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Testing Environmental Kuznets Curve Hold in South Africa: An Econometric Approach

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ABSTRACT

The study investigates if the environmental Kuznets curve hold in South Africa. It employed available annual time series data spanning for the years from 1961 to 2020 collected from World Bank data. The study employs a Vector Error Correction Model (VECM) to investigate the short run and long run relationship. The results revealed that the Environmental Kuznets Curve hypothesis hold in South Africa. The policy recommendations are that the policymaker must implement environmentally friendly economic growth to reduce environmental degradation in South Africa.

Keywords: Carbon Dioxide (CO_2) Emissions, Economic Growth, VECM, South Africa
JEL Classifications: C32, O52, Q43, Q5

1. INTRODUCTION

The debate on the applicability of the Environmental Kuznets Curve (EKC) has resulted in a series of debates among scholars and policy makers in different countries. Some scholars have found that it is applicable in certain countries while others found that it is not applicable in certain countries due to differences in data and methodologies employed in the study. The extant empirical research on the link between energy consumption and economic growth, as well as economic growth and pollution, is insufficient to provide policy recommendations that can be applied across nations. Because the available literature reveals that most research focus on the relationship of growth-energy or growth-environmental contaminants, with little effort made to evaluate these two linkages within the same framework (Shahbaz et al., 2015).

By predicting an Environmental Kuznets Curve for carbon dioxide emissions in South Africa, this study contributes to the discussion on environmental deterioration. Given its environmental concerns, South Africa was chosen for our study because it has launched several programs and policy efforts that include all the enhanced factors discussed in this study.

1.1. Overview of the Study

As per Antony (2021), a carbon emissions research organization's study, Eskom generated 1 600 kilotons of the pollutant in 2019, the most recent year for which corresponding information is available. Apart from India, this was more than any firm and the entire emissions of any country's power industry. While China, the United States, and the European Union have decreased sulphur dioxide emissions in recent years by upgrading power plants with pollution-control technology, Eskom has only done so at one of its 15 coal-fired power plants. Eskom has denied a 2019 research that linked its emissions to more than 2000 fatalities per year, stating that its pollution kills 320 people per year (Antony, 2021). To lessen the strain on public health, there is a necessity to adhere to environmental emissions standards.

Antony (2021) emphasizes that Eskom's pollution is also high due to the high sulphur content of the coal it burns. South Africa's sulphur dioxide emission limits were reduced in 2019 from 3 500 milligrams per normal cubic meter to 1000 milligrams, still far exceeding those of India and China. The cost of equipping Eskom's power stations with flue-gas desulfurization units is expected to be between R100 billion and R200 billion. Eskom has indicated that it would require 300 billion rand in investment to fulfil South Africa's emission limits. The state-owned power provider is in debt to the tune of more than 400 billion rand, and it plans to cut sulphur dioxide emissions by two-thirds by 2035.

Indian coal contains much less sulphur than South African coal, despite having more than five 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 (Evans, 2021). 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.

According to 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.

The United States of America, United Kingdom, France, Germany and the European Union donated a multibillion-dollar to help South Africa finance transition from coal, which they hope will serve as a model for other countries (Staff, 2021). South Africa is the 12th largest emitter of climate-warming gases and relies heavily on coal-fired power plants for electricity and the funds would help it meet a more ambitious pledge to cut emissions by 2030. South Africa pledged to cut emissions by 2030 in a contribution to global efforts, employed more than 90 000 people in coal mines alone in 2020 (Staff, 2021).

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 company, relies primarily on aging coal-fired power plants to supply 90 percent 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 mainly 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 and economic growth in South Africa through testing the applicability of the environmental Kuznets curve in South Africa. Several studies have been studying the relationship between CO_2 emissions and economic growth in South Africa, but only one study has focused on the applicability of the environmental Kuznets curve in South Africa.

2. LITERATURE

2.1. Theoretical Literature

The Environmental Kuznets Curve hypothesis explains an inverted relationship between economic growth and environmental degradation. This hypothesis was developed by Simon Kuznets (1955). According to environmental Kuznets curve, economic development initially causes environmental degradation, but after a certain level of economic growth, a society begins to improve its relationship with the environment, and levels of environmental degradation decrease (Pettinger, 2019).

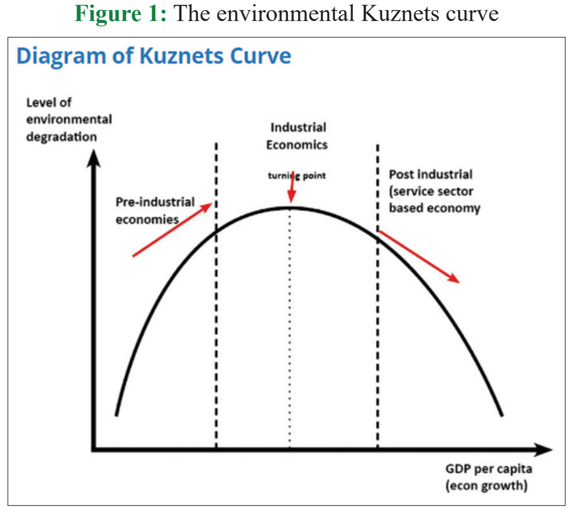
Environmental pressure increases during the early stages of economic growth due to increased pollutant release and extensive and intensive exploitation of natural resources associated with increased use of production resources and adoption of certain production technologies for expanding economic activities up to a certain level. When GDP grows rapidly, national income rises and then falls because of rising public awareness and concern about environmental degradation, as well as research and development activities aimed at green economy.

