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The Relationship between Energy Consumption, Economic Growth and Carbon Dioxide Emission: The Case of South Africa

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ABSTRACT

This paper investigates the relationship between energy consumption, carbon dioxide (CO_2) emission, economic growth, trade openness and urbanization for South Africa. The annual data for the period between 1971 and 2013 is employed. The results of Johansen test of co-integration show that there is a long run relationship between energy consumption, CO_2 emission, economic growth, trade openness and urbanization in South Africa. The results for the existence and direction of vector error correction model (VECM) Granger causality indicates that there is bidirectional causality flowing between energy consumption and economic growth in the long run. The VECM results further found a unidirectional causality flowing from CO_2 emissions, economic growth, trade openness and urbanization to energy consumption and from energy consumption, CO_2 emissions, trade openness and urbanization to economic growth. These results posit a fresh perspective for creating energy policies that will boost economic growth in South Africa.

Keywords: Energy Consumption, Economic Growth, Carbon Dioxide Emission, South Africa
JEL Classifications: O13, Q43

1. INTRODUCTION

The world has experienced major changes in economic and environmental scopes in South Africa due to the great reform and economic transition in the past two decades. South Africa has experienced increasing demand in energy following the increase in economic growth post-apartheid era. The country's energy intensity is above average which indicates that much energy is required to produce a single unit of gross domestic product (GDP). However, South Africa's energy utilization is characterized by high dependence on low-cost and abundantly available coal. A large amount of crude oil is imported into the country while a small amount of renewable energy is used.

Table 1 shows the trends of the total energy supply from 2003 to 2006. It can be seen from Table 1 that coal dominates the energy supply while hydroelectricity contributes the least to energy supply. However, coal was subjected to a mix of trends since 2003. Its contribution decreased by 4.5% from 2003 to 2004, and increased by 3.6% from 2004 to 2005; from 2005 to 2006, it fell again by 5.9%. In general, the contribution of coal has decreased by 6.8% for the entire period. The contribution of hydroelectricity has increase by 0.1% since 2003. Crude oil has experienced an increase of 7.8% since 2003 while gas supply increased by 1.7%. The nuclear contribution dropped from 3.1% in 2003 to 1.9% in 2006. The renewables have decreased from 9.4% in 2003 to 7.6% in 2006.

Coal and crude oil remain the major primary energy suppliers in South Africa despite their effects on air quality, human health, wildlife and climate change. South Africa is the ranked number six among the world's largest recoverable coal reserves (Department of Energy, 2009). It is 12th highest carbon dioxide (CO_2) emitter in the world and number one greenhouse gas emitter in Africa (USAID, 2016). The increasing concern of the greenhouse gas emission has motivated many researchers to investigate relationship the between energy consumption, CO_2 emission and economic growth in different countries and regions. However, this relationship has been rarely examined in South Africa despite the fact that South Africa's energy consumption and carbon emission increased more than double in the last two decades. While there are studies carried in the international literature to investigate

Table 1: Total primary energy supply-TJ: 2003-2006

Variables	2003	%	2004	%	2005	%	2006	%
Coal	3,227,600	72.7	3,573,343	68.2	3,651,726	71.8	3,721,156	65.9
Crude Oil	615,689	13.7	1,016,664	19.4	724,774	14.2	1,214,122	21.5
Gas	50,218	1.1	84,152	1.6	153,078	3.0	160,318	2.8
Nuclear	138,142	3.1	145,801	2.8	123,193	2.4	109,375	1.9
Hydro	2890	0.1	2890	0.1	4199	0.1	11,069	0.2
Nuclear	422,979	9.4	418,058	8.0	430,427	8.5	428,396	7.6
Total	4,507,518		5,240,908		5,089,397		5,644,436	

Source: Department of Energy (2009)

the relationship between energy consumption, CO_2 emission and economic growth, they do not focus on South Africa (Saidi and Hammami, 2015; Arouri et al., 2012; Linh and Lin, 2014; Vidyarthi, 2013).

The studies which were done in South Africa focused on energy consumption and economic growth (Okafor, 2012; Wolde-Rufael, 2009 and Odhiambo, 2010). The only South African study that covered energy consumption, economic growth and pollutant emissions was done by Menya and Wolde-Rufael (2010). Our study differs from Menya and Wolde-Rufael (2010)'s study in that we included trade openness and urbanization as the additional variables to form a multivariate framework.

