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Carbon Dioxide Emissions from Electricity Power Generation and Economic Growth in South Africa

Nyiko Worship Hlongwane*, Olebogeng David Daw

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

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ABSTRACT

This study analyses the relationship between CO_2 emissions from electricity generation and economic growth in South Africa. The study utilises annual time series data spanning for the period from 1971 to 2014 sourced from the World Bank. The study employs a Vector Error Correction Model (VECM) to analyse the short run and long run relationships. Empirical results revealed that there is a negative statistically insignificant short run relationship and long run negative statistically significant relationship between CO_2 emissions and economic growth in South Africa. The Granger causality results revealed noncausal relationship between CO_2 and economic growth. The policy implication of this study is that Eskom and policy makers must propose and implement policies aimed at reducing CO_2 emissions from electricity generation as it will improve economic growth in South Africa.

Keywords: CO_2 Emissions, Economic Growth, Electricity Consumption, Vector Error Correction Model, South Africa
JEL Classifications: C32, C40, E23, F40

1. INTRODUCTION

Eskom Holdings is the majority producer of electricity in South Africa generating almost 90% of the electricity consumed. The state owned entity has came to adopt policies that favour green energy or environmental friendly electricity generation processes. Antony (2021) stresses that according to the Centre for Research on Energy and Clean Air, Eskom Holdings SOC Ltd., South Africa's coal-dependent power utility, has become the world's largest emitter of sulphur dioxide, a pollutant linked to ailments ranging from asthma to heart attacks. This has created interest among scholars and policy makers into analysing the impact of the carbon emissions from electricity generation and heat processes in South Africa.

According to Antony (2021), the report released by CREA, an air pollution research organization, Eskom produced 1600 kilotons of the pollutant in 2019, the most recent year for which comparable data is available. Apart from India, this was more than any company and the total emissions of the power sector of any country. While China, the United States, and the European Union have reduced sulphur dioxide emissions by retrofitting power plants with pollution abatement equipment in recent years, Eskom has only done so at one of its 15 coal-fired power plants. Eskom has refuted a 2019 study linking its emissions to over 2000 deaths/year, claiming that its pollution kills 320 people/year (Antony, 2021). To reduce the burden on public health, they must adhere to minimum emissions standards.

Antony (2021) further stresses that because of the high sulphur content of the coal it burns, Eskom's pollution is also high. In 2019, South Africa's sulphur dioxide emission limits were reduced from 3500 milligrams per normal cubic meter to 1000 milligrams, still far exceeding India, and China's limits. The cost of retrofitting Eskom's power plants with the equipment known as flue-gas desulfurization units, is estimated to be between 100 billion rand and 200 billion rand. Eskom previously stated that it would need to invest 300 billion rand to meet South Africa's emission standards. The state-owned power utility is in debt to the tune of more than 400 billion rand,

and the company intends to reduce sulphur dioxide emissions by two-thirds by 2035.

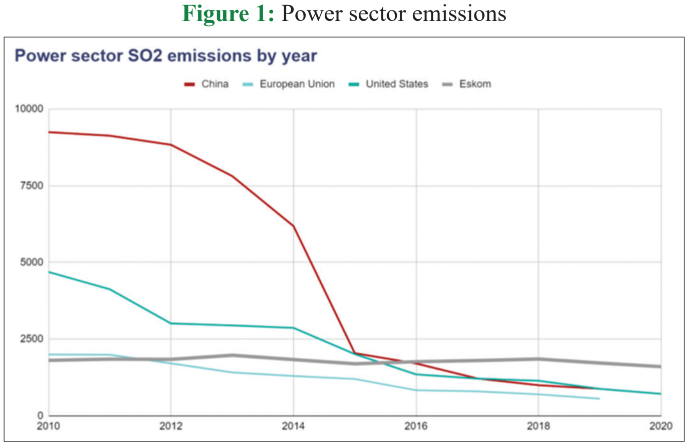
According to Evans (2021), because Indian coal contains much less sulphur than South African coal, despite having more than 5 times the coal-fired capacity, emissions are only twice as high. China and the United States were by far the most polluters a decade ago as shown in Figure 1 above. Massive retrofit programs and the installation of cutting-edge desulphurisation equipment at their power plants have resulted in a rapid reduction in emissions. In comparison, although they began lower, Eskom's emissions have remained relatively stable over the last decade. Eskom has begun a program to transition from retiring coal-fired power plants to renewable energy, with the goal of becoming net-zero by 2050.