The environmental Kuznets curve theory suggests that environmental degradation increases at initial levels of economic growth and then starts to decrease at a higher level of economic growth (Figure 1). In other words, in the long run, economic growth or development reduces per-capita environmental damage. Sufficient wealth and technology lead to countries adopting clean production methods and move to service-based economy. This is represented by the inverted U-shaped relationship between economic growth or development and environmental damages, where the environmental damage per-capita increases in the early stages of economic development, reaches a maximum, and then diminishes as a country attains higher levels of income as shown in the diagram above.

2.2. Studies that Found a Positive Relationship

Choi et al. (2010) investigated the link between CO_2 emissions, economic growth, and trade openness in China, Korea, and Japan. The study made use of annual time series data spanning the years

Figure 1: The environmental Kuznets curve



Source: Pettinger (2019)

1971 to 2006. The vector error correction model and vector autoregressive model were employed in the study to examine the relationship between the variables. The empirical findings revealed that CO_2 emissions have a positive impact on economic growth. The researchers recommend that each country volunteer to reduce carbon emissions to alleviate environmental problems.

Ozturk and Acaravci (2010) examined the relationship between European energy consumption, CO_2 emissions, and economic growth. The data for the study was collected between 1960 and 2005. To examine the relationship between the variables, the study used an autoregressive distributed lag model. The findings revealed a positive relationship between carbon emissions and economic growth in European countries. According to the Granger causality results, policies aimed at energy conservation, such as rationing energy consumption and controlling carbon dioxide emissions, are unlikely to have a negative impact on economic growth.

In India and China, Govindaraju and Tang (2013) investigated the dynamic relationships between CO_2 emissions, economic growth, and coal consumption. Annual time series data was used in the study, which covered the years 1965 to 2009. To examine the relationship between the variables, the researchers used the Engle-Granger causality test. Economic growth and CO_2 emissions have a bidirectional causal relationship, according to the findings. According to the researchers, reducing CO_2 emissions will have a negative impact on these countries' economic growth in the short and long term.

In China's Jiangsu Province, Zhang and Wang (2013) conducted a decouple indicators study on CO_2 emissions and economic growth linkages. The research was based on data from 1995 to 2009. To examine the relationship, the researchers used a decoupling index. According to the empirical findings, there is a positive relationship between industrialisation and CO_2 emissions in China's Jiangsu Province.

Saidi and Hammami (2015) looked at the impact of CO_2 emissions and economic growth on energy consumption in four groups of 58 countries, including Europe and North Asia, Latin America and the Caribbean, and Sub-Saharan Africa, the Middle East, and Sub-Saharan Africa. The research used data from a borrowed panel that spanned the years 1990 to 2012. To examine the relationship between the variables, the study uses a generalized method of moments model. Economic growth, CO_2 emissions, and energy consumption, according to the researchers, are all complementary.

Shahbaz et al. (2015) conducted a study testing the environmental Kuznets curve theory in Portugal. The study employed annual time series data spanning from 1971 to 2008. The study employed an ARDL model to analyse the relationship between the variables. Empirical results revealed the presence of the environmental Kuznets curve in Portugal both in the short and long run period. The researchers recommend that, to comply with the 1992 Kyoto Protocol on CO_2 emissions, policies focusing on the sectors responsible for CO_2 emissions are required.

Azam and Khan (2016) conducted a study testing the environmental Kuznets curve hypothesis performing a comparative analysis of low, lower middle, upper middle- and higher-income countries. The study employed annual time series data spanning from 1975 to 2014. The study employed Johansen cointegration test and Pearson correlation test to analyse the relationship between the variables. The results revealed that the environmental Kuznets curve hold in low and lower-middle income countries.

With evidence from Algeria, Bouznit and Pablo-Romero (2016) investigated CO_2 emissions and economic growth. The research used time series data spanning the years 1970 to 2010. To examine the relationship in the nexus, the researchers used an autoregressive distributed lag model and an error correction model. Economic growth is positively related to CO_2 emissions in Algeria, according to the empirical findings. To reduce CO_2 emissions in Algeria, the researchers also recommend that renewable energy sources and efficient energy policies be promoted.