The remainder of the study is organized as follows: Section 2 studies the review of the empirical literature. Section 3 presents the data and methodology used in the study followed by the discussion of the findings in Section 4. Section 5 concludes the study with some policy implications.

2. LITERATURE REVIEW

The relationship between economic growth and energy consumption had been researched extensively over the past three decades. However, the results concerning the direction of causality between these variables are still mixed. The results range from no causality to unidirectional or bidirectional causality. The difference is caused by different methodologies applied, different countries' data applied and the particular period of the study.

The pioneers of the studies on energy consumption and economic growth are Kraft and Kraft (1978). Their study considered the case of USA for the period 1947 to 1974. The results from Sims Granger-causality supported a unidirectional causality flowing from gross national product to energy consumption. This implies that energy conservation policies can be introduced without causing any harm to economic growth. Shyamal and Rabindra (2004) undertook a study to investigate the causal relationship between energy consumption and economic growth in India covering the period 1950-1996. The study utilized Engle-Granger co-integration to estimate the long run relationship between these variables and the standard Granger-causality to find the direction of causality. The results supported a unidirectional causality flowing from energy consumption to economic growth. The results from Engle-Granger co-integration detected a one-way causality flowing from economic growth to energy consumption in the long term. The combination of standard Granger-causality and the Engle-Granger approach revealed bidirectional causality between energy consumption and economic growth.

Saidi and Hammami (2015) conducted a study to assess the link between energy consumption and economic growth in Tunisia. The annual data was used for the period between 1974 and 2011. The Johansen technique results suggested that there is a long run relationship between economic growth and energy consumption. The Granger-causality results found a bidirectional causality flowing between energy consumption and economic growth in Tunisia.

Tang et al. (2016) investigated the long run relationship between energy consumption and economic growth for the period between 1971 and 2011. The results from co-integration technique revealed existence of co-integration among the variables. The Granger-causality results suggested a one-way causality running from energy consumption to economic growth in Vietnam. This implies that Vietnam is an energy-intensive country and there is a need to implement renewable energy policy to provide sufficient supply as this will speed up economic growth.

Albiman et al. (2015) conducted a study to determine the relationship between energy consumption, environmental pollution and per capita economic growth in Tanzania for the period between 1975 and 2013. The study investigated the causality relationship by employing the more robust causality technique of Toda and Yamamoto's non-causality test. The findings revealed a unidirectional causality flowing from economic growth and energy consumption to environmental pollution through CO_2 emissions.

Vidyarthi (2013) carried out a study to investigate the long term and causal relationship between energy consumption, economic growth and carbon emissions in India. The data used in this study covered a period from 1971 to 2009. To determine the co-integration between the selected variables, the Johansen co-integration technique was employed while the vector error correction model (VECM) Granger-causality test was used to find the direction of causality between the variables. The Johansen co-integration technique results established a long term relationship between energy consumption, carbon emissions and economic growth. The long term causality results validated a unidirectional causality flowing from energy consumption and CO_2 emissions to economic growth while the short term causality revealed mixed results: A unidirectional causality flowing from energy consumption to carbon emission; carbon emission to economic growth and; economic growth to energy consumption.

Another study that used a trivariate framework is by Dehnavi and Haghnejad (2012) which aimed to determine the relationship between energy consumption, pollution and economic growth for a selected panel of eight Organization of the Petroleum Exporting Countries. The study used a panel data technique for the period 1971-2008. The Granger-causality identified a two-way causality between CO_2 emissions and energy consumption and a one-way causality flowing from economic growth to energy consumption and pollution in the long term. The short run results observed that economic growth Granger-causes CO_2 emission while energy consumption Granger-cause CO_2 emission and economic growth.