People are becoming ill and dying because of air pollution in Mpumalanga, which has a high concentration of Eskom's coal-fired power stations. The National Council for Geosciences has named Emalahleni in Mpumalanga as the city with the most poisonous air in the world. Environmental Affairs (2021) highlights that the South African economy's energy intensity, owing largely to the importance of mining and minerals processing in the economy and our coal-intensive energy system, has resulted in an emissions profile that differs significantly from that of other developing countries at a similar stage of development as measured by the Human Development Index. South Africa's economy is very emissions-intensive because coal is the most emissions-intensive energy carrier.

Reuters (2021) contents that coal funding is being phased out ahead of a UN climate conference in Glasgow, Scotland, in November. The fuel is a major source of greenhouse gas emissions, but it is also a relatively inexpensive form of power generation that many emerging economies rely on. South African banks say they will continue to support the industry despite local conditions, but they are under increasing pressure from international investors in the push to reduce emissions, and fewer insurers are willing to share the risks associated with coal assets.

South Africa was the world's 12th largest emitter of climate-warming gases in 2019, with Eskom accounting for more than 40% of the total. Eskom, South Africa's state-owned power

Figure 1: Power sector emissions



Source: CREA

company, relies primarily on aging coal-fired power plants to supply 90% of the country's electricity. In 2020, more than 90,000 people were employed in coal mines. We rely on Eskom, so we can't stop funding Eskom or our entire economy will collapse (Reuters, 2021).

In South Africa we have a problem of CO_2 emissions from Eskom and a low economic growth. The problem with cutting off these CO_2 emissions will lead to retrenchment of workers and increased power supply cuts hence the significance of this study is to analyse the relationship between CO_2 emissions from electricity generation and economic growth in South Africa. Studies that focused on CO_2 emission were analysing CO_2 emissions as a whole and this study narrows the scope and focus on CO_2 emissions from electricity generation and heat processes in South Africa.

The remainder of the study is therefore organized as follows: Section 2 is the theoretical literature as well as the empirical literature of studies that found a positive, negative, noncorrelation and nonlinear relationship between the variables from developed, developing and finally South African economy. Section 3 gives the methodology and data used in the study to analyse the relationship between the variables. Section 4 gives the results and their accompanying interpretations. Section 5 finally gives the conclusion and policy recommendations of the study.

2. LITERATURE

2.1. Theoretical Literature

An inverted U-shaped relationship between economic growth and environmental degradation is explained by the Environmental Kuznets Curve hypothesis. Environmental pressure rises in the early stages of economic growth because of increased pollutant release and extensive and intensive exploitation of natural resources associated with increased use of production resources and the adoption of certain production technologies for expanding economic activities up to a certain level. When GDP grows at a high level, national income rises and then falls, owing to rising public awareness and concern about environmental degradation, as well as research and development activities geared toward green economy.

2.2. Empirical literature

Studies that found a positive relationship: Choi et al. (2010) conducted a study on the relationship between CO_2 emissions, economic growth and trade openness for China, Korea and Japan. The study utilized annual time series data spanning for the period from 1971 to 2006. The study employed the vector autoregressive and vector error correction model to analyse the relationship between the variables. The empirical results reviewed a positive impact of CO_2 emissions on economic growth. The researchers recommends that each country should volunteer to reduce their carbon emissions to reduce environmental problems.

Acaravci and Ozturk (2010) investigated the relationship between energy consumption, CO_2 emissions and economic growth in Europe. The study utilised the data for the period spanning from

1960 to 2005. The study employed an autoregressive distributed lag model to analyse the relationship between the variables. The results revealed that there is a positive relationship between carbon emissions and economic growth in European countries. The study recommends that policies aimed at energy conservation, such as rationing energy consumption and controlling carbon dioxide emissions are likely to have no adverse effects on economic growth based on the Granger causality results.