Energy consumption, CO_2 emissions, and economic growth were studied in 106 countries by Antonakakis et al. (2017). The research made use of data from a borrowed panel that covered the years 1971 to 2011. To examine the relationship between the variables, the researchers used a panel vector autoregressive (PVAR) model. The findings supported the EKC theory that CO_2 emissions rise in tandem with economic expansion. As a result, the researchers advise that the efficacy of recent government policies in various countries to promote renewable energy consumption be questioned, and that attention be focused on more communally just approaches endorsed by degrowth.

In South Africa, Khobai and Le Roux (2017) looked into the link between energy consumption, economic growth, and carbon dioxide emissions. Annual time series data spanning the years 1971 to 2013 were used in the study. To examine the relationship between the variables, the researchers used a vector error correction model and a granger causality test. The findings revealed that carbon dioxide emissions and economic growth in South Africa are linked. According to the researchers, policies aimed at reducing carbon dioxide emissions will harm South Africa's economic growth.

Khobai (2018) investigated the relationship between electricity consumption and economic growth in BRICS countries. The study used annual time series data from 1990 to 2014. The relationship between the variables was investigated using a vector error correction model. The empirical findings revealed that CO_2 emissions and economic growth in the BRICS countries are linked. To reduce emissions and sustain economic growth and development in the BRICS community, the researcher recommends a significant transformation of low-carbon technologies such as renewable energy.

In Azerbaijan, Mikayilov et al. (2018) looked into the impact of economic growth on CO_2 emissions. The research was based on data from 1992 to 2013. To examine the relationship between the variables, the researchers used cubic, quadratic, and linear (ARDLBT, FMOLS, DOLS, and CCR) specifications. For the period under study, the empirical results revealed a positive relationship between economic growth and CO_2 emissions in

Azerbaijan. Measures to improve energy efficiency, carbon pricing instruments in production and international-domestic trade activities, and national-level social awareness programs to educate about the negative consequences of pollution, according to the researchers, can all be considered relevant environmental policies aimed at reducing carbon emissions.

On a global scale, Acheampong (2018) looked at economic growth, CO_2 emissions, and energy consumption in 116 countries. Panel data from 1990 to 2014 was used in the research. To investigate the dynamic causal relationships between the variables, researchers used multivariate panel vector autoregressive, and system generalized method of moment models. CO_2 emissions have a positive effect on economic growth in these countries, according to the findings. Policies aimed at reducing carbon emissions should be implemented with caution, according to the researchers, as they will harm the panel countries' future economic growth.

In the G7 countries, Cai et al. (2018) looked into the relationship between clean energy consumption, economic growth, and CO_2 emissions. Annual time series data was used in the study, which covered the years 1965 to 2015. To examine the relationship between the variables, the researchers used an autoregressive distributed lag model. In the G7 countries, the results revealed a positive relationship between CO_2 emissions and economic growth. Clean energy, according to the researchers, is a good way to reduce CO_2 emissions because it has a negative relationship with CO_2, bridging the gap between economic growth and environmental protection in G7 and developing countries.

CO_2 emissions, economic growth, renewable and non-renewable energy production, and foreign trade in China were investigated by Chen et al. (2019). The research used available annual time series spanning the years 1980 to 2014. To examine the relationship between the variables, the researchers used an autoregressive distributed lag model. Economic growth in China increases CO_2 emissions, according to the findings. Renewable energy, according to the researchers, is the key to lowering CO_2 emissions.

Mardani et al. (2019) examined the relationship between CO_2 emissions and economic growth by reviewing the literature from 1995 to 2017. To examine the relationship between the variables, the researchers used 175 published articles from 1995 to 2017. For systematic reviews and meta-analyses, the study uses a set of preferred reporting items (PRISMA). The empirical findings revealed a link between CO_2 emissions and economic growth. According to the researchers, policies that limit CO_2 emissions will also slow economic growth.

Mahmood et al. (2019) conducted a study testing the environmental Kuznets curve in Egypt focusing on the role of foreign investment and trade. The study utilised time series data spanning from 1990 to 2014. The study employed an ARDL model to analyse the relationship between the variables. The empirical results validated the environmental Kuznets curve in Egypt. The researchers recommend that the Egyptian government attract further foreign investment to support a cleaner environment.

Boubellouta and Kusch-Brandt (2020) conducted a study testing the environmental Kuznets curve theory for E-waste in the EU28+2 countries. The study utilised annual panel data spanning from 2000 to 2016. The study employed generalized method of moments, 2SLS estimator and cross-section method to analyse the robustness of the results. The results revealed that E-waste supported the environmental Kuznets curve theory in the EU28+2 countries. The researchers further highlight that there is an urgent need to implement effective e-waste collection and valorisation schemes.

Güngör, Abu-Goodman et al. (2021) investigated the environmental Kuznets curve in South Africa by analysing the role of globalization, energy use and regulations. The study utilised quarterly data spanning from Q1 1996 to Q4 2016. The study employed an ARDL model to analyse the relationship between the variables. Empirical results revealed that the Environmental Kuznets Curve holds in South Africa. The policy implication of the study is that increasing the pace of globalization and strengthening regulations are efficient strategies to improve environmental quality and sustain a stable EKC in South Africa.