A multi-country study was conducted by Vidyarthi (2014) to investigate the relationship between energy consumption, carbon emissions and economic growth for five South Asian countries: Bangladesh, India, Pakistan, Nepal and Sri Lanka. The study used Pedroni's co-integration to determine the long term relationship among the variables and panel VECM Granger-causality to find the direction of causality between the variables. In using data for the period between 1972 and 2009, the study found that there exists a long term relationship between energy consumption, carbon emissions and economic growth in all these countries. The VECM Granger-causality suggested bidirectional causality between energy consumption and economic growth, a unidirectional causality flowing from carbon emissions to economic growth and energy consumption in the long term. The short term results identified a unidirectional causality flowing from energy consumption to carbon emissions.

Another multi-country study was carried out by Ahmed and Azam (2016) who served to examine the nexus between energy consumption and economic growth for 119 countries all over the world. The countries were categorized as follows; 30 high income OECD, 13 high income non-OECD, 65 middle income and 11 low income countries. The Granger-causality results detected feedback hypothesis for 18 countries (5 high income OECD, 2 high income non-OECD, 10 middle income OECD and 1 low income). It was further established that there is a growth hypothesis in 25 countries which comprises of 4 high income OECD, 3 high income non-OECD, 14 middle income and 4 low income countries. conservation hypothesis was revealed for 6 high income OECD, 6 high income non-OECD, 27 middle income and 1 low income countries. finally, there was no causality established in 15 high income OECD, 2 high non-OECD, 14 middle income and 5 low income countries.

Moubarak and Lin's (2014) research aimed to determine the long term and short run relationship between renewable energy consumption and economic growth in China. The data used in the study covered the period 1977-2011. CO_2 emissions and labor were used as additional variables to form a multivariate framework. The results from the autoregressive distributed lag technique and the Johansen co-integration test found that there is a long term relationship between the selected variables. The Granger-causality test suggested a two-way causality flowing between renewable energy consumption and economic growth in the long-term. The causality results further established a unidirectional causality flowing from labor to renewable energy consumption. There was no causality found between carbon emissions and renewable energy consumption in the long term and short term. This implies that renewable energy has not been exploited in China to mitigate CO_2 emissions.

Pablo-Romero and De Jesús (2016) conducted a study to examine the link between energy consumption and economic growth using the hypothesis postulated for the energy-environmental Kuznets curve. A panel data of 22 Latin American and Caribbean countries were employed covering the period between 1990 and 2011. Their findings showed existence of a U-shaped relationship between energy consumption and economic growth.

Linh and Lin (2014) contribute to the most recent studies that assessed the dynamic relationship between energy consumption and economic growth using multivariate framework by adding the variables foreign direct investments and CO_2 emissions. This Vietnam study used data for the period between 1980 and 2010. The co-integration findings show that there is a long term relationship between economic growth, energy consumption, foreign direct investments and CO_2 emissions. The Granger-causality results established bidirectional causality between foreign direct investment and income in Vietnam. This implies that an increase in Vietnam's income has a potential of attracting more capital from overseas.

Kais and Sami (2016) investigated the impact of energy consumption and economic growth on CO_2 emissions in 58 countries covering the period between 1990 and 2012. The countries were divided into three regional subgroups as follows: European and North Asian region, Latin American and Caribbean region and Sub-Saharan region. The results posit that energy consumption has a positive impact on CO_2 emissions all panels. It is further revealed that economic growth has a positive and a statistically significant impact on CO_2 emissions European and North Asian region and North Africa and Sub-Saharan Africa.

Streimikiene and Kasperowicz (2016) served to determine the nexus between energy consumption and real GDP by incorporating fixed capital and total employment to form multivariate framework. The study used data for 18 European Union countries for the period from 1995 to 2012. It was established that economic growth, energy consumption and gross fixed capital move along in the long run. The findings from the fully modified ordinary least squares (FMOLS) and dynamic ordinary least squares estimators indicated a positive relationship between economic growth, energy consumption and gross fixed capital.

Arouri et al. (2012) examined the link between energy consumption, CO_2 emission and economic growth for 12 Middle East and North African countries spanning the period 1981-2005. The bootstrap panel unit root tests and co-integration techniques were applied. The findings indicated a long run positive relationship between energy consumption and CO_2 emissions. Furthermore, real GDP showed a quadratic relationship with CO_2 emissions for the entire region.

