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# The Relationship between Economic Growth and Carbon Emissions in South Africa

**Hlalefang Khobai*, Katlego Sithole**

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

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**ABSTRACT**

South Africa has been dismantling the challenges of Global warming and climate change issues pertaining Carbon emissions which have aggravated environmental problems over the past years due to its heavy reliance on coal. About 77% of South Africa's electricity needs are been bestowed by coal. This study serves to determine the relationship between carbon emissions and economic growth in South Africa covering the period between 1984 and 2018. The study employed the ARDL bounds technique to determine the long run relationship among the variables and the VECM to determine the direction of causality among variables. The findings established that there is a long relationship between carbon emission, economic growth, energy consumption, foreign direct investment and trade openness in South Africa. The VECM suggested that there is bidirectional causality flowing between economic growth and carbon emissions. The results also validated the EKC hypothesis both in the long run and short run. It is thus imperative for the policy makers and government to divert their thoughts to more innovative and creative strategies of attaining alternative energy sources especially renewable sources. There is a need for the best environmental policy to enhance infrastructure investment to improve energy efficiency and reduce emissions.

**Keywords:** Carbon Emissions, Economic Growth, ARDL Model, South Africa
**JEL Classifications:** C32, D04, Q47, Q42, Q01

## 1. INTRODUCTION

Energy and environmental sustainability are of paramount importance for economic growth and improvement of social welfare. This shows that policies formed to boost economic growth should not be at the cost of environmental degradation. The exponential incline of energy consumption and a rapid increase of population has gained popularity within the global environment. This is on account of the persistent threats of the environmental degradation to the long term surface of the earth by disrupting the entire world's weather and climate patterns including rainfall, extreme weather events and sea-level rise. The major forms of pollution include water pollution, noise pollution, atmospheric pollution, soil pollution and land pollution.

Health effects are also at the receiving end of the rising environmental degradation, as a result leading to lower economic development. It is evident that pollution resulting from contaminated water will lead to diseases such as skin cancer, while air pollution will result in lung cancer. The negative effect on health can lead to inefficient human capital to contribute much to boost production. It can also be argued that climate changes is associated with the rise in poverty more especially for developing countries, due to these countries' reliance on agricultural sector. Climate changes are major causes of acid rain which is detrimental to the crops and also causes the land to be infertile. The wild life species are also endangered by climate change. This will further enhance levels of poverty in some developing countries as they rely much on fishing. It is evident that pollution has ruthless effects on health, production as well as availability of resources. This will result in the slowdown in economic growth and development.

Indeed, global warming has become a major concern worldwide and South Africa is no exception. South Africa experienced an increase in carbon emission by a staggering amount of 8.9 metric tons/capita (World Bank 2014). This landed the country on the 16th rank in the global emission list as the dirtiest energy producer in the world. The environmental problems in South Africa are due to its heavy reliance on coal for electricity production. According to Khobai and Le Roux (2018), coal accounts for about 77% of the country's electricity generation. This dependence on the fossil fuel saw South Africa increasing the ranks to the 14th place in 2015 of the global emission list. It was also discovered that South Africa was failing to maintain their global warming below 2°C as per the Paris Agreement which called for blocking of global warming at well below 2°C and 1.5°C if possible.

Figure 1 illustrates compares South African carbon emissions with that of some developing countries (Angola, Botswana, China and Zimbabwe) from 2007 to 2014 using the World Bank data. It can be realized that Zimbabwe was the least carbon emitting country of the countries chosen followed by Angola. South Africa on the other hand recorded the highest carbon metric tons than the rest of the countries followed by China. Even though China is known of its 40 consecutive years of rein as the world most polluted country, it is still better than South Africa. According to China invested much to move away from the usage of coal for electricity production to renewable sources, more especially hydroelectricity, wind and solar power.

The relationship between carbon emissions and economic growth has gained much attention in economic literature, thus investigating whether carbon emissions have a positive, negative or no effect at all on economic growth. It is evident that energy is one of the drivers of economic growth, therefore it is important to ensure that its generation does not temper with environmental sustainability resulting in adverse effects on economic growth and development. Thus, the purpose of this study is to determine the impact of carbon emissions on economic growth in South Africa covering the period between 1984 and 2018.

The remainder of this papers include the literature review on the carbon emission and economic growth nexus section which will be followed by data description and methodology section. The estimation of data and interpretation of results section will follow. The last section will focus on the conclusion and recommendations emanating from the findings of the study.

## 2. LITERATURE REVIEW

There has been an increasing literature on the relationship between carbon emissions and economic growth owing to the rising environmental degradation. The theoretical literature and empirical literature is rooted to the notorious hypothesis – the Environmental Kuznets Curve (EKC). The EKC purports that environmental degradation rises at the stage of development and then decreases as growth advances (Stern, 2004). This supports the U-shaped curve of the EKC which shows that at the initial stage of production, the more the country produces, the more pollution. But in the long run as the country develops, more strategies to curb environmental degradation and more technologies will decrease contamination. Scant literature has focused on the relationship between carbon emissions and economic growth, most studies focused on economic growth and energy consumption and included carbon emissions as an intermittent variable. This study is going to concentrate on both lines commencing with the studies that focused solely on carbon dioxide emissions and economic growth and then the ones with energy consumption, economic growth and carbon emissions

### 2.1. Carbon Emissions and Economic Growth

Grossman and Krueger (1991) purposed to determine the environmental impact of on North American countries. The study employed three air pollutants in a cross-section of urban areas located in 42 countries to try and establish if there is a nexus between air pollution and economic growth. The results revealed that pollution increase with per capita GDP at low levels of national income, but declines with GDP growth at higher levels of income. Similar results were validated by Stern (2004) and Dinda (2005) who specifically focused on the theoretical basis and extensive surveys.