Güngör, Olanipekun et al. (2021) conducted a study testing the environmental Kuznets curve hypothesis in 9 countries by focusing on the role of energy consumption and democratic accountability in Algeria, Haiti, Iran, Kenya, Romania, Sri Lanka, Turkey, Yemen, and Zimbabwe. The study utilised panel data spanning from 1990 to 2014. The study employed a Pooled Mean Group estimator to analyse the relationship between the variables. The empirical results validated the presence of the environmental Kuznets curve in these countries.

Ouédraogo et al. (2021) conducted a study on the dynamic effects of oil resources on environmental quality by testing the environmental Kuznets curve hypothesis for 11 oil producing African countries. The study utilised panel data spanning from 1980 to 2014. The study employed panel ARDL model top analyse the relationship between the variables. The empirical results revealed that the bell-shaped Kuznets curve only hold in Cameroon, Cote d'Ivoire, and Nigeria.

Liu et al. (2022) investigated tourism development, energy consumption, trade openness and economic growth matter for ecological footprint by testing the environmental Kuznets curve in Pakistan. The study utilised annual time series data spanning from 1980 to 2017. The study employed and ARDL and Toda-Yamamoto non-causality test to analyse the relationship between the variables. The results revealed an inverted U-shaped curve implying that the EKC holds in Pakistan.

Ongan et al. (2021) conducted a study on economic growth and environmental degradation with evidence from the US case environmental Kuznets hypothesis with application decomposition. The study utilised monthly time series data spanning from M1-1990 to M9 -2019. The study employed an ARDL model and detects the EKC in US. The study proposes the use of decomposition method when testing the environmental Kuznets curve as the undecomposed method is not able to detect the EKC and conceal validity of the theory.

2.3. Studies that Found an Inverse Relationship

Vincent (1997) conducted a study testing the environmental Kuznets curve in Malaysia. The study utilised panel data spanning from 1973 to 1991. The study employed fixed effects regression to analyse the relationship between the variables. The results revealed that the environmental Kuznets curve was inconsistent in Malaysia. The researcher highlights that the lack of evidence of the environmental Kuznets curve in Malaysia does not prove that the EKC do not exist anywhere, however, it does indicate that policymakers in developing countries should not assume that economic growth will automatically solve air and water pollution.

Pao et al. (2011) created a model of Russia's CO_2 emissions, energy consumption, and economic growth. Data from 1990 to 2007 was used in the study. To examine the relationship between the variables, researchers used an error correction model and granger causality tests. Economic growth and CO_2 emissions in Russia have a negative relationship, according to the empirical findings. Based on the granger causality test, the researchers suggest that policies to reduce emissions are not harmful to economic growth, and that Russia should increase infrastructure investment to improve energy efficiency and thus promote economic growth.

Borhan et al. (2012) investigated the relationship between CO_2 emissions and economic growth in the eight ASEAN countries. The research used annual panel data from 1965 to 2010 that had been borrowed. The relationship between the variables was examined using panel estimation techniques in this study. Carbon emissions had a negative impact on economic growth in the eight Asian countries, according to the empirical findings. The researchers suggest that variables like solid waste treatment, hazardous waste, and noise in the city be included because carbon emissions cause death and slow economic growth.

Azam and Khan (2016) conducted a study testing the environmental Kuznets curve hypothesis performing a comparative analysis of low, lower middle, upper middle- and higher-income countries. The study employed annual time series data spanning from 1975 to 2014. The study employed Johansen cointegration test and Pearson correlation test to analyse the relationship between the variables. The results revealed that the environmental Kuznets curve does not hold in upper-middle- and high-income countries.

Demissew Beyene and Kotosz (2020) conducted a study testing the environmental Kuznets curve theory in East African countries. The study utilised panel data spanning from 1990 to 2013. The study employed Pooled Mean Group approach to analyse the applicability of the theory. The empirical results confirmed a bell-shaped curve implying that the Kuznets curve does not hold in East African countries. The study recommends that environmental conservation policies, technological advancement and modern industrial policies are required to make the economic growth of East African countries effective in reducing CO_2 emissions.

Vollebergh and Dijkgraaf (2001) conducted a study on testing the environmental Kuznets curves on 24 OECD countries. The study utilised panel data spanning from 1960 to 1997. The study employed fixed-effects estimation techniques to evaluate the applicability of the hypothesis. The study rejected the model specification that feature even weaker homogeneity assumptions than are commonly used and further challenge the existence of an overall Environmental Kuznets Curve for carbon dioxide emissions.