Saidi and Hammami's (2015) study serves to investigate the impact of economic growth and CO_2 emissions on energy consumption for

58 countries. Dynamic panel data model for the period between 1990 and 2012 was estimated using the generalized method of moments (GMM). The findings show that CO_2 emission have a positive and significant impact on energy consumption for four global panels. The results further show that economic growth has a positive effect on energy consumption.

Wang et al. (2016) detected the causal link between urbanization, energy consumption and CO_2 emissions for the Association of Southeast Asian Nations countries covering the period between 1980 and 2009. The findings from the Pedroni panel co-integration tests evidenced existence of a long run relationship among the variables. Employing the FMOLS, it was established that all else the same, a 1% rise in urbanization leads to CO_2 emissions increasing by 0.20%. The Granger-causality results suggested a unidirectional short run causality flowing from urbanization to energy consumption and from urbanization to CO_2 emissions. It was further detected that urbanization and energy consumption Granger-cause CO_2 emissions in the long run. Ozturk and Al-Mulali (2015) investigate whether better governess and corruption control help to form the inverted U-shaped relationship between income and pollution in Cambodia for the period of 1996-2012. The outcome from the GMM and the two-stage least squares revealed that GDP, urbanization, energy consumption, and trade openness increase CO_2 emission while the control of corruption and governess can reduce CO_2 emission. It is fundamental to note that the environmental Kuznets curve hypothesis was not confirmed in Cambodia.

Okafor (2012) and Odhiambo (2010) employed energy consumption and economic growth nexus in South Africa. Odhiambo (2010) applied the Granger-causality test while Okafor (2012) employed Hsiao's Granger-causality test. The results of Odhiambo's (2010) study validated a one-way causality flowing from energy consumption to economic growth while Okafor's (2012) results suggested a unidirectional causality flowing from energy consumption to economic growth.

Menyah and Wolde-Rufael's (2010) research investigated the relationship between economic growth, pollutant emissions and energy consumption. Their study added labor and capital to form a multivariate model and used South African data for the 1965-2006 period. A modified version of the Granger-causality test and bounds test approach to co-integration were applied to analyze the direction of causality and long term relationships between the variables. A long term relationship was established between the variables. The Granger-causality results showed unidirectional causality flowing from pollutant emissions to economic growth. It also found a unidirectional causality from energy consumption to CO_2 emission and from energy consumption to economic growth. Al-Mulali et al. (2015) investigate the influence of disaggregated renewable electricity production by source on CO_2 emission in 23 selected European countries for the period of 1990-2013. The Pedroni cointegration results indicated that CO_2 emission, GDP growth, urbanization, financial development, and renewable electricity production by source were cointegrated. Moreover, the fully modified ordinary least-square results revealed that GDP growth, urbanization, and financial development increase CO_2 emission in the long run, while trade openness reduces it.

From the empirical literature, it can be realized that no study was done to investigate the relationship between energy consumption, economic growth and CO_2 emission incorporating trade openness and urbanization as controlling variables in South Africa. Therefore, this current study endeavors to fill that gap.

3. METHODOLOGY

3.1. Model Specification

This study analyses the relationship between energy consumption, CO_2 emissions and economic growth by adding trade openness and urbanization as intermittent variables to form a multivariate framework. To address the issue of heteroskedasticity, all the variables are converted into logarithm form. The log linear quadratic form is used to analyze the relationship between energy consumption, CO_2 emissions and economic growth using the following model;

$$LEC_t = \alpha_1 + \alpha_{LCO_2} LCO_{2t} + \alpha_{LGDP} LGDP_t + \alpha_{LTO} LTO_t + \alpha_{LUBN} LUBN_t + \varepsilon_t \quad (1)$$

LEC represents the natural log of energy consumption per capita *LGDP* indicates the natural log of real GDP (using constant prices of 2010), LCO_2 is the natural log of CO_2 emissions, *LTO* denotes natural log trade openness and *LUBN* represents natural log of urbanisation. Furthermore, α_1 and ε_t represent the constant and an error term, respectively.

3.2. Data Sources

The study employs annual time-series data covering the period between 1971 and 2013 for energy consumption, economic growth, CO_2 emissions, trade openness and urbanization. Different sources have been used to gather data of the mentioned variables. Real GDP (using constant prices of 2010) was collected from the South African Reserve Bank. The data for CO_2 emissions, energy consumption and urbanization were collected from Word Development Indicators while data for trade openness was sourced from United Nations and Trade Development.