Coondoo and Dinda (2007) aimed to examine relationship between carbon dioxide and income focusing on a cross-country distributional patterns. Using the Johansen cointegration technique, the study found that inter-country income inequality has a significant impact on emissions. Focusing on Turkey, Akbostancı et al. (2008) failed to established EKC hypothesis, meaning they study did not find the U-shaped relationship between environmental degradation and income.

Khan et al. (2015) focused on selected higher carbon emissions countries to investigate the relationship between carbon emissions and income level covering the period between 1971 and 2013. The results from the panel group FMOLS indicated that carbon emissions have an impact on economic growth. Focusing also on individual countries, the study revealed that carbon emission has a positive and significant effect on economic growth in China, Japan and USA but for India it has a negative impact.

Kasperowicz (2015) examined the relationship between carbon emissions and economic growth for 18 EU Member countries for the period from 1995 to 2012. The empirical results from the ECM estimation affirmed that there is negative relationship between carbon emissions and economic growth in the long run but a positive relationship is revealed in the short run.

Cederborg and Snobohm (2016) investigated the relationship between per capita emission and per capita GDP focusing on 69 industrial countries and 45 poor countries. The findings suggested a positive relationship between carbon emissions and economic growth. This implies that increasing per capita GDP increases carbon emissions. Contrary to the EKC hypothesis, the study failed to establish a turn point, whereby the more per capita GDP increases, carbon emissions start to fall.

Aslan et al. (2018) examined the validity of the EKC hypothesis for sub-elements of carbon dioxide emissions (total $CO_2$ emission, commercial $CO_2$ emission, electrical $CO_2$ emission, industrial $CO_2$ emission, residential $CO_2$ emission and transportation $CO_2$

emission in the United States covering the period between 1973 and 2015. The findings from the rolling window estimation procedure revealed that the inverted U-shaped EKC hypothesis is valid for total $CO_2$ emission, industrial $CO_2$ emission, electrical $CO_2$ emission and residential $CO_2$ emission.

Khan et al. (2020) conducted a study to assess the relationship between energy consumption, carbon dioxide emissions and economic growth in Pakistan covering the period between 1965 and 2015. Their findings from the ARDL bounds test revealed that economic growth and energy consumption increase carbon dioxide emission both in the long run and short run. Olubusoye and Musa (2020) focused on 43 African countries to test if there is a relationship between Economic growth and Carbon emissions. The findings suggested that in 79% of the countries, carbon emissions increase as economic growth increases while 21% of the countries showed a negative relationship between economic growth and carbon emissions.

Osadume (2021) served to examine the impact of economic growth on carbon emissions on six selected West African countries covering the period from 1980 to 2019. To do statistical analysis, the study used panel econometric methods. It was established that there is a long relationship among the variable and economic growth a positive and significant effect on carbon dioxide emissions in the short run

Shikwambana et al. (2021) purposed to determine the relationship between the emissions and economic growth in South Africa. The study employed the linear correlation coefficient and the environmental Kuznets curve hypothesis test together with the sequential Mann-Kendall (SQMK) test to analyse the study trends. It was discovered that there is a strong positive linear relationship between carbon dioxide emissions and economic growth.

## 2.2. Carbon Emissions and Energy Consumption

Soytas et al. (2006) instead of testing existence of the EKC hypothesis, they focused on the Granger causality relationship between income, energy consumption and carbon emissions. Their study included labor and gross fixed capital as the intermittent variables. The results affirmed that there is no long run causality flowing from income to carbon emissions in the US but energy consumption does Granger cause carbon emissions.

Halicioglu (2008) examined the nexus between carbon emissions, energy consumption, income and foreign trade in Turkey for the period between 1960 and 2005. Employing the bounds test, the study found two forms of long run relationship among the variables. The first one, carbon emissions are explained by energy consumption, foreign trade and income while the second one, income is determined by foreign trade, energy consumption and carbon emissions.

Zhang and Cheng (2009) purposed to determine the presence of Granger causality relationship between energy consumption, carbon emissions and economic growth in China. The study included capital and urban population as intermittent variables and applied a time series data for a period 1960-2007. The results from the multivariate model indicated that economic growth Granger-cause energy consumption and energy consumption Granger cause carbon emissions.

Soytas and Sari (2009) investigated the Granger causality relationship between energy consumption, economic growth and carbon emissions for Turkey. It was established that carbon emissions Granger cause economic growth but the reverse is not true. This shows that it is not ncessary to forgo economic growth in order curb carbon emissions.

Apergis and Payne (2009) served to examine the presence of Granger causality relationship between carbon emissions, energy consumption and economic growth in six Central American countries covering the period between 1971 and 2004. It was found that energy consumption has a positive and statistically significant impact on emissions while real output exhibits the inverted U-shape pattern associated with the Environmental Kuznets Curve (EKC) hypothesis in the long run. The Granger causality results established bidirectional causality flowing between energy consumption and real out in the short run and a short run causality flowing from energy consumption and real output to emissions. Finally, bidirectional causality flowing between energy consumption and emissions was affirmed.

