent variable explained by LPOP and LGDP. The results shows that there is a negative statistically significant relationship between population growth and electricity consumption in South Africa. A 1% increase in population growth in South Africa, will significantly result in electricity consumption declining by 0.09%, ceteris paribus. These results are inconsistent with the studies conducted by Al-Bajjali and Shamayleh (2018), Zaman, Khan et al. (2012) and Huang (2015) that found a positive relationship between population growth and electricity consumption. This means that an increase in population growth in South Africa has a detrimental effect on electricity consumption. This may be a result of people in South Africa using alternative sources of energy. The recent load shedding affecting South Africa since 2009 has resulted in the people switching to alternative sources of energy such as paraffin, firewood, gas, solar and biogas for their daily activities. Therefore, policies that results in increase in electricity consumption might have a detrimental effect on the environment and people resulting call to switch to greener energy as Eskom is heavily reliant on non-renewable sources of energy.

The results further shows that there is a positive statistically significant relationship between economic growth and electricity consumption in South Africa. A 1% increase in economic growth in South Africa, will significantly result in electricity consumption increasing by 0.01, ceteris paribus. These results are consistent with the studies conducted by Huang (2015), Al-Bajjali and Shamayleh (2018) and Zaman, Khan et al. (2012) that found that economic growth has a positive relationship with electricity consumption. This entails that increase in economic growth result in an increase in electricity consumption since firms will be expanding the scale of their activities and industries requiring more electricity to cater for increasing demand in electricity. This calls for policy makers and the government to implement policies that results in an increase in renewable electricity generation to match with the growing electricity demand from economic growth. The Durbin-Watson statistic is greater than the R-squared which means the regression is not spurious. The R-squared is 0.45%, meaning 45% of the variation in electricity consumption is explained by population growth and economic growth in South Africa. The Adjusted R-squared is 0.41, meaning that 41% is adjusted for the degrees of freedom. The study therefore continues to perform the Cross-section dependence as shown in Table 5 below.

Table 5: Cross-section dependence on SA provinces

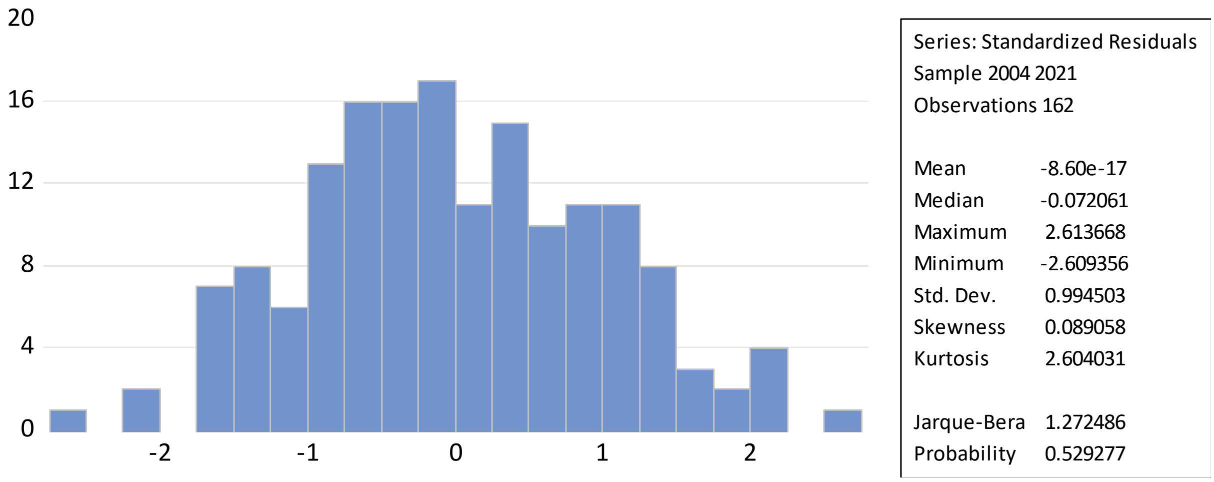
Test	**Statistics**	**d.f.**	**Probability**
Breusch-Pagan LM	1.877601	36	1.0000

Pesaran scaled LM	-4.021363		0.0001
Bias-corrected scaled LM	-4.286069		0.0000
Pesaran CD	0.006560		0.9948

Source: Author's own computation

The study performed cross-sectional dependence test as shown in Table 5 above. When there is presence of cross-sectional dependence across the panels, this impact on the efficiency of estimators and leads to biased results. The null hypothesis is that there is no cross-sectional dependence among residuals of the variables in the model. The results of Breusch and Pagan (1980) are reliable since it is good and powerful when time period (T) is greater than the cross-sectional dimension (N), while the Pesaran (2015) is perfect when either N is big or small (Stungwa and Daw 2021). The probability values of the Breusch-Pagan LM (1.0000) and Pesaran CD (0.9948) are greater than 5% implying that we fail to reject the null hypothesis cross-sectional dependence and concluding that there is cross-sectional independence between the cross-sectional units. This entails that the South Africa provinces are independent of each other when it comes to the relationship between electricity consumption, population growth and economic growth. The study continues to perform the residual normality test as shown in Figure 2 below.