3.3. Data Analysis

3.3.1. Unit root test

The unit root test is used to determine whether or not the variables energy consumption, CO_2 emission, economic growth, trade openness and urbanization are stationary series. This study employs two unit root tests; augmented Dickey–Fuller (ADF) unit root test by Said and Dickey (1984) and another one by Phillips and Perron (1988) termed Phillips-Perron (PP) unit root test. When the variables are found to be integrated of the same order, co-integration between the variables will be tested.

3.3.2. Co-integration test

The long run relationship between energy consumption, CO_2 emissions, economic growth, trade openness and urbanization is estimated using the Johansen co-integration technique (Johansen, 1988; Johansen and Juselius, 1990). This technique involves the estimation of a VECM to determine the likelihood-ratios. It works in a way that there are at most $n-1$ cointegrating vectors if there are n variables which all have unit roots. The VECM model employed in this study is as follows:

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

Where, Δ is the difference operator, Y_t is (*LEC*, LCO_2, *LGDP*, *LTO*, *LUBN*), θ is stands for the intercept and ε is the vector of white noise process.

The Johansen technique comprises of two likelihood ratio tests namely; the maximum eigenvalue and the trace test. The number of co-integrating vectors in the system is determined by the number of significant non zero Eigen values.

3.3.3. Granger-causality

The presence of co-integration implies that there is a causality but it does not show the direction of causality among the variables. To estimate causality between energy consumption, CO_2 emission, economic growth, trade openness and urbanization, the VECM is employed. The empirical equations of the VECM Granger-causality are presented as follows:

$$\Delta LEC_t = \alpha_{10} + \sum_{i=1}^{q} \alpha_{11} \Delta LEC_{t-i} + \sum_{i=1}^{r} \alpha_{12} \Delta LCO_{2t-i} + \sum_{i=1}^{s} \alpha_{13} \Delta LGDP_{t-i} + \sum_{i-1}^{t} \alpha_{14} \Delta LTR_{t-i} + \sum_{i-1}^{u} \alpha_{15} \Delta LUBN_{t-i} + \psi_1 ECT_{t-1} + \varepsilon_{1t} \quad (3)$$

$$\Delta LCO_{2t} = \alpha_{20} + \sum_{i=1}^{q} \alpha_{21} \Delta LCO_{2t-i} + \sum_{i=1}^{r} \alpha_{22} \Delta LEC_{t-i} + \sum_{i=1}^{s} \alpha_{23} \Delta LGDP_{t-i} + \sum_{i-1}^{t} \alpha_{24} \Delta LTR_{t-i} + \sum_{i-1}^{u} \alpha_{25} \Delta LUBN_{t-i} + \psi_2 ECT_{t-1} + \varepsilon_{2t} \quad (4)$$

$$\Delta LGDP_t = \alpha_{30} + \sum_{i=1}^{q} \alpha_{31} \Delta LGDP_{t-i} + \sum_{i=1}^{r} \alpha_{32} \Delta LEC_{t-i} + \sum_{i=1}^{s} \alpha_{33} \Delta LCO_{2t-i} + \sum_{i-1}^{t} \alpha_{34} \Delta LTR_{t-i} + \sum_{i-1}^{u} \alpha_{35} \Delta LUBN_{t-i} + \psi_3 ECT_{t-1} + \varepsilon_{3t} \quad (5)$$

$$\Delta LTR_t = \alpha_{40} + \sum_{i=1}^{q} \alpha_{41} \Delta LTR_{t-i} + \sum_{i=1}^{r} \alpha_{42} \Delta LEC_{t-i} + \sum_{i=1}^{s} \alpha_{43} \Delta LCO_{2t-i} + \sum_{i-1}^{t} \alpha_{44} \Delta LGDP_{t-i} + \sum_{i-1}^{u} \alpha_{45} \Delta LUBN_{t-i} + \psi_5 ECT_{t-1} + \varepsilon_{5t} \quad (6)$$

$$\Delta LUBN_t = \alpha_{50} + \sum_{i=1}^{q} \alpha_{51} \Delta LUBN_{t-i} + \sum_{i=1}^{r} \alpha_{52} \Delta LEC_{t-i} + \sum_{i=1}^{s} \alpha_{53} \Delta LCO_{2t-i} + \sum_{i-1}^{t} \alpha_{54} \Delta LGDP_{t-i} + \sum_{i-1}^{u} \alpha_{55} \Delta LTR_{t-i} + \psi_5 ECT_{t-1} + \varepsilon_{5t} \quad (7)$$