Pao and Tsai (2010) purposed to determine the relationship between carbon emissions, energy consumption and foreign direct investment in the BRIC countries for the period 1980-2007 except for Rusia which data was available from 1992 to 2007. The findings of the study suggested that carbon emissions are energy consumption elastic in the long which seem to support the EKC hypothesis. The results further revealed bidirectional causality flowing between emissions and FDI and a one way causality running from output to FDI.

Pao and Tsai (2011) investigated the dynamic relationship between energy consumption, output and pollutant emissions in Brazil for the period 1980 and 2007. The findings validated the existence of the inverted U-shaped relationship between emissions – income and energy-income. This implies that both environmental damage and energy consumption firstly rises with income, then stabilize and eventually fall. The Granger causality results suggest that there is bidirectional causality flowing between income, energy consumption and emissions.

Li et al. (2017) purposed to investigate the nexus between $CO_2$ emission, economics growth and three selected types of fossil energy consumption (coal, gas and oil) in China for the 1965-2015 period. The results from Johansen cointegration test supports an existence of a long run relationship among the variables. The findings from the VECM show a two-way causality between coal consumption and $CO_2$ emissions, and between GDP and gas consumption. The results further revealed a unidirectional causality flowing from GDP and oil consumption to $CO_2$ and from GDP to oil consumption.

Cetin et al. (2018) examined the effect of economic growth, energy consumption, trade openness and financial development on carbon emissions in Turkey covering the period between 1960 and 2013. The findings from the ARDL bounds test established that carbon emissions are mainly determined by economic growth, energy consumption, trade openness and financial development in the long run. The results further revealed that the EKC hypothesis is valid for Turkey both in the long run and short run. A long run causality flowing from economic growth to carbon emissions was also found.

Khoshnevis and Dariani (2019) investigated the causal relationship between carbon emissions, energy consumption, economic growth, trade openness and urbanization for Asian countries for the period from 1980 to 2014. The study employed pooled mean group (P.M.G) approach and panel Granger causality tests. The findings from the Pedroni panel cointegration test suggested an existence of a long run relationship among the variables. The Granger causality results revealed bidirectional causality flowing between economic growth, urbanization and $CO_2$ emissions.

Vo and Le (2019) study served to determine the causal relationship between carbon dioxide emissions, energy consumption, renewable energy, population and economic for countries for five ASEAN member countries (Indonesia, Myanmar, Malaysia, the Philippines, and Thailand) covering the period 1971-2014. The results showed that there is a long run relationship among the variables only for Indonesia, Myanmar and Malaysia. It is further discovered that the EKC hypothesis is validated in Myanmar but not in Malaysia and Indonesia. Neutrality hypothesis was established among the variables for Malaysia, Thailand and the Philippines but one-way causality flowing from economic growth to carbon emission and energy consumption was established in Indonesia. In Myanmar a unidirectional causality flowing from economic growth, energy consumption and population to renewable energy.

Mathieu et al. (2019) investigated the relationship between energy consumption, carbon emissions and economic growth in Togo. Using the ARDL model, the study found that there is a long relationship among the variables. Osobajo et al. (2020) served to assess the impact of energy consumption and economic growth on carbon dioxide emissions for 70 countries covering the period between 1994 and 2013. The results suggested a long run relationship between the variables. The pooled OLS and fixed method revealed that energy consumption and economic growth have a positive effect on carbon emissions.

Fong et al. (2022) examine the relationship between energy consumption and unfavorable $CO_2$ emissions for the 11 cities of the Guangdong-Hong Kong-Mocao covering the period from 2010 to 2016. The finding indicated that the average efficiency of the GBA cities is 0.708, with only Macao SAR, Shenzhen and Hong Kong SAR having an efficiency of 1 throughout the study period.

## 3. METHODOLOGY AND DATA

This section examines the long run relationship between economic growth and carbon emissions in South Africa using the ARDL bounds test approach. It also examines the direction of causality among the variables using the Vector Error Correction Model (VECM). However, the section first commences with the data used.

### 3.1. Model Specification

Some of the research on carbon emission and economic growth nexus, such as Boutabba (2014), Shahbaz et al. (2013), Ozturk and Acaracvi (2013) and Jalil and Feridum (2011) among others, added energy consumption, trade openness, foreign direct investment and financial development. Our proposed model, which seems to be consistent with the broader literature on the nexus between carbon emission and economic growth cited above, takes the following form:

$$\begin{aligned} LCO_{2t} &= \alpha_0 + \beta_1 LGDP_t + \beta_2 LGDP_t^2 + \beta_3 LEN_t \\ &+ \beta_4 \text{üüüü}\ {}_t + \beta_5 \quad {}_t + \varepsilon_t \end{aligned} \tag{1}$$

This equation essentially stipulates that carbon emission ($CO_2$) (measured in metric tons per capita) is a function of economic growth (GDP) (measured as a percentage of real per capita), energy consumption (EN) (measured in metric tons per capita), foreign direct investment (FDI), trade openness (TR) (measured as a ration of imports plus exports over GDP) and $\varepsilon_t$ is the error term.

### 3.2. Data Collection

Table 1 illustrates the description of data covering the period from 1984 to 2016 for South Africa. The data for economic growth and carbon emissions, energy consumption, foreign direct investment and trade openness variables was collected from difference Sources. Economic growth, foreign direct investment and trade openness were sourced from the South African Reserve Bank (SARB). Carbon emission data was collected from the Worldbank while energy consumption was sourced from International Energy Statistics.