Govindaraju and Tang (2013) conducted a study on the dynamic relationships between CO_2 emissions, economic growth and coal consumption in India and China. The study utilised annual time series data spanning for the period from 1965 to 2009. The study employed an Engle-Granger causality test to analyse the relationship between the variables. The empirical results revealed that there is bidirectional causality between economic growth and CO_2 emissions. The researchers recommend that reducing CO_2 emissions will have negative impact on economic growth of these countries both in the short and long run period.

Zhang and Wang (2013) conducted a decouple indicators study on CO_2 emissions and economic growth linkages in the Jiangsu Province in China. The study utilised data spanning for the period from 1995 to 2009. The study employed a decoupling index to analyse the relationship. The empirical results reviewed that there is a positive relationship between industrialisation and CO_2 emissions in Jiangsu Province of China.

Saidi and Hammami (2015) investigated the relationship between CO_2 emissions and economic growth on energy consumption in four panels of 58 countries form Europe and North Asia, Latin America and Caribbean, and Sub-Saharan, Northern African and Middle East. The study utilised borrowed panel data spanning for the period from 1990 to 2012. The study employs generalized method of moments model to analyse the relationship between the variables. The researchers recommend that economic growth, CO_2 and energy consumption are complementary.

Bouznit and Pablo-Romero (2016) investigated CO_2 emissions and economic growth with evidence from Algeria. The study utilised time series data spanning for the period from 1970 to 2010. The study employed an autoregressive distributed lag model and error correction model to analyse the relationship in the nexus. The empirical results reviewed that economic growth is positively related to CO_2 emissions in Algeria. The researchers further recommend that it is important to promote renewable energy sources and efficiency energy policies to reduce CO_2 emission in Algeria.

Antonakakis et al. (2017) investigated energy consumption, CO_2 emissions, and economic growth form 106 countries. The study utilised borrowed panel data spanning for the period from 1971 to 2011. The study employed a panel vector autoregressive (PVAR) model to analyse the relationship between the variables. The results revealed applicability of the EKC theory that CO_2 emissions increase with economic growth. The researchers therefore recommends that the efficacy of recent government policies in various countries to promote renewable energy consumption to be questioned and concentrate on more communally just ways endorsed by degrowth.

Khobai and Le Roux (2017) investigated the relationship between energy consumption, economic growth, and carbon dioxide emission in South Africa. The study utilised annual time series data spanning for the period from 1971 to 2013. The study employed a vector error correction model and granger causality test to analyse the relationship between the variables. The results revealed a positive relationship between carbon dioxide emissions and economic growth in South Africa. The researchers recommend that policies aiming at reducing carbon dioxide emissions will be detrimental to economic growth in South Africa.

Khobai (2018) investigated electricity consumption and economic growth in the BRICS countries. The study utilised annual time series data for the period spanning from 1990 to 2014. The study employed a vector error correction model to analyse the relationship between the variables. The empirical results revealed that there is a positive relationship between CO_2 emissions and economic growth in the BRICS countries. The researcher recommends that significant transformation of low carbon technologies such as renewable energy should be implemented to curb emissions and sustain economic growth and development in the BRICS community.

Mikayilov et al. (2018) investigated the impact of economic growth on CO_2 emissions in Azerbaijan. The study utilised data spanning for the period from 1992 to 2013. The study employed cubic, quadratic, and linear (ARDLBT, FMOLS, DOLS and CCR) specification to analyse the relationship between the variables. The empirical results revealed a positive relationship between economic growth and CO_2 emissions in Azerbaijan for the period understudy. The researchers recommends that measures to increase energy efficiency, carbon pricing instruments in production and international-domestic trade activities and nation-wide social awareness programs to instruct about the negative consequences of pollution can be considered as relevant environmental policies aimed at reducing carbon emissions.

Acheampong (2018) investigated economic growth, CO_2 emissions and energy consumption on a global scale for 116 countries. The study utilized panel data spanning for the period from 1990 to 2014. The study employed a multivariate panel vector autoregressive, and system generalized method of moment models to examine the dynamic causal relationships between the variables. The results revealed that CO_2 emissions positively impact economic growth in these countries. The researcher recommend that policies aimed at reducing carbon emissions must be implemented with care as they will hurt future economic growth of the panel countries.