Where, EC_t, CO_{2t}, GDP_t, TR_t, UBN_t, represent energy consumption, CO_2 emissions, *GDP,* trade openness and urbanization, respectively. ε_{it} (for $i = 1, 2, 3, 4, 5$) represents serially uncorrelated random error terms. ECT_{t-1} (error correction term) represents the co-integrating vectors. The adjustment coefficient is ψ and it shows how much disequilibrium is corrected (Jamil and Ahmed, 2010).

To find the long term causality flowing from the dependent variable(s) to the dependent variable, the coefficient of the *ECT* (ψ) should be significant. From equation 3, the causality from CO_2, *GDP*, *TR*, *UBN* to *EC* can be tested. From equation 4, the causality from *EC*, *GDP*, *TR*, *UBN* to CO_2 can be estimated while from equation 5, the causality from *EC*, CO_2, *TR*, *UBN* to *GDP* can be tested. The causality from *EC*, CO_2, *GDP*, *UBN* to *TR* can be estimated from equation 6 and from equation 57, the causality from *EC*, CO_2, *GDP*, *TR* to *UBN* can be tested. The Wald test on differenced and lagged differenced terms of the dependent variables is employed to estimate the short run causality.

4. FINDINGS

4.1. Unit Root Tests

The time series properties of the variables are tested using the ADF test by Dickey and Fuller (1984) and PP test by Phillips–Perron (1988). The results are presented in Table 2.

The results at level form show that all the five variables are non-stationary at the 5% level of significance, whereas at first difference the variables are stationary. This implies that energy consumption, economic growth, CO_2, trade openness and urbanization are integrated of order one.

4.2. Co-integration

The presence of a similar order of integration, as reported by ADF and PP unit root tests, endorses the application of the Johansen co-integration test. But prior to estimating co-integration among the variables, the optimum lag is determined. The results are

Table 2: Unit root tests

Variables	ADF unit root test		PP unit root test	
	Levels	1st difference	Levels	1st difference
LCO_2	−1.6661	−5.9022*	−1.8363	−5.8988*
LENC	−1.9875	−6.2656*	−1.8922	−6.2663*
LGDP	−1.7242	−4.4481*	−1.0698	−4.2660*
LTO	−2.1026	−5.4221*	−2.0581	−5.4427*
LUBN	−1.7675	−2.0591***	−1.3083	−1.3742***

Source: Own calculation. *,***Represent 1% and 10% significance levels, respectively. ADF: Augmented Dickey–Fuller, PP: Phillips–Perron, CO_2: Carbon dioxide, GDP: Gross domestic product illustrated in Table 3. The study selects the optimum lag to be 2, according to the Schwarz information criterion and Akaike information criterion.

Co-integration among the variables is explored using the Johansen co-integration test and the results are presented in Table 4. The Johansen co-integration test exhibits that for r = 0, the λ max statistics is 36.135, which is greater than the 95% critical value of 33.877. On the other hand, maximal Trace statistics is 79.054, which is greater than the 95% critical value of 69.819. This implies that the null hypothesis r = 0 is rejected at 5% level of significance. But the results for R ≤ 1, R ≤ 2, R ≤ 3 and R ≤ 4 shows that the null hypotheses cannot be rejected. As a result, the trace test and the maximum Eigen test detected the existence of a single co-integrating vector. Therefore, the study concludes that there is a long run relationship between energy consumption, CO_2 emissions, economic growth, trade openness and urbanization in South Africa.