Adu and Denkyirah (2017) conducted a study on economic growth and environmental pollution in West Africa by testing the Environmental Kuznets Curve theory. The study utilised panel data spanning from 1970 to 2013. The study employed panel estimation techniques to evaluate the relationship between the variables. The results revealed that the environmental Kuznets Curve does not hold in West African countries. The study recommends that West African countries should pursue efficiency improvement policy intervention to prevent environmental degradation.

Arnaut and Lidman (2021) conducted a study on environmental sustainability and economic growth in Greenland by testing the environmental Kuznets curve. The study utilized annual time series data spanning from 1970 to 2018. The study employed an ARDL model to evaluate the relationship between the variables. The empirical results revealed a U-shaped Kuznets curve implying that the Kuznets curve does not hold in Greenland.

Ouédraogo et al. (2021) conducted a study on the dynamic effects of oil resources on environmental quality by testing the environmental Kuznets curve hypothesis for 11 oil producing African countries. The study utilised panel data spanning from 1980 to 2014. The study employed panel ARDL model top analyse the relationship between the variables. The empirical results revealed that a U-shaped Kuznets curve only hold in Algeria and Morocco.

Setyari and Kusuma (2021) investigated economics and environmental development by testing the environmental Kuznets curve hypothesis in 62 countries. The study utilised panel data spanning from 1992 to 2017. The study employed an ECM to analyse the relationship between the variables. The results revealed that the EKC does not hold in these countries since at higher levels of development there was higher levels of environmental degradation.

Zeraibi et al. (2021) conducted a study on testing the environmental Kuznets Curve hypothesis in Chinese provinces focusing on the nexus between regional government expenditures and environmental quality. The study utilised panel data spanning from 2007 to 2017 for 31 Chinese provinces. The study employed GMM and FMOLS models to analyse the relationship between the variables. The results revealed an N-shaped curve implying that the EKC does not hold now in Chinese provinces. The study recommends that developing countries should allocate larger budgets for environmental projects in their reforms for the sake of moving greener and more inclusive economies with low-carbon activities.

2.4. Studies that Found No Causal Relationship

Economic growth, CO_2 emissions, and fossil fuel consumption in Iran were investigated by Lotfalipour et al. (2010). Annual time series data for the years 1967 to 2007 were used in the research. To investigate the relationship between the variables, the researchers used Toda-Yamamoto Granger causality tests, modified vector autoregressive models, and apparently unrelated regression. CO_2 does not cause economic growth in Iran, according to the study's findings. Although Iran has made no commitments to reduce greenhouse gas emissions, the researchers believe that energy-efficient investments and emissions reductions will not harm the country's economic growth.

CO_2 emissions, energy consumption, and economic growth in Turkey were investigated by Ozturk and Acaravci (2010). Annual time series data was used in the study, which covered the years 1968 to 2005. To examine the relationship between the variables in Turkey, the researchers used an autoregressive distributed lag model and the granger causality test. The findings revealed that there is no causal relationship between the model's variables. Energy conservation policies such as rationing energy consumption and controlling carbon dioxide emissions, according to the researchers, are unlikely to have a negative impact on Turkey's economic growth.

2.5. Studies that Found Non-linear Relationship

Wang (2012)used a panel of 98 countries to model a nonlinear relationship between CO_2 emissions from oil and economic growth. Annual panel data was used in the study, which covered the years 1971 to 2007. The relationship between the variables was investigated using a nonlinear dynamic panel threshold model (DPTM). In the panel countries, the results revealed a positive nonlinear relationship between CO_2 emissions and economic growth. The researchers also recommend looking for alternative ways to reduce oil CO_2 emissions growth, finding alternative energy sources, reducing oil CO_2 emissions directly in medium and high-growth countries, and reducing population growth.

Wang (2013) investigated the functional sensitivity of testing the environmental Kuznets curve theory. The study employed a non-linear regression to analyse the relationship between the variables in OECD countries. The results revealed that the environmental Kuznets curve did not hold in the OECD countries.

In five Asian countries, Heidari et al. (2015) looked at economic growth, CO_2 emissions, and energy consumption. The study used data from a panel that spanned the years 1980 to 2008. To examine the relationship between the variables, the researchers used the panel smooth transition regression (PSTR) model. In the five Asian countries studied, the results revealed a nonlinear relationship between CO_2 emissions and economic growth. The researchers also recommend that these countries reduce their emissions to reduce their emissions.

3. METHODOLOGY

3.1. Empirical Model Estimation

The primary objective of the study is to investigate the presence or applicability of the Environmental Kuznets Curve hypothesis in South Africa. This will be achieved by CO_2 emissions as a proxy of environmental degradation, gross domestic product per capita as a proxy of economic growth and government expenditure as a proxy of legislation to formulate a multivariate model. The study makes use of 60 observations of annual time series data spanning from 1961 to 2020. The empirical model can therefore be specified as follows:

$$LCO_{2t} = \alpha_1 + \alpha_{LGDP} LGDP_t + \alpha_{LGOV} LGOV_t + \varepsilon_t \quad (1)$$

Where LCO_{2t} represents CO_2 emissions in natural logarithms, $LGDP_t$ represents economic growth in natural logarithms, $LGOV_t$ represents government expenditure in natural logarithms, α_1 is the constant and ε_t is the error term.