Cai et al. (2018) investigated the nexus between clean energy consumption, economic growth, and CO_2 emissions in the G7 countries. The study utilized annual time series data spanning for the period from 1965 to 2015. The study employed an autoregressive distributed lag model to analyse the relationship between the variables. The results revealed a positive relationship between CO_2 emissions and economic growth in the G7 countries. The researchers recommend that clean energy is a way to reducing C02 emissions as it has a negative relationship with CO_2 emissions thereby bridging the gap between economic growth and environmental protection in G7 and developing countries.

Chen et al. (2019) investigated CO_2 emissions, economic growth, renewable and non-renewable energy production, and foreign trade in China. The study utilized available annual time series for the period spanning from 1980 to 2014. The study employed an autoregressive distributed lag model to analyse the relationship between the variables. The empirical results revealed that economic growth increases CO_2 emissions in China. The researchers recommend that renewable energy is the key to reduce C02 emissions.

Mardani et al. (2019) investigated C02 emissions and economic growth through analysing available literature for the period spanning from 1995 to 2017. The study utilised 175 published articles for the period from 1995 to 2017 to analyse the relationship between the variables. The study employs a preferred reporting items for systematic reviews and meta-analyses (PRISMA). The empirical results revealed that there is a positive relationship between CO_2 emissions and economic growth. The researchers recommend that policies that limits CO_2 emissions will reduce economic growth as well.

2.3. Studies that Found a Negative or Inverse Relationship

Pao et al. (2011) modelled the CO_2 emissions, energy use, and economic growth in Russia. The study utilised available data spanning for the period from 1990 to 2007. The study employed an error correction model and granger causality tests to analyse the relationship between the variables. The empirical results revealed that there in a negative relationship between economic growth and CO_2 emissions in Russia. The researchers recommend that policies that reduce emissions is not detrimental for economic growth based on the granger causality test and that Russia should increase infrastructure investment to improve energy efficiency and thereby promoting economic growth.

Borhan et al. (2012) conducted a study on the impact of CO_2 emissions and economic growth in the 8 Asean countries. The study utilized borrowed annual panel data spanning for the period from 1965 to 2010. The study employed panel estimation techniques to analyse the relationship between the variables. The empirical results reviewed a negative impact of carbon emissions on economic growth in the 8 Asean countries. The researchers recommend that the inclusion of variables such as solid waste treatment, hazardous waste, and noise in the city as carbon emissions cause death and reduce economic growth.

2.4. Studies that Found No Causal Relationship

Lotfalipour et al. (2010) investigated economic growth, CO_2 emissions, and fossil fuels consumption in Iran. The study utilized annual time series data spanning for the period from 1967 to 2007. The study employed Toda-Yamamoto Granger causality tests, modified vector autoregressive models and seemingly unrelated regression to analyse the relationship between the variables. The empirical results revealed that CO_2 does not cause economic growth in Iran. The researchers recommend that though Iran does not have any commitments to reducing greenhouse gas emissions, energy efficient investments and emissions reduction will not hurt economic growth in Iran.

Ozturk and Acaravci (2010) investigated CO_2 emission, energy consumption and economic growth in Turkey. The study employed annual time series data spanning for the period from 1968 to 2005. The study employed autoregressive distributed lag model and the granger causality test to analyse the relationship between the variables in Turkey. The results revealed that there is no causal relationship among the variables in the model. The researchers recommend that energy conservation policies such as rationing energy consumption and controlling carbon dioxide emissions are likely to have no adverse effect on economic growth in Turkey.

2.5. Studies that Found Nonlinear Relationship

Wang (2012) modelled a nonlinear relationship between CO_2 emissions from oil and economic growth in a panel of 98 countries. The study utilised annual panel data spanning for the period from 1971 to 2007. The study employed a nonlinear dynamic panel threshold model (DPTM) to analyse the relationship between the variables. There results revealed a positive nonlinear relationship between CO_2 emissions and economic growth in the panel countries. The researchers further recommend the search for substitute ways to reduce oil CO_2 emissions growth, search for substitute energy sources, directly reduce oil CO_2 emissions growth medium and high economic growth countries and reduce population growth.