4.3. Granger-causality

The direction of causality between the variables is estimated using the VECM and the findings of both long and short run causalities are presented in Table 5. When energy consumption was used as the dependent variable, the lagged error term was found to negative and significant. This shows that there is one-way causality flowing from CO_2 emissions, economic growth, trade openness and urbanization to energy consumption in the long run. Similar results were established when economic growth was used as the dependent variable. This implies that there is existence of a one way causality flowing from energy consumption, CO_2 emissions, trade openness and urbanization. Generally, it can be realized that there is bidirectional causality flowing between energy consumption and economic growth. This shows increasing economic growth is essential for the improvement of the energy industry which in turn helps boost economic growth in South Africa.

The short run results exhibit no short run causality flowing between energy consumption, economic growth, CO_2 emissions, trade openness and urbanization. The absence of a short run causality flowing from energy consumption to economic growth means that environmentally friendly policies such as energy conservation, efficiency improvements measures and demand-side management policies can be implemented in South Africa without adversely affecting economic growth.

4.4. Variance Decomposition

Tables 6-8 present variance decomposition results for CO_2 emissions, energy consumption and economic growth, respectively. Table 6 illustrates that in the 10th year, one standard deviation shock in energy consumption, economic growth, trade openness and urbanization, reveals 8.10%, 6.97%, 11.45% and 4.61% of the forecast error variance of CO_2 emissions, respectively. A greater percentage of 68.88 of variation in economic growth becomes self-explanatory after 10 periods.

The variance decomposition approach findings in Table 7 posit that a 62.09% portion of energy consumption is contributed by its own innovative shocks. A one standard deviation shock in CO_2 emission explains energy consumption by 13.06% while economic growth, trade openness and urbanization support energy consumption by 9.08%, 12.09% and 3.68%, respectively.

Table 3: Selection order criteria

Lag	LogL	LR	FPE	AIC	SC	HQ
0	402.7047	NA	1.59e-15	−19.88523	−19.6741	−19.80890
1	724.3525	546.8014	5.82e-22	−34.71763	−33.4509	−34.25964*
2	756.1016	46.03614*	4.42e-22*	−35.05508*	−32.7329*	−34.21544
3	771.8888	18.94460	8.24e-22	−34.59444	−31.2167	−33.37315

Source: Own calculation. *indicates lag order selected by the criterion. LR: Sequential modified LR test statistic (each test at 5%), FPE: Final prediction error, AIC: Akaike information criterion, SC: Schwarz information criterion, HQ: Hannan-Quinn information criterion

Table 4: Johansen co-integration

H_1: Alternative hypothesis	H_0: Null hypothesis	λ_{max} test	λ_{max} test (0.95)	Trace test	Trace test (0.95)
R=1	R=0	36.135	33.877	79.054	69.819
R=2	R≤1	16.262	27.584	42.919	47.856
R=3	R≤2	12.232	21.132	26.658	29.979
R=4	R≤3	9.661	14.256	14.425	15.495
R=5	R≤4	4.764	3.841	4.764	3.841

Source: Own calculation

Table 5: VECM

Dependent variable	Types of causality					
	Short run					Long run
	∑Δ*LGDP*	∑Δ*LENC*	∑Δ*LCO*$_2$	∑Δ*LTO*	∑Δ*LUBN*	ECT_{t-1}
Δ*LGDP*	…….	0.3189	0.1391	0.1027	1.0345	−0.005*
Δ*LENC*	0.0086	……….	0.1464	0.1783	0.3882	−0.066*
Δ*LCO*$_2$	0.6474	0.1554	………….	0.2462	1.8034	0.170*
Δ*LTO*	2.5025	1.5289	0.6362	……….	0.8510	0.003
Δ*LUBN*	0.3142	0.6291	0.3651	0.1978	……….	−0.106

Source: Own calculation. CO_2: Carbon dioxide, GDP: Gross domestic product, ECT: Error correction term, VECM: Vector error correction model. *Represent 1% significance level, respectively

Table 8 illustrate the results of variance decomposition of economic growth. The results exhibit that only 3.83% of the variation in economic growth is self-explanatory, while CO_2 emissions accounted for a larger forecast error variance. CO_2 emission explain 78.60% of the forecast error variance after 10 periods. The other variables account for the remaining percentages: Energy consumption (7.27%), trade openness (3.00%), and urbanization (7.30%).