#### *3.2.1. Unit root*

To evaluate the order of integration among the variables, several unit root tests are employed. These include the two traditional unit root tests – Augmented Dickey-Fuller (ADF) developed by Dickey and Fuller (1979) and Phillips and Perrron (PP) developed by Phillips and Perron (1988). The ADF unit root test is soley based on the regression of the observed variable while the PP test enables a wide class of time series with serially correlated terms.

The prominence uses of Augmented Dickey-Fuller (ADF) and Phillip Perron test has nurtured throughout the years and are now commonly used by enormous researchers. However, according to Perron and Serena (1994), the Phillip Perron test suffer from severe size distortions whenever there are negative moving average errors. Likewise, Tang (2008) believes that the Augmented Dickey Fuller (ADF) test is incapable of differentiating when there is unit root or when the series is nearer to the unit root due to its lack of power. However, Hu and Ling (2008) added to the criticism of Perron and Serena (1994), by stating the fact that they additionally suffer from severe size distortions. Moreover, the KPSS test is used to halt some of the flaws of both Augmented Dickey-Fuller test and Phillip Peron test, likewise the test objectives are in line with that of Hu and Lin (2008) which are its ability to differentiate

**Table 1: Variables description**

| Variables | Definaton | Description | Source |
|---|---|---|---|
| $CO_2$ | Carbon emission | Metric tons per capita | World Bank |
| GDP | Growth | Percentage of real per capita | South African Reserve Bank |
| EC | Energy consumption | Metric tons per capita | International energy statistics |
| FDI | Foreign direct investment | In millions | South African Reserve Bank |
| TR | Trade openness | Percentage | South African Reserve Bank |

$CO_2$ : Carbon emission, GDP: Gross domestic product, FDI: Foreign direct investment, TR: Trade openness, EC: Energy consumption

**Table 2: The results of the Augmented Dickey-Fuller, Phillips and Perrron and Kwiatkowski-Phillips-Schmidt-Shin unit root tests**

| Variables | Levels | | | First difference | | |
|---|---|---|---|---|---|---|
| | ADF | PP | KPSS | ADF | PP | KPSS |
| $LCO_2$ | 0.4360 | 0.3851 | 0.1209 | 0.0002* | 0.0000* | 0.1537*** |
| LGDP | 0.0359 | 0.0368** | 0.1177 | 0.0000* | 0.0000* | 0.1518*** |
| LEN | 0.9315 | 0.9139 | 0.1380*** | 0.0010* | 0.0010* | 0.1583*** |
| LFDI | 0.8972 | 0.8368 | 0.1225*** | 0.0012* | 0.0012* | 0.1411*** |
| LTO | 0.2776 | 0.3851 | 0.1173 | 0.0002* | 0.0000* | 0.1344*** |

*, **, ***Implying 1%, 5% and 10% respectively. The null hypothesis is that the variable has a unit root. The alternative hypothesis is that the variable does does not have a unit root. The probability value is used as a decision rule. ADF: Augmented Dickey-Fuller, PP: Phillips and Perrron, KPSS: Kwiatkowski-Phillips-Schmidt-Shin, $CO_2$: Carbon emission, GDP: Gross domestic product, FDI: Foreign direct investment, TR: Trade openness, EC: Energy consumption

between variables that have similarities of being stationary as well as integrated and lastly variables which are not informative in terms of its stationarity properties

### *3.2.2. Co-integration*

To determine where there is an existence of a long run relationship between carbon emissions and economic growth, the study employs the Autoregressive Distributed Lag Model (ARDL). This model is chosen for various reasons. Firstly, the technique is feasible in situations where the variable is integrated at I (0) or I (1). Secondly, the short and long-run parameters can be simultaneously estimated through an unrestricted error correction model (UECM) derived from the ARDL model. Thirdly, the test can handle small sample sizes and all the variables are assumed to be endogenous. Lastly, the Granger causality can be applied to evaluate the long-term relationship among the adopted variables, due to the fact that the ARDL test doesn't rely on the properties of unit root tests. The equation of UECM for the ARDL bounds approach can be expressed as

$$\begin{aligned} \Delta LCO_{2t} = {} & \alpha_1 + \alpha_T T + \alpha_{CO2} LCO_{2t-1} + \alpha_{GDP} LGDP_{t-1} \\ & + \alpha_{üüüü}\ GDP^2_{-1} + \alpha \quad LEN_{-1} \\ & + \alpha_{üüüü}\ üüüü \quad _{-1} + \alpha \qquad _{-1} \\ & + \sum_{i=1}^{p} \alpha_i \Delta üüüü_{\ 2t-i} + \sum_{j=0}^{q} \alpha_j \Delta \qquad _{t-j} \\ & + \sum_{k=0}^{r} \alpha_k \Delta üüüü \quad ^{2}_{t-k} + \sum_{l=0}^{s} \alpha_l \Delta \qquad _{t-l} \\ & + \sum_{m=0}^{u} \alpha_{üüüü} \Delta üüüü \quad _{-} + \sum_{v=0}^{v} \alpha\ \Delta \qquad _{-} + \varepsilon \end{aligned} \tag{2}$$

Where $\alpha_1$ is a constant parameter, $\Delta$ is the first difference operator, $T$ is the time trend and $\varepsilon_t$ is the error term. L $CO_{2t}$ is the natural logarithm of carbon emissions, $LGDP_t$ is the natural logarithm of Gross domestic product, $LEN_t$ is the natural logarithm of energy consumption, $FDI_t$ is the natural logarithm of foreign direct investment and $TO_t$ is the natural logarithm of trade openness.