Heidari et al. (2015) investigated economic growth, CO_2 emissions, and energy consumption in five Asean countries. The study borrowed panel data spanning for the period from 1980 to 2008. The study employed panel smooth transition regression (PSTR) model to analyse the relationship between the variables. The results revealed a nonlinear relationship that CO_2 emission increase with increase in economic growth in the five Asian countries. The researchers further recommend that to reduce emissions these countries need to reduce emissions.

3. METHODOLOGY

3.1. Model Specification

The study analyses the relationship between CO_2 emissions from electricity generation and economic growth by adding intermittent variables of coal electricity generation and electricity power consumption to formulate a multivariate model. The variables are transformed into log to analyse the relationship between CO_2 emissions from electricity generation and economic growth in South Africa. The model that will be utilised in this study is specified as given below in equation 1:

$$LGDP_t = \alpha_1 + \alpha_{LCO2} LCO2_t + \alpha_{LCEP} LCEP_t + \alpha_{LEPC} LEPC_t + \varepsilon_t \tag{1}$$

LGDP represents natural log of gross domestic product per capita, LCO_2 represents logged C02 emissions from electricity generation and heat processes, LCEP represents natural log of coal electricity production and LEPC logged electric power consumption. Furthermore, α and ε represents the intercept and error term.

3.2. Data Sources

The study utilises borrowed annual time series data from 1971 to 2014 for gross domestic product, CO_2 emission from electricity production, coal electricity power generation and electric power consumption sourced from the World Bank.

3.3. Data Analysis

The study employs the augmented Dickey-Fuller and Phillips-Perron unit root test to check for stationarity of the variables. This will enable to avoid problems of spurious regressions and help to determine the order of integration of the variables for appropriate model selection. The study further employs the lag length criteria to determine the appropriate legs to be utilised in the model. The study employs the Johansen cointegration test to check for long run relationships in the variables. The study therefore adopts a Vector Error Correction Model (VECM) utilised in the study carried by Khobai and Le Roux (2017) and Khobai (2018). The VECM employed in the study therefore works in a way that at most, there are n−1 cointegration vectors and can be specified as given below:

$$\Delta Y_t = \theta_0 + \sum_{i=1}^{k-1} \theta_i \Delta Y_{t-1} + \propto \beta^{'Y_{t-k}} + \varepsilon_t \quad (2)$$

Where Δ is a differencing operator, Y is the variables (LGDP, LCO_2, LCEP and LEPC), θ represents the constant and ε represents the vector of white noise process.

VECM Granger-causality: The empirical estimation of the VECM is specified as given below to show short run and long run causal relationships:

$$\Delta LDGP_t = \alpha_{10} + \sum_{i=1}^{p} \alpha_{11} \Delta LGDP_{t-i} + \sum_{i=1}^{q} \alpha_{12} \Delta LCO1_{t-i} + \sum_{i=1}^{r} \alpha_{13} \Delta LCEP_{t-i} + \sum_{i=1}^{s} \alpha_{24} \Delta LEPC_{t-i} + \psi_2 ECT_{t-1} + \varepsilon_{2t} \quad (3)$$

$$\Delta LCO2_t = \alpha_{20} + \sum_{i=1}^{p} \alpha_{21} \Delta LCO2_{t-i} + \sum_{i=1}^{q} \alpha_{22} \Delta LGDP_{t-i} + \sum_{i=1}^{r} \alpha_{23} \Delta LCEP_{t-i} + \sum_{i=1}^{s} \alpha_{24} \Delta LEPC_{t-i} + \psi_2 ECT_{t-1} + \varepsilon_{2t} \quad (4)$$

$$\Delta LCEP_t = \alpha_{30} + \sum_{i=1}^{p} \alpha_{31} \Delta LCEP_{t-i} + \sum_{i=1}^{q} \alpha_{32} \Delta LCO2_{t-i} + \sum_{i=1}^{r} \alpha_{33} \Delta LGDP_{t-i} + \sum_{i=1}^{s} \alpha_{34} \Delta LEPC_{t-i} + \psi_3 ECT_{t-1} + \varepsilon_{3t} \quad (5)$$

$$\Delta LEPC_t = \alpha_{40} + \sum_{i=1}^{p} \alpha_{41} \Delta LEPC_{t-i} + \sum_{i=1}^{q} \alpha_{42} \Delta LCEP_{t-i} + \sum_{i=1}^{r} \alpha_{43} \Delta LCCO2_{t-i} + \sum_{i=1}^{s} \alpha_{44} \Delta LGDP_{t-i} + \psi_4 ECT_{t-1} + \varepsilon_{4t} \quad (6)$$