3.2. Data Analysis

The study employs the unit root test of Augmented Dickey-Fuller and Phillips-Perron tests to check the stationarity levels of the data. This will help avoid the problem of spurious regressions as well as aiding in the selection of the model to be employed for the investigation. The study employs the lag length criteria to determine the optimal lags to be utilised in the model and the Johansen cointegration test to check if there is long run relationship between the variables. Data sources and their description is presented in Table 1.

The study by Güngör, Abu-Goodman et al. (2021) employed an ARDL model in testing the Environmental Kuznets Curve in South Africa and found that it is applicable. This study, however, will employ a Vector Error Correction Model (VECM) to investigate if the EKC hold in South Africa. The VECM-Granger Causality model was employed in the studies by Khobai and Le Roux (2017) analysing the relationship between CO_2 emissions and economic growth in South Africa. The VECM employed in this investigation works in a way that at most, there are n-1 cointegrating vectors and is therefore 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 (L CO_2, LGDP and LGOV), 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:

$$\Delta LCO_{2t} = \alpha_{10} + \sum_{i=1}^{p} \alpha_{11} \Delta LCO_{2t-i} + \sum_{i=1}^{q} \alpha_{12} \Delta LGDP_{t-i} + \sum_{i=1}^{r} \alpha_{13} \Delta LGOV_{t-i} + \psi_1 ECT_{t-1} + \varepsilon_{t-i} \quad (3)$$

Table 1: Data sources and description

Variable	Description	Unit	Source
L CO_2	Carbon dioxide emissions	As a percentage of GDP	World Bank and Statista
LGDP	Gross domestic product per capita	Annual growth percentage	World Bank
GOV	Government expenditure	Percentage of GDP	World Bank

Source: Author's own compilation

$$\Delta LGOV_t = \alpha_{30} + \sum_{i=1}^{p} \alpha_{31} \Delta LGOV_{t-i} + \sum_{i=1}^{q} \alpha_{32} \Delta LGDP_{t-i} + \sum_{i=1}^{r} \alpha_{33} \Delta LCO_{2t-i} + \psi_3 ECT_{t-1} + \varepsilon_{3t} \quad (4)$$

$$\Delta LGOV_t = \alpha_{30} + \sum_{i=1}^{p} \alpha_{31} \Delta LGOV_{t-i} + \sum_{i=1}^{q} \alpha_{32} \Delta LGDP_{t-i} + \sum_{i=1}^{r} \alpha_{33} \Delta LCO_{2t-i} + \psi_3 ECT_{t-1} + \varepsilon_{3t} \quad (5)$$

Where L CO_2, LGDP and LGOV represents carbon dioxide emissions, gross domestic product, and government expenditure respectively. ε represents serially uncorrelated random error term in period 1 to 3. 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 AND INTERPRETATIONS

The ADF and PP unit root tests were used in the investigation to eliminate spurious regressions and to establish the order of variable integration. The results in Table 2 shows that the L CO_2 is stationary at first difference, that is integrated of order one I(1), while LGD and LGOV are stationary at both level and first difference. This implies that the data is a mixture of I(0) and I(1), and this makes it suitable to employ the VECM model since it requires the variables to be integrated of I(0) or I(1) or a mixture of I(0) and I(1) but no variables should be integrated of I(2).

The study continues to estimate the optimal number of lags to be used in the investigation as shown in Table 3.

The study performed an optimal leg length criterion to determine the number of lags to be used in the model as shown in Table 3. The results shows that only one leg can be utilised in the investigation according to the LR, FPE and AIC criterion. The study therefore continues to perform the Johansen cointegration test as shown in Table 4 to determine if there is long run relationship between the variables.

The study performed the Johansen cointegration test to see if there are long relationships among the variables in the investigation. The Trace test indicates 3 cointegration equations at 0.05 level of significance and the Maximum-Eigen shows 1 cointegration equation at 0.05 level of significance. This implies that there is a long run relationship among the variables in the model. The investigation, therefore, continues to estimate both the short and long run relationships as given in Tables 5 and 6.

The investigation employed the VECM to estimate the short run relationships in the model and the results are given in Table 5. The ECT term is negative and statistically significant. The coefficient of the error correction term is 0.846303, meaning if there are errors in CO_2 emissions in the model, 84.63% of the errors are adjusted annually towards long run equilibrium.