The first step of the ARDL bounds technique is to compare the computed $F$-statistics with the critical bounds generated by Pesaran et al. (2001) or Narayan (2005). The two sets of critical values include the upper critical bound (UCB) and lower critical bound (LCB).

The null hypothesis of no co-integration is tested against the alternative hypothesis of co-integration as follows:

H0: $\alpha$ $CO_2$ = $\alpha$GDP= $\alpha GDP^2$ = $\alpha$EN = $\alpha$FDI = $\alpha$TO = 0

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H0: $\alpha$C $CO_2$ = $\alpha$GDP= $\alpha GDP^2$ = $\alpha$EN = $\alpha$FDI = $\alpha$TO = 0

The following results are derived from the hypothesis: Firstly, if the computed F-statistics is greater than the upper-bound critical values, the null hypothesis of no co-integration is rejected. Secondly, the null hypothesis of no co-integration cannot be rejected if the computed F-statistics is less than the lower-bound critical values. Lastly, if the computed F-statistics falls between the lower-bound and upper-bound critical values, the results become inconclusive. Ziramba (2008) purported that the critical values are implemented on larger sample sizes of about 500 and 1000 observations. But Shahbaz et al. (2011) indicated that the critical values from Narayan (2005) are appropriate for small samples of between 30 and 80. Therefore for the purpose of this study, the critical bounds values from Narayan (2005) are used. The stability of long run parameters is examined by applying the Brown et al. (1975) tests termed cumulative sum of recursive residuals (CUSUM) and CUSUM of recursive squares (CUSUMSQ).

### *3.2.3. Granger-causality*

The ARDL bounds test is employed to determine the long run relationship among the variables but it cannot detect the direction of causality among the variables. Therefore, the study will apply the Granger causality test which will state the direction of causality among the variables. The Vector Error Correction Model (VECM) Granger causality will be employed in this study. The error correction model works in a way that the error in the previous period reviews the correction toward long run equilibrium (Jamil and Ahmed, 2010). It was chosen for its ability to develop longer term forecasting, when dealing with an unconstrained model. The VECM granger causality is applicable when the variables are integrated of the same order of integration.

The information pertaining to long run relationship between the variables is contained in the ECT while the short run information is determined by the lagged terms of individual coefficients (Adebola, 2011). Adebola (2011) further showed that the long run relationship is depicted by a negative sign on the coefficient of the

ECT. To determine the direction of causality between the variables, the VECM is presented by the following equation

$$(1-L)\begin{bmatrix} LCO_{2t} \\ LGDP_t \\ LGDP_t^2 \\ LEN_t \\ LFDI_t \\ LTO_t \end{bmatrix} = \begin{bmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \\ a_5 \\ a_6 \end{bmatrix} + \sum_{i=1}^{p}(1-L)\begin{bmatrix} b_{11i} & b_{12i} & b_{13i} & b_{14i} & b_{15i} & b_{16i} \\ b_{21i} & b_{22i} & b_{23i} & b_{24i} & b_{25i} & b_{26i} \\ b_{31i} & b_{32i} & b_{33i} & b_{34i} & b_{35i} & b_{36i} \\ b_{41i} & b_{42i} & b_{43i} & b_{44i} & b_{45i} & b_{46i} \\ b_{51i} & b_{52i} & b_{53i} & b_{54i} & b_{55i} & b_{56i} \\ b_{61i} & b_{62i} & b_{63i} & b_{64i} & b_{65i} & b_{66i} \end{bmatrix} x \begin{bmatrix} LCO_{2t-1} \\ LGDP_{t-1} \\ LGDP_{t-1}^2 \\ LEN_{t-1} \\ LFDI_{t-1} \\ LTO_{t-1} \end{bmatrix} + \begin{bmatrix} \alpha \\ \beta \\ \gamma \\ \delta \\ \theta \\ \vartheta \end{bmatrix} ECT_{t-1} + \begin{bmatrix} \mu_{1t} \\ \mu_{2t} \\ \mu_{3t} \\ \mu_{4t} \\ \mu_{5t} \\ \mu_{6t} \end{bmatrix} \quad (3)$$

Where (1-L) is the difference operator and $ECT_{t-1}$ is the lagged error term obtained from the long-run relationship. $\alpha, \beta, \gamma, \delta, \vartheta, \theta$ denote the adjustment coefficient and shows how much disequilibrium is corrected (Jamil and Ahmed, 2010). "The size and statistical significance of ECT is a measure of extent to which the left hand side variable in each equation returns in each short-run period to its long-run equilibrium in response to random shocks" (Jamil and Ahmed, 2010: 6020). This makes the Error Correction Model more powerful over Standard Granger causality and Sims tests because it comes up with channels of identification which would not be realised by these two tests. Hence this study adopted the Error Correction Model.

The VECM works in a way that a significant t-statistic on the coefficient of the lagged error correction term indicates that there exists a causal relation between the variables in the long run. On the other hand, a significant F-statistic on the first differences of the variables reveals an evidence for the presence of a short-run causality between the variables.

## 4. FINDINGS OF THE STUDY

### 4.1. Unit Root Tests

Table 2 illustrates the results of the ADF, PP and KPSS unit root tests on the levels and the first difference of the variables. The null hypothesis of the tests suggest that the data series under consideration has unit root and is tested against the alternative hypothesis that the series has no unit root. Table 2 depicts that all variables are non-stationary at levels under the ADF test but become stationary at first difference. The results further show under PP test the variables are non-stationary at levels except for the GDP but when differenced once, all the variables become stationary. Finally, the findings from the KPSS suggest that the variables are non-stationary at levels except for EN and FDI but all the variables become stationary when differenced once.