Where LGDP, LCO_2, LCEP and LEPC represents gross domestic product, carbon dioxide emissions from electricity production, coal electricity generation and electric power consumption respectively. ε represents serially uncorrelated random error term in period 1-4. ECT represents cointegrating vectors. ψ represents adjustment coefficient and it shows level of corrected disequilibrium as expressed by Khobai and Le Roux (2017). The researchers further express that the ECT (ψ) should be significant to find long term causality.

4. RESULTS

The study conducted the ADF and PP unit root test to avoid problems of spurious regression and determine the order of integration of the variables. The results displayed in Table 1 above shows that according to the ADF and PP all the variables are stationary at first difference I(1) except for LGDP that is stationary at both level I(0) and first difference I(1). This makes it suitable to employ the Autoregressive Distributed Lag (ARDL) Model proposed by Pesaran et al. (2001) that requires variable to be stationary at level or first difference but no variable should be stationary at second difference. The study therefore continues to determine the optimal lag length criteria as shown in Table 2 below.

The ADF and PP unit root tests were used in the study, and it was discovered that all the variables are stationary at first difference. As a result, the study performed a lag length test, as shown in Table 2 above, and determined that the optimal number of lags to include in the study is one, as determined by the LR, FPE, AIC, SC, and HQ criterion.

The Johansen technique is then used with the Trace and Maximum Eigenvalue based on the optimal lag length of 1. The results in Table 3 suggest two cointegrating equation based on the Trace test, whereas the results of Maximum Eigenvalue suggest none. As a result, the paper accepted the Trace results based on Trace statistic confirmation is more advantageous as highlighted by Lüutkepohl et al. (2001).

The results of the error correction model in Table 4 above reveals a negative statistically insignificant relationship between CO_2 emissions from electricity production and economic growth in South Africa in the short run since its t-statistic (−1.9974) is greater than −2 the critical value. This implies that a 1% increase in CO_2 emissions in the short run, will insignificantly result in economic growth declining by 18.34%, ceteris paribus.

Furthermore, the results reveal a negative statistical insignificant relationship between coal electricity generation (LCEP) and electric power consumption (LEPC) on economic growth in the short run. This implies that a 1% increase in the short run in LCEP and LEPC, will insignificantly reduce economic growth by 0.46% and 4.03%, ceteris paribus. The coefficient of the error term is negative (−0.702805) and statistically significant (−4.2793), indicating that previous year's deviation from long run equilibrium is corrected at a speed of 70.28% Table 5.

The long run relationship reveals a negative statistically significant relationship between CO_2 emissions from electricity generation and economic growth in South Africa. A 1% increase in CO_2 emissions in the long run, will significantly results in a decrease in economic growth by 17.08%, ceteris paribus. This can be caused by the commitments by Eskom to reduce its CO_2 emissions and

Table 1: ADF and PP unit root test

Variables	ADF unit root test				PP unit root test			
	Constant		Trend and Intercept		Constant		Trend and Intercept	
	Level	Δ	Level	Δ	Level	Δ	Level	Δ
LGDP	−4.1194 ***	−6.6429 ***	−4.3098 ***	−6.5566 ***	−4.1113 ***	−21.5805 ***	−4.1990 ***	−21.1597 ***
LCO_2	−1.8893	−−7.7976 ***	−1.6212	−8.1037 ***	−1.8745	−7.7918 ***	−1.6212	−8.1873 ***
LEPC	−4.4603 ***	−4.5090 ***	−1.6631	−5.7014 ***	−4.2853 ***	−4.4596 ***	−1.6574	−5.6553 ***
LNREP	−2.1162 ***	−8.3572 ***	−2.4135	−8.2892 ***	−2.0908	−8.2206 ***	−2.5141	−8.1688 ***