There is a positive statistically insignificant relationship between economic growth and CO_2 emissions in the short run in South Africa. A 1% increase in economic growth in the short run in South Africa, will insignificantly result in CO_2 emissions increasing by 0.02%, ceteris paribus. This means that economic growth is not good for environmental degradation in the short run in South Africa. These results are consistent with the studies of Güngör, Abu-Goodman et al. (2021), Güngör, Olanipekun et al. (2021), Liu et al. (2022) and Ongan et al. (2021)This means that the early stages of Environmental Kuznets Curve hypothesis hold in South Africa since, in the short run, an increase in economic growth results in an increase in environmental degradation. Therefore, policies that reduce economic growth in sectors that contributes to CO_2 emissions must be implemented in South Africa.

There is a negative statistically insignificant short run relationship between government expenditure and economic growth in South Africa. A 1% increase in government expenditure in the short run in South Africa, will insignificantly result in CO_2 emissions declining by 0.02%, ceteris paribus. These results implies that government expenditure plays an important role in reducing CO_2 emissions in South Africa in the short run. Therefore, policies that increase government expenditure on reducing environmental degradation

Table 2: Augmented Dickey-Fuller (ADF) and Phillips-Perron (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
L CO_2	−2.0170	−6.3446***	−1.8761	−6.3377***	−2.2553	−6.3543****	−2.1503	−6.3469***
LGDP	−3.4190**	−7.2492***	−3.6977**	−7.1961***	−3.4278**	−10.242***	−3.6977**	−9.9266***
LGOV	−5.0823***	−7.0917***	−6.3386***	−7.0672***	−5.0743***	−23.980***	−6.4007***	−28.611***

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

Table 3: Optimal lag length criteria

Lag	LogL	LR	FPE	AIC	SC	HQ
0	−293.1557	NA	11.64772	10.96873	11.07923*	11.01134*
1	−281.6231	21.35668*	10.61335*	10.87493*	11.31692	11.04539
2	−278.9569	4.641135	13.46756	11.10951	11.88301	11.40782
3	−275.6745	5.349073	16.78718	11.32128	12.42627	11.74743
4	−270.8500	7.326096	19.90979	11.47593	12.91241	12.02992
5	−260.4093	14.69430	19.37309	11.42257	13.19055	12.10441

Source: Author's own computation

must be promoted in the short run in South Africa to reduce CO_2 emissions. The study therefore continues to estimate the long run relationships as shown in Table 6.

The study employed the VECM model and estimated the long run relationships as shown in Table 6 above. There is a negative statistically insignificant long run relationship between economic growth and CO_2 emissions in South Africa. A 1% increase in economic growth in the long run in South Africa, will insignificantly result in CO_2 emissions declining by 0.45%, ceteris paribus. This means that economic growth is important for reducing CO_2 emissions in the long run in South Africa. These results are consistent with the studies of Ongan et al. (2021), Güngör, Olanipekun et al. (2021); Güngör, Abu-Goodman et al. (2021), Liu et al. (2022) that found an inverted U-shaped Kuznets curve. Therefore, policies that increases economic growth in the long run must be promoted as this reduces CO_2 emissions. These results are consistent with the Environmental Kuznets Curve hypothesis in the long run since an increase in economic growth in the long run in South Africa, results in reduction in environmental degradation. Therefore, the EKC hypothesis holds in the long run in South Africa.

There is a negative statistically insignificant long run relationship between government expenditure and CO_2 emissions in South Africa. A 1% increase in government expenditure in the long run in South Africa, will insignificantly result in CO_2 emissions declining by 0.04%, ceteris paribus. This means that government expenditure is important for reducing environmental degradation in the long run in South Africa. Therefore, policies that result in an increase in government expenditure in the long run must be promoted to reduce CO_2 emissions. The study therefore continues to perform the Granger Causality checks to see if there are causal relationships between the variables in the model as shown in Table 7.

The study performed the Granger causality test to check for causal relationships in the model. The results reveal non-causal relationships between economic growth and CO_2 emissions, and government expenditure and CO_2 emissions. There is unidirectional causality running from economic growth to government expenditure, meaning that, economic growth granger causes government expenditure or increase in government expenditure is because of economic growth. These results, therefore, validates the results in Table 5 and 6. The study therefore continues to perform variance decomposition as shown in Table 8 and 9.

The results of the variance decomposition for CO_2 emissions are presented in Table 8. The results reveal that in the 10th year, one standard deviation shock from economic growth and government expenditure, will result in 30.14% and 7.12% forecast error variance respectively. After 10 periods, a greater percentage of 62.74% becomes self-explanatory. The study continues to perform variance decomposition for economic growth as shown in Table 9.