### 4.2. Co-Integration

The unique order of integration shows that co-integration among the variables can be determined. However, prior to testing for co-integration, it is necessary to determine the maximum lag length. Table 3 presents the results for the selection order criteria. The optimal lag length of p* = 3 is chosen (Table 3)

The findings for the ARDL bounds technique, based on Narayan (2005) are presented in Table 4. The results suggest that there is co-integration when carbon emission is used as a dependent variable. This is on account that the *F*-statistics (15.33) is greater than the upper critical bound value of 4.37. The same results were depicted when economic growth is used as a dependent because its *F*-statistics (4.40) is greater than the upper critical bound value of 4.37. This indicates that there is a long run relationship between carbon emissions, economic growth, energy consumption, foreign direct investment and trade openness in South Africa. Validate Having determined the long run relationship among the variables, the next step is to estimate the long run and short run coefficients of the impact of economic growth, energy consumption, foreign direct investment and trade openness on carbon emissions. The findings for the long run and short run estimates are presented in panel A and B of Table 5. The long run results suggest that economic growth has a positive and statistically significant effect on carbon emissions at 5% level of significance. More specifically, the elasticity of economic growth indicate that a 1% increase in economic growth results in carbon emissions increasing by 0.02% on average, holding all else constant. The effect of the square of real GDP per capita is negative and significant at 10% level of significance. More specifically, a 1% increase in real GDP per capita leads to a fall in carbon emissions by 0.0087%.

The long run results validate the existence of the EKC hypothesis in South Africa. This indicates that as economic growth increases, carbon emissions will also increase but to a certain point where further increase in economic growth will lead to a fall in carbon emissions. This finding is confirmed by Pao and Tsai (2010), Grossman and Krueger (1991), Stern (2004) and Dinda (2005)

The results further established that energy consumption has a positive and significant impact on carbon emissions in the long run. This implies that 1% increase in energy consumption increases carbon emissions by 0.72%, all else the same. This empirical evidence is in line with the findings of Apergis and Payne (2009)

It was also revealed that foreign direct investment have a negative and significant effect on carbon emissions. More specifically, a 1% increase in foreign direct investment leads to fall of 0.11% in carbon emissions, ceteris paribus. This finding is in line with the findings of Pao and Tsai (2010). Finally, Table 5 depicts that trade openness has a positive and a statistically significant impact on carbon emissions. This means that a 1% increase in trade openness increases carbon emissions by 0.01% in the long run, holding all else constant.

**Table 3: Selection order criteria**

| Lag | LogL | LR | FPE | AIC | SC | HQ |
|---|---|---|---|---|---|---|
| 0 | −104.5478 | NA | 0.001022 | 7.303187 | 7.536720 | 7.377897 |
| 1 | 28.44746 | 212.7924 | 7.84e-07 | 0.103503 | 1.504700* | 0.551758 |
| 2 | 51.89567 | 29.70107 | 1.01e-06 | 0.206955 | 2.775817 | 1.028756 |
| 3 | 93.01412 | 38.37722* | 5.34e-07* | −0.867608* | 2.868918 | 0.327739* |

*The“lag order selected by the criterion.” LR: Sequential modified LR test statistic (each test at 5% level), FPE: Final prediction error, AIC: Akaike information criterion, SC: Schwarz information criterion, HQ: Hannan-Quinn information criterion, NA: Not available

**Table 4: Autoregressive distributed lag results**

| *F*-statistic bound test (K=4) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Per dependent | *F*-stat | 10% @ level | | 5% @ level | | 1% @ level | | |
| | | I (0) | I (1) | I (0) | I (1) | I (0) | I (1) | |
| $LCO_2$ | 15.33 | 2.2 | 3.09 | 3.56 | 3.49 | 3.29 | 4.37 | |
| LRGDP | 4.40 | 2.2 | 3.09 | 2.56 | 3.49 | 3.29 | 4.37 | |

$CO_2$: Carbon emission, GDP: Gross domestic product

**Table 5: Long run and short run results**

| Panel A: Long run results ($LCO_2$=RGDP+LEN+LFDI+TO) | | | |
|---|---|---|---|
| Variables | Coefficients | P | Statistics |
| $LC_2$ (constant) | −1.7678 | 0.0000 | −13.2618 (significant) |
| LRGDP | 0.0191 | 0.0459 | 2.9427 (significant) |
| $LRGDP^2$ | −0.0087 | 0.0577 | 2.1546 (significant) |
| LEN | 0.7154 | 0.0031 | 3.6843 (significant) |
| LFDI | −0.1138 | 0.0002 | −5.3377 (significant) |
| TO | 0.0098 | 0.0000 | 6.7880 (significant) |
| $R^2$ | | 0.95 | |
| *F*-statistics | | 15.33 | |
| D.W test | | | |
| **Panel B: Short run results ($LCO_2$=RGDP+LEN+LFDI+TO)** | | | |
| Variables | Coefficients | P | *T*-statistics |
| cointEQ (−1) | −0.9314 | 0.0000 | −11.4164 (significant) |
| D (RGDP) | 0.2590 | 0.0000 | 8.1399 (significant) |
| D ($RGDP^2$) | 0.0569 | 0.0568 | 2.2478 (significant) |
| D (LEN) | 0.9823 | 0.0002 | 5.2470 (significant) |
| D (LFDI) | 0.0893 | 0.0058 | 3.3475 (significant) |
| D (TO) | −0.0034 | 0.0042 | −3.5261 (significant) |
| $R^2$ | | 0.92 | |
| *F*-statistics | | 15.33 | |
| D.W test | | 2.06 | |