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

Table 2: Optimal lag length criteria

Lag	LogL	LR	FPE	AIC	SC	HQ
0	−262.8603	NA	5.291529	13.01758	13.18475	13.07845
1	−140.1173	215.5488*	0.029129*	7.810599*	8.646488*	8.114983*
2	−133.3244	10.60346	0.046760	8.259728	9.764328	8.807621
3	−121.8400	15.68607	0.061978	8.479999	10.65331	9.271399

Source: Author's own computation

Table 3: Johansen Cointegration test

Hypothesized No. of CE (s)	Max-Eigen Statistic	0.05 Critical Value	Trace Statistic	0.05 Critical Value
None	23.96724	27.58434	54.39281*	47.85613
At most 1	16.77689	21.13162	30.42557*	29.79707
At most 2	8.033069	14.26460	13.64868	15.49471
At most 3	5.615610*	3.841465	5.561274*	3.841465

Source: Author's own computation

Table 4: Vector error correction model and short run relationship

Variable	Coefficient	Standard error	t-statistic
D (LGDP(−1))	0.154991	0.14798	1.0474
D (LCO_2 (−1))	−18.33925	9.18143	−1.9974
D (LCEP(−1))	0.461752	0.29125	1.5854
D (LEPC(−1))	4.027602	9.96569	0.4042
ECT(−1)	−0.702805	0.16424	−4.2793
C	0.230221	0.36297	0.6343

Source: Author's own computation

Table 5: VECM and long run relationship

Variable	Coefficient	Standard error	t-statistic
LGDP(−1)	1.000000	-	-
LCO_2 (−1)	−17.08015	7.27339	−2.3483
LCEP(−1)	−0.536211	0.34105	−1.5722
LEPC(−1)	6.296315	5.32149	1.1830
C	68.24723	-	-

Source: Author's own computation

these results are inconsistent with the study carried by Khobai and Le Roux (2017).

Furthermore, there is a negative statistically insignificant relationship between coal electricity generation and economic growth in the long run. A 1% increase in coal electricity generation in the long run will insignificantly result in economic growth declining by 0.53%, ceteris paribus. There is a positive statistically insignificant relationship between electric power consumption and economic growth in the long run. For a 1% increase in electric power consumption will insignificantly result in economic growth by 6.30%, ceteris paribus. Therefore, the study further employs a Granger causality test to validate the results and determine the causal relationship between the variables.

Table 6: Granger causality test

Null Hypothesis	F-statistic	Prob.
LCO_2 does not Granger cause LGDP	0.8175	0.3713
LGDP does not Granger cause LCO_2	0.0049	0.9446
LCEP does not Granger cause LGDP	0.0153	0.9023
LGDP does not Granger cause LCEP	0.4503	0.5061
LEPC does not Granger cause LGDP	0.0879	0.7684
LGDP does not Granger cause LEPC	0.0907	0.7648
LCEP does not Granger cause LCO_2	0.8345	0.3665
LCO_2 does not Granger cause LCEP	6.8260	0.0126
LEPC does not Granger cause LCO_2	4.1424	0.0485
LCO_2 does not Granger cause LEPC	0.0618	0.8049
LEPC does not Granger cause LCEP	3.9342	0.0542
LCEP does not Granger cause LEPC	1.4001	0.2437

Source: Author's own computation

The results of Granger causality tests in Table 6 above revealed noncausal effect between CO_2 emissions from electricity generation and economic growth in South Africa. The results further reveal one-way causality running from CO_2 emissions to coal electricity generation. The results also reveal a one-way causality running from electric power consumption to CO_2 emissions and coal electricity generation.