Figure2: Histogram Normality Test



Source: Author's own compilation

The study performed the residual normality test as shown in Figure 2 above. The value of the Jarque-Berra is 1.272486 and its corresponding probability value is 0.529277 meaning that we fail to reject the null hypothesis that the residuals are normally distributed. This means that the results from the model are reliable since the residuals are normally distributed that is consistent with the prior expectations of a normal OLS regression model. The study continues to perform the Dumtrescu Hurlin causality test as shown in Table 6 below to check for causal relationships among the variables in the model.

Table 6: Pairwise Dumitrescu Hurlin Panel Causality Tests

Pairwise Dumitrescu Hurlin Panel Causality Test Lags: 1			
Null Hypothesis	**W-Stat**	**Zbar-Stat.**	**Probability**
LPOP does not homogeneously cause LELC	2.80584	2.69216	0.0071
LELC does not homogeneously cause LPOP	1.11709	-0.05989	0.9522
LGDP does not homogeneously cause LELC	0.61155	-0.88527	0.3760
LELC does not homogenously cause LELC	1.09725	-0.11070	0.9119
LGDP does not homogenously cause LPOP	12.6464	18.3071	0.0000
LPOP does not homogenously cause LGDP	2.57784	2.25045	0.0244

Source: Author's own computation

The study performed the Pairwise Dumitrescu Hurlin Panel causality test as shown in the Table 6 above to check for causal relationship among the variables. The study employed 1 lag to check is the effect of the previous year on explanatory variables have an impact in the presence results of the electricity consumption in South Africa. The results reveals that there is unidirectional causality running from population growth to electricity consumption since the probability values is 0.0071 which is significant at 1% level of significance. These results are consistent with the study that was conducted by Al-Bajjali and Shamayleh (2018) that found that population Granger causes electricity consumption. The results show bidirectional causality between economic growth and population growth in South Africa since the probability values are 0.0000 and 0.0244 which are statistically significant at 1% and 5% level of significance, respectively. This means that policies that affect economic growth and population growth will have causal effect on each other. The results reveal absence of causality between economic growth and electricity consumption since the probability values (0.3760 and 0.9119) are insignificant at 1%, 5% and 10% level of significance. This means that policies that affect economic growth will not have causal effect on electricity consumption and vice versa. The study therefore continues to give the conclusion and recommendations of the study as shown in Section 5 below.

5. Conclusion and Recommendations

The study examined the relationship between population growth and electricity consumption using economic growth as an intermittent variable and discovered that population growth and economic growth are significantly related to electricity consumption in South African provinces in both negative and positive ways, respectively. The study employed a Seemingly Unrelated Regression Model using panel data spanning the years 2002 to 2021. The panel unit root test was used in the study to establish the order of cointegration and to assist prevent the problem of spurious regressions. The study used the cross-section dependence diagnostic test and discovered that the provinces are independent of one another, avoiding misleading findings and inefficient parameters. The residual normality test findings indicated that the residuals are normally distributed, which is compatible with the expectations of a normal OLS model. The policy recommendations of this study are therefore as follows:

Firstly, the negative statistically significant relationship between population growth and electricity consumption calls for the policy makers, the government and Eskom to speed up policies that increase renewable electricity consumption. This will help reduce reliance on non-renewable electricity consumption and leading to households altering to environmentally friendly sources of energy such as wind and solar. The government must increase investment in the wind farms in the Eastern Cape province and solar in the Northern Cape and Limpopo provinces to take advantage of the abundant wind and higher temperature to generate electricity.

Secondly, the one-way causality from population growth to electricity consumption calls for the government, Eskom and policy makers must audit on electricity consumption to reduce people who are illegally connected to the grid municipalities who does not pay for their electricity bills to comply and pay their debts. This will help reduce the problem of heavy debts on Eskom, reducing financial problems and allowing Eskom the opportunity to be able to produce electricity that matches with a growing population.

Thirdly, the positive relationship between economic growth and electricity generation calls for the policy makers to implement policies that result in an increase in electricity generation to match the growing demand in electricity consumption because of economic growth. The Electricity is the backbone of an economy, electricity is needed to grow the economy. An increase in economic growth means the expansion of the activities of firms, households, and other sectors in the economy. Most of the sectors in the economy depends on electricity for caring their daily activities such as in the primary, secondary and tertiary sectors. This growing in electricity demand because of economic growth then needs to be accounted for by an increase in electricity generation to avoid problems of constant load shedding that has recently marred the South African economy.

Fourthly, bidirectional causality between population growth and economic growth calls for the policymakers to revise policies aimed at increasing population growth. Policies that will have an impact on population growth will also have a causal effect on economic growth. If the government implement policies that increase population growth, this will result in a causal effect on economic growth in South Africa. This is what Solow Growth Model allude when a countries are having the same population growth, saving rate and capital accumulation, then they have the same steady state, so they will converge. Solow (1956) then alludes to say along the convergence path, a poorer country then grows faster.

In conclusion, the study's main objective was to investigate the relationship between population growth and electricity consumption in South Africa by utilising economic growth as an intermittent variable. The objective was accomplished by the discovery of a negative relationship between population growth and electricity consumption and a positive relationship between economic growth and electricity consumption. This study therefore recommends that in future, the research should consider investigating the relationship between population growth and electricity consumption by employing the panel models and more variables such as unemployment, electricity generation and sectorial analysis to discover new knowledge in the field.

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