$CO_2$ : Carbon emission, GDP: Gross domestic product, FDI: Foreign direct investment, TR: Trade openness, EC: Energy consumption

**Table 6: Short-run diagnostics**

| Test | F-statistics | P |
|---|---|---|
| Normality | 3.3125 | 0.1032 |
| Heteroskedasticity | 1.8088 | 0.1500 |
| Serial correlation | 2.2777 | 0.1067 |

Part B of Table 6 presents the findings for short run estimates. The results show that there is a positive and significant nexus between real GDP per capita and carbon emissions in the short run. It further reveal that there is a negative and statistically significant relationship between carbon emissions and the square of real GDP per capita. This shows that the EKC is valid in the short run for South Africa. This result is supported by Aslan et al. (2018) and Cetin et al. (2018).

The findings reveal that there is a positive and a significant relationship between carbon emissions and energy consumption. This implies that 1% increase in energy consumption increases carbon emissions by 0.98%. This results are in line with Soytas et al. (2006). The short run results further indicate that foreign direct investments affect carbon emissions positively. This means that a 1% increase in foreign direct investment leads to 0.09% increase in carbon emission.

The coefficient of lagged error term ($ECT_{t-1}$) is negative and statistically significant. This affirms that there is a long run relationship between carbon emissions, economic growth, energy consumption, foreign direct investments and trade openness. This coefficient suggests that a deviation from the long run equilibrium level of output in 1 year is corrected by 14% over the following year.

The results for the short-run diagnostics tests are shown in Table 6. The results posit that the error terms of the short run models have no serial correlation, they are free of heteroskedasticity and are normally distributed. It is established that the short run models are not spurious because the Durban-Watson statistics was found to be greater than the R2. The Ramsey RESET test validated that the functional form of the model is well specified.

### 4.3. Stability Tests

The stability of the long run parameters were tested using the cumulative sum of recursive residuals (CUSUM) and CUSUM of recursive squares (CUSUMSQ). The results are illustrated in Figures 2 and 3. The results fail to reject the null hypothesis at 5% level of significance because the plot of the tests fall within the critical limits. Therefore, it can be realised that our selected ARDL model is stable.

### 4.4. Granger-Causality

The presence of a long run relationship between the variables indicates that there is an existence of a causal relationship among the variables. The VECM has been employed to determine the direction of causality and the results for both long run and short run causality are illustrated in Table 7. Commencing with the long run results when real GDP per capita is the dependent variable, it is derived that there is a long run causality flowing from carbon emission, energy consumption, foreign direct investment and trade openness to real GDP per capita. This is because the error correction term (−4.45) is negative and significant at 1% level of significance. The results further indicated that there is a long run causality flowing from economic growth, energy consumption, foreign direct investment and trade openness to carbon emissions. These findings are supported by Apergis and Payne (2009), Zhang and Cheng (2009), Vo and Le (2019) and Li et al. (2017)

It can be derived that there is a bidirectional causality flowing between economic growth and carbon emissions in the long run. The results are supported by Khoshnevis and Dariani (2019) who

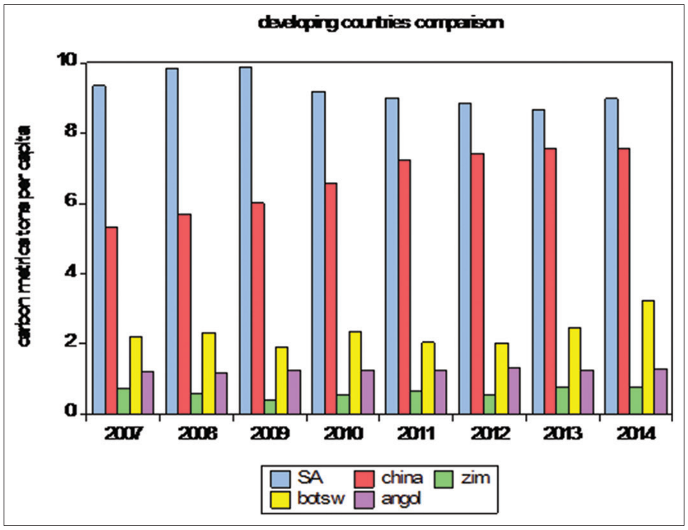
**Table 7: Vector error correction model results**

| DEP VAR | Types of causality (short run) | | | | | Long run |
|---|---|---|---|---|---|---|
| | ΣΔLGDP P | ▲L ΣΔLEN EC | V ΣΔLFDI | ΣΔLTO | ΣΔ$LCO_2$ | |
| ▲RGDP | _____ | 0.76 | 0.41 | 0.49 | 0.08 | −4.45 |
| ▲LEN | 0.21 | _____ | 8.30* | 8.51* | 0.001 | 0.16*** |
| ▲LFDI | 0.42 | 0.39 | _____ | 0.64 | 0.13 | −0.18 |
| ▲TO | 3.32*** | 0.001 | 1.07 | _____ | 0.03 | −7.85 |
| ▲$LC_2$ | 31.91* | 19.68* | 7.34** | 0.28 | _____ | −0.69* |