5. CONCLUSION

The study analyses the relationship between energy consumption, economic growth and CO_2 emissions by incorporating trade openness and urbanization as the control variables to form a multivariate framework. The Johansen co-integration technique and the VECM were used to estimate the long run relationship and the direction of causality among the variables. The findings of the Johansen co-integration test demonstrate an existence of one co-integrating equation. This shows that there is a long run relationship between energy consumption, economic growth, CO_2 emission, trade openness and urbanization in South Africa.

The VECM results detect bidirectional causality flowing between energy consumption and economic growth. This shows that an energy-led growth hypothesis exists in South Africa. The results further proved existence of a one-way causality flowing from CO_2 emissions, trade openness and urbanization to economic growth and energy consumption. The findings of the variance decomposition analysis show that the share of energy consumption in explaining economic growth is minimal.

The results of this study indicate that policies aiming at reducing energy consumption and controlling for CO_2 emissions in South Africa could slow down growth. This implies that any energy conservation measures undertaken should consider the adverse impact on economic growth. South Africa has been found to be one of the highest CO_2 emitters in the world. It is therefore important that in finding ways of proving energy services, South Africa

Table 6: Variance decomposition of CO_2 emissions

Period	*SE*	*CO_2*	*EC*	*GDP*	*TO*	*UBN*
1	0.019628	100.0000	0.000000	0.000000	0.000000	0.000000
2	0.026562	91.89339	4.589901	2.555510	0.156643	0.804559
3	0.030665	85.57634	7.246649	3.083585	1.711180	2.382247
4	0.033072	81.11732	7.874258	2.950823	4.377137	3.680463
5	0.034440	77.54523	8.121085	2.866657	7.083195	4.383833
6	0.035192	74.98575	8.241193	2.966109	9.158480	4.648468
7	0.035647	73.16568	8.270247	3.379795	10.47951	4.704775
8	0.036017	71.67708	8.243090	4.221844	11.17391	4.684075
9	0.036394	70.26940	8.180441	5.471839	11.43646	4.641854
10	0.036795	68.87592	8.099492	6.966451	11.44830	4.609839

CO_2: Carbon dioxide, GDP: Gross domestic product

Table 7: Variance decomposition of energy consumption

Period	*SE*	*EC*	*CO_2*	*GDP*	*TO*	*UBN*
1	0.015500	77.83988	22.16012	0.000000	0.000000	0.000000
2	0.020594	82.72739	14.97301	1.759080	0.098657	0.441873
3	0.023183	78.77644	14.16628	2.991576	2.271403	1.794303
4	0.024914	74.54362	14.05594	3.103013	5.430711	2.866717
5	0.025942	71.44868	13.85322	3.219925	8.080770	3.397404
6	0.026544	69.00323	13.72646	3.641936	10.01734	3.611028
7	0.026959	67.00582	13.60893	4.468539	11.24390	3.672818
8	0.027317	65.26040	13.45389	5.732366	11.87785	3.675495
9	0.027673	63.62673	13.26384	7.340313	12.10238	3.666734
10	0.028034	62.09049	13.05784	9.086054	12.08886	3.676760

CO_2: Carbon dioxide, GDP: Gross domestic product

Table 8: Variance decomposition of economic growth

Period	*SE*	*GPD*	*EC*	*CO_2*	*TO*	*UBN*
1	0.009458	3.194818	12.13791	84.66727	0.000000	0.000000
2	0.014698	1.655402	9.026458	87.64497	0.526282	1.146883
3	0.018176	1.123524	8.384503	85.92335	1.553330	3.015294
4	0.020480	0.884926	8.298630	83.73153	2.353602	4.731316
5	0.022015	0.850080	8.192801	82.10033	2.838178	6.018612
6	0.023039	1.127241	8.004994	80.94399	3.083956	6.839818
7	0.023719	1.715172	7.777171	80.10167	3.148813	7.257179
8	0.024172	2.477627	7.560666	79.46727	3.103363	7.391073
9	0.024471	3.232140	7.389231	78.97630	3.031177	7.371148
10	0.024663	3.830934	7.274707	78.59727	2.998905	7.298182

CO_2: Carbon dioxide, GDP: Gross domestic product should pay attention to the environmental impact associated with different uses of energy. It is recommended that policy makers should advocate for renewable energy such as wind and solar to ensure sustainable growth of the economy.

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