The results of the variance decomposition for economic growth are presented in Table 7 above. The results reveal that in the 10th year,

Table 7: Variance Decomposition economic growth

Variance Decomposition of LGDP:					
Period	S.E.	LGDP	LCO_2	LCEP	LEPC
1	2.091639	100.0000	0.000000	0.000000	0.000000
2	2.473860	85.28490	0.110196	14.60227	0.002632
3	2.586358	78.30236	2.011928	18.37258	1.313138
4	2.694376	72.21374	5.442227	19.61529	2.728739
5	2.790996	67.61605	8.098671	20.59160	3.693680
6	2.883749	63.82650	10.12152	21.65311	4.398876
7	2.973729	60.48708	11.83247	22.68154	4.998908
8	3.061151	57.49043	13.37436	23.59424	5.540974
9	3.146137	54.49043	14.77033	24.39662	6.030286
10	3.228866	52.38820	16.02855	25.11326	6.469998

Source: Author's own computation

Table 8: Variance decomposition CO_2 emissions

Variance Decomposition of LCO_2:					
Period	S.E.	LGDP	LCO_2	LCEP	LEPC
1	0.039401	0.088947	99.91105	0.000000	0.000000
2	0.051722	0.230910	98.45136	0.190670	1.127056
3	0.062350	0.936579	96.65423	0.223894	2.185299
4	0.071183	1.340335	95.41964	0.195284	3.044738
5	0.079122	1.511170	94.71239	0.177439	3.598999
6	0.086388	1.594180	94.25995	0.167427	3.978441
7	0.093111	1.650488	93.93085	0.161468	4.257194
8	0.099383	1.695068	93.67554	0.157041	4.472350
9	0.105283	1.730710	93.47314	0.153471	4.642677
10	0.110870	1.759216	93.31014	0.150562	4.780084

Source: Author's own computation

one standard deviation shock from CO_2 emissions, coal electricity generation and electric power consumption will result in 16.03%, 25.11% and 6.47% forecast error variance respectively. After 10 periods, a greater percentage of 52.39% becomes self-explanatory.

From Table 8 below, 93.31% is self-explanatory for CO_2 emissions in the 10^{th} year for forecast error variance. Coal electricity generation, electric power consumption and economic growth will all result in a standard deviation shock of 0.15%, 4.78% and 1.76% respectively.

5. CONCLUSION AND RECOMMENDATIONS

The study investigates the relationship between CO_2 emissions and economic growth by using coal electricity generation and electric power consumption as control variables in a multivariate framework. To estimate the long run relationship and direction of causality among the variables, the Johansen co-integration technique and the VECM were used. Johansen's results revealed the existence of a cointegration relationship in the equation. This demonstrates that there is a long-term relationship in South Africa between economic growth, CO_2 emissions, coal electricity generation, and electric power consumption.

The VECM results show a statistically significant negative noncausality long run relationship between CO_2 emissions and economic growth in South Africa. This refutes the idea that CO_2 emissions from electricity generation cause or increase economic growth. The findings also show a one-way causal relationship between electric power consumption and coal electricity generation, as well as CO_2 emissions from electricity generation. The results displays that the share of CO_2 emissions on economic growth is minimal.

The policy implications of this study based on empirical evidence is that: Firstly, Eskom and policy makers must propose and implement policies aimed at reducing CO_2 emissions from electricity generation as it is detrimental for economic growth. These policies might be increasing the pace and investment in retrofitting Eskom's power plants. This will reduce the level of CO_2 emissions from electricity generation and help improve economic growth in South Africa.

Secondly, policy makers must formulate policies that encourages electric power consumption efficiency as it has a causal effect on coal electricity generation and CO_2 emissions from electricity generation. This will help reduce the level of CO_2 emissions that are produced from electricity generation hence shifting the focus to a cleaner environment and efficient use of electricity power.

Thirdly, the government must encourage electric power consumption as it contributes positively to economic growth both in the short and long run period. Majority of the sectors in South Africa uses electricity on daily basis. The government and Eskom must implement policies that favours legal and efficient electricity consumption so that it can boost economic growth. The legal part of electricity consumption will help Eskom to forecast how much electricity is needed at a particular time and reduce constant load-shedding by balancing the overwhelming electricity demand and limited electricity supply.

Fourthly, Eskom must minimize producing electricity from coal as it is detrimental to economic growth in South Africa. This must be implemented with care by placing much focus on renewable sources of electricity to balance the control output of coal electricity generation. The study notes that the sign of the coefficient might not be harmonious with the theory. Studies in future must also consider utilising other models for the study to reveal if the impact is still the same.

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