Table 4: Johansen cointegration test

Hypothesized No. CE(s)	Trace statistic	0.05 Critical value	Max-Eigen statistic	0.05 Critical value
None	33.5656*	29.7971	14.5874	29.1316
At most 1	18.9782*	15.4947	13.0785	14.2646
At most 2	5.89966*	3.84147	5.89966*	3.84147

Source: Author's own computation (*) denotes rejection of the hypothesis at the 0.05 level

Table 5: VECM and short run relationship

Variable	Coefficient	Standard error	t-Statistic
D(L CO_2 (-1))	−0.061879	0.14443	−0.42842
D(LGDP(-1))	0.015005	0.02876	−0.52178
D(LGOV(-1))	−0.020235	0.01844	−1.09744
ECT(-1)	−0.846303	0.19175	−4.41363
C	−0.004576	0.06390	−0.07161

Source: Author's own computation

Table 6: VECM and long run relationships

Variable	Coefficient	Standard Error	t-Statistic
L CO2 (-1)	1.000000	-	-
LGDP(-1)	−0.048883	0.03758	−1.30094
LGOV(-1)	−0.037762	0.03068	−1.23097
C	0.143226	-	-

Source: Author's own computation

Table 7: Granger causality test

Null hypothesis	F-statistic	Prob
GDP does not Granger Cause CO_2	1.51478	0.2236
CO_2 does not Granger Cause GDP	0.43481	0.5124
GOV does not Granger Cause CO_2	0.53591	0.4672
CO_2 does not Granger Cause GOV	0.28405	0.5962
GOV does not Granger Cause GDP	0.00207	0.9639
GDP does not Granger Cause GOV	5.48272	0.0228

Source: Author's own computation

Table 8: Variance decomposition CO_2 emissions

Period	SE	CO_2	GDP	GOV
1	0.480952	100.0000	0.000000	0.000000
2	0.509238	92.13072	7.403652	0.465633
3	0.527253	87.05946	11.10774	1.832797
4	0.547325	82.18257	14.95660	2.860838
5	0.565794	77.87847	18.33255	3.788980
6	0.583770	74.12761	21.24994	4.622457
7	0.601241	70.79061	23.85845	5.350933
8	0.618191	67.81725	26.17847	6.004283
9	0.634698	65.14923	28.26101	6.589758
10	0.650785	62.74142	30.14048	7.118107

Source: Author's computation

Table 9: Variance decomposition economic growth

Period	SE	CO_2	GDP	GOV
1	2.463420	7.752203	92.24780	0.000000
2	3.174133	5.478407	93.14809	1.373504
3	3.738562	8.716204	89.86145	1.422342
4	4.271326	10.09821	88.20043	1.701360
5	4.723922	10.88191	87.30619	1.811905
6	5.143401	11.52799	86.57262	1.899400
7	5.529951	11.96219	86.07432	1.963488
8	5.891167	12.30248	85.68610	2.011417
9	6.231612	12.56944	85.38099	2.049578
10	6.554335	12.78479	85.13491	2.080296

Source: Author's own computation

The results of the variance decomposition for economic growth are shown in Table 9. From Table 9, 12.78% is self-explanatory for CO_2 emissions in the 10^{th} year for forecast error variance. Economic growth and government expenditure will result in a standard deviation shock of 85.13% and 2.08% respectively.

5. CONCLUSION AND RECOMMENDATION

The study investigated the applicability of the Environmental Kuznets Curve hypothesis in South Africa by using CO_2 emissions, economic growth, and government expenditure to formulate a multivariate equation. The study performed the ADF and PP unit root test, Johansen cointegration test and optimal leg length criteria. The objective was fulfilled by employing the VECM model to check the short and long run relationships as well as the Granger Causality test to check for causal relationships among the variables.

The VECM results revealed that there is a positive statistically insignificant relationship and long run negative statistically insignificant relationship between economic growth and CO_2 emissions in South Africa. This supports the idea of the inverted U-shaped Environmental Kuznets Curve hypothesis in South Africa. The results of the Granger causality test revealed that there are no causal relationships between economic growth, government expenditure and CO_2 emissions in South Africa.

The policy implications of the study based on empirical results are therefore that: Firstly, the positive statistically insignificant short run relationship and long run negative statistically insignificant relationship between CO_2 emissions and economic growth calls for the policymakers to propose policies that reduce economic growth in the shorth run. These policies must be policies that reduce economic activities in the sectors that contribute to CO_2 emissions. Them policymakers might increase carbon tax to reduce the CO_2 emissions in industries, automobiles, and residential areas. In the long run, environmentally friendly economic growth must be prioritised in South Africa.

Secondly, the negative relationship between government expenditure and economic growth in both in the short and long run calls for the government to increase its expenditure to enforce rules and laws that reduce CO_2 emissions. The government might achieve this by issuing heavy fines to those that are emitters of CO_2 gases. The government might also put legislatures that limit the amount of CO_2 emissions that an industry can emit.

Thirdly, the government must increase taxes on carbon fuels and increase investment in renewable energy. This can be achieved by the government subsidizing the production of electric cars and renewable energy such as solar and wind to power the industries, residentials and automobiles in South Africa.

The primary objective of the study was to investigate if the Environmental Kuznets Curve hypothesis hold in South Africa. The objective was achieved by the discovery of the positive short run relationship and negative long run relationship between economic growth and CO_2 emissions in South Africa. In conclusion, it is indeed true that the Environmental Kuznets Curve hypothesis hold in South Africa.

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