Where *,**, *** represent significance at 1%, 5% and 10%, respectively

$CO_2$ : Carbon emission, GDP: Gross domestic product, FDI: Foreign direct investment, TR: Trade openness, EC: Energy consumption

**Figure 1:** Developing countries carbon emissions comparison (2007-2014)




Source: Author's own construction

**Figure 2:** Plot of Cumulative Sum of Recursive Residuals

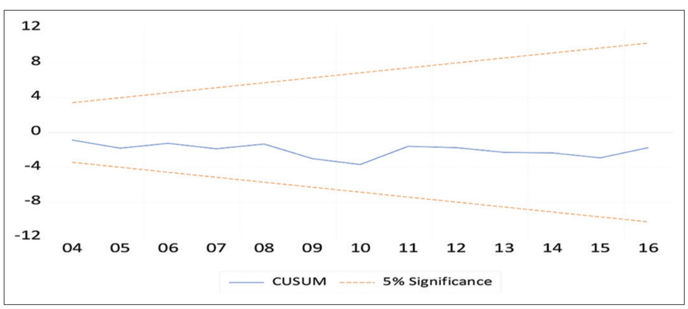
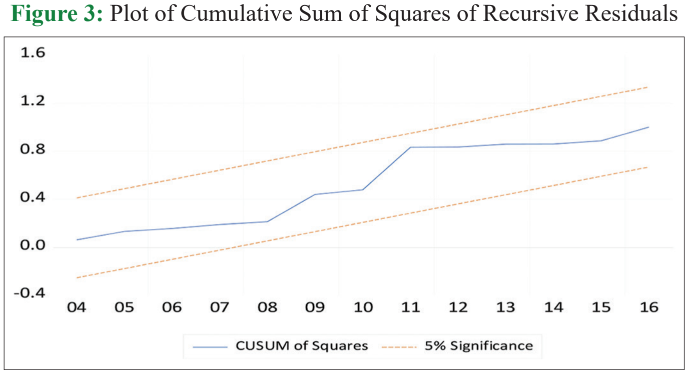



**Figure 3:** Plot of Cumulative Sum of Squares of Recursive Residuals




focused on the Asian economies and Pao and Tsai (2011) who focused on the BRIC countries.

The results depict that there is a short run causality flowing from trade openness and foreign direct investment to energy consumption. There is also a short run causality flowing from economic growth to trade openness. Finally, there is a short run causality running from foreign direct investment, energy consumption and economic growth to carbon emissions.

### 4.5. Stability Test

The study commenced by examining the VAR model using the unit circle. Likewise, Figure 4 shows that all lagged variables are within the unit circle, hence implying that the model is significantly stable.

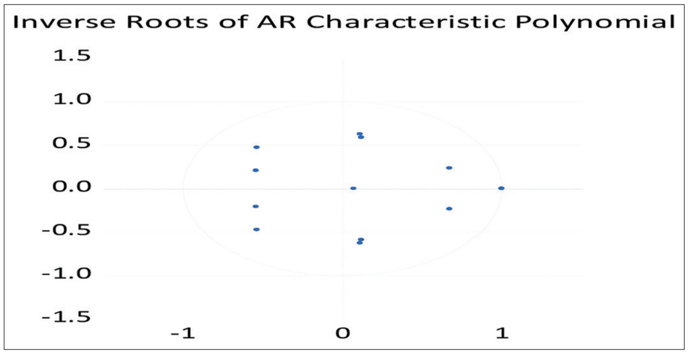
## 5. CONCLUSION

The main purpose of the study was to investigate the long run relationship and direction of causality between carbon emission, economic growth, energy consumption, foreign direct investment and trade openness for South Africa covering the period between 1984 and 2018. To determine the long run relationship among the variables, the ARDL bounds technique by Pesaran et al. (2001) was employed. The ARDL bounds approach affirmed that there is a long run relationship between carbon emissions, economic growth, energy consumption, foreign direct investment and trade openness in South Africa. The long run and short run results revealed that the coefficients of GDP are positive and significant both in the long run and short while the coefficients of $GDP^2$ are significant and negative both in the long run and short. This validates the EKC hypothesis both in the long run and short which suggest an inverted U-shaped relationship between real GDP per capita and carbon emissions. This shows that the carbon emissions increase with income to a certain point whereby a further increase in the level of income, carbon emissions will decrease.

The results further revealed that energy consumption has a positive and significant impact on carbon emissions both in the long run and short run. This also has very important policy implications for energy and environmental issues of South Africa. It is important that the country should come up alternative energy sources which will ensure clean energy and energy efficiency. It was also established that foreign direct investment positively affect carbon emissions in the short run but negatively in the long run. Finally, trade openness was found to affect carbon emissions negatively in the short run but positively in the long run.

Our empirical results show that there is a need for South Africa to investment more in the renewable energy sources such as

**Figure 4:** Inverse roots




solar, wind and hydro as a way to curb the carbon emissions. The investment into renewable energy sources will play a huge role in ensuring that South Africa achieves the 2030 energy sustainability target. It should also be noted that when coming up with strategies to ensure clean energy in South Africa, the other variables such as trade openness and foreign direct investments should not be compromised. This is on account that environmentally sensitive trade subsidies can be imposed to the critical industries while taxes can also be imposed on pollution-intensive industries. Finally, Over a long period of time, foreign direct investment (FDI) has been found to create many externalities in many economies in the form of benefits available through transfers of general knowledge, specific technologies in production and distribution. South Africa can get access to new technologies which will help curb the carbon emissions and ensure environmental sustainability.

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