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Does Renewable Energy Consumption Drive Economic Growth: Evidence from Granger-Causality Technique

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ABSTRACT

This study investigates the causal relationship between renewable energy consumption and economic growth in South Africa. It incorporates carbon dioxide emissions, capital formation and trade openness as additional variables to form a multivariate framework. Quarterly data is used for the period 1990–2014 and is tested for stationarity using the augmented dickey fuller, dickey fuller generalised least squares and Phillips and Perron unit root tests. The study employs the autoregressive distributed lag model to examine the long run relationship among the variables. Lastly, the study determines the direction of causality between the variables using the vector error correction model. The results validated an existence of a long run relationship between the variables. Moreover, a unidirectional causality flowing from renewable energy consumption to economic growth was established in the long run. The short run results suggested a unidirectional causality flowing from economic growth to renewable energy consumption. The findings of the study suggest that an appropriate and effective public policy is required in the long run, while considering sustainable economic growth and development.

Keywords: Renewable Energy Consumption, Economic Growth, Causality, South Africa
JEL Classifications: D04, Q47, Q42, Q01

1. INTRODUCTION

The exponential increase of energy consumption and the rapid growth of pollutant emissions is expected to have a noticeable effect in the global environment, such as, rising of global temperatures, erratic climate and weather extremes. All of these effects present increasing challenges for energy production and use and coming to play a growing role in the design of the future energy system and energy policies. South Africa, in particular has been warned of its contribution to greenhouse gas emissions in the world summit on Sustainable Development in 2002. But the country continued to commit to the project of building coal fired power stations (Medupi and Kusile). As a result, the greenhouse gas emissions are projected to increase to 36.7 billion metric tonnes in 2020.

South Africa's indigenous energy resource base is dominated by coal. Coal contributes close to 77% of South Africa's primary energy demand. Apart from being one of the highest carbon dioxide emitters, a coal produced electricity saw the country into a crisis in 2008. The country experienced a failure from the national grid and experienced high increases in electricity demand while there was not enough supply to sustain the demand. The 2008 electricity power outages led to firms shutting down due to breakage in their machinery and loss of production. The household consumers were forced to buy electricity at high prices. On this accord, it is important to analyse the relationship between energy consumption and economic growth in South Africa. The knowledge of the direction of causality between renewable energy consumption and economic growth is essential if energy policies which will support economic growth of the country are to be advised.

There are four hypotheses regarding the causal relationship between energy consumption and economic growth: Growth, conservation, feedback and neutrality. The growth hypothesis argues that energy consumption is a major factor in boosting economic growth and validates a unidirectional causality flowing from energy consumption to economic growth. This means that a fall in energy consumption will negatively affect economic growth. The conservation hypothesis argues that there is a one-way causality flowing from economic growth to energy consumption and this implies that a reduction in energy consumption will not affect economic growth unfavorably. The feedback hypothesis validates that energy consumption and economic growth Granger-cause each other, that is there is bidirectional causality running between energy consumption and economic growth. This implies that energy consumption supports economic growth and economic growth enhances energy consumption. The neutrality hypothesis contents that there is no causality flowing between economic growth and energy consumption. This means that a reduction in energy consumption has no adverse impact on economic growth.

The studies which were done in South Africa focused on energy consumption and economic growth (Okafor, 2012; Wolde-Rufael, 2009; Odhiambo, 2010; Khobai and Le Roux, 2017; Menyah and Wolde-Rufael, 2010). The only South African study that covered renewable energy consumption and economic growth was conducted by Apergis and Danuletiu (2014). Our study differs from Apergis and Danuletiu (2014) study in that we specifically focus on South Africa while Apergis and Danuletiu (2014) studied a panel of 80 countries in which South Africa was one of them. Our study also incorporated carbon dioxide emissions, trade openness and capital to avoid the problem of omitted variables bias.

The remainder of the paper is structured as follows: Section 2 presents the review of the empirical literature. Section 3 presents the model specification and the estimation technique followed by Section 4 which discusses the empirical analysis of the study's results. Section 5 concludes the study and provides policy recommendations.

2. LITERATURE REVIEW

The relationship between renewable energy consumption and economic growth can be classified under four testable hypotheses, namely; conservation, growth, feedback and neutrality. The conservation hypothesis requires a unidirectional causality flowing economic growth to energy consumption. This hypothesis implies that implementing energy conservation policies that curb energy consumption would not adversely affect economic growth. The growth hypothesis requires a unidirectional causality running from energy consumption to economic growth. This hypothesis posits that energy consumption contributes to economic growth. The feedback hypothesis requires bidirectional causality flowing between energy consumption and economic growth. This implies that energy consumption depends on economic growth and economic growth also depends on energy consumption. The neutrality hypothesis requires no causality flowing between energy consumption and economic growth. This implies that energy consumption has a small effect or no effect at all on economic growth.

Many studies have been conducted on the causal relationship between economic growth and renewable energy consumption but have found mixed results (Apergis et al., 2013, Hassine and Harrathi, 2017; Mahmoodi, 2017; Burakov and Freidin, 2017; Sasana and Ghozali, 2017; Jebli et al., 2015; Jebli et al., 2016; Al-mulali et al., 2016). Amri (2017) examined the relationship between economic growth and energy consumption under two categories- renewable and non-renewable energy consumption. The findings from the autoregressive distributed lag (ARDL) model supported a long run relationship between economic growth and non-renewable energy consumption but no co-integration was found between renewable energy consumption and economic growth. The results posited bidirectional causality between non-renewable energy consumption and economic growth both in the short run and long run. Furthermore, the results revealed a unidirectional causality flowing from renewable energy consumption to economic growth in the long run.

Apergis et al. (2013) served to investigate the long run relationship between hydroelectricity consumption and economic growth for the 10 largest hydroelectricity consuming countries (Brazil, Canada, China, France, India, Japan, Norway, Sweden, Turkey and the USA). The study used annual data for the period 1965 to 2012. The results from the Bai and Perron (2003) tests of co-integration suggested an existence of a long run relationship between economic growth and hydroelectricity consumption. The results from a nonlinear panel smooth transition vector error correction model (VECM) were divided based on the three structural breaks, 1988, 2000 and 2009. A one-way causality from economic growth to hydroelectricity consumption was established in the long run and short for the period before 1988. For the period after 1988, a feedback hypothesis was realised between economic growth and hydroelectricity consumption in the long run and short run.

Omri et al. (2015) examined the causal link between energy consumption (nuclear energy and renewable energy) and economic growth for 17 developed and developing countries covering the period between 1991 and 2011. Mixed results were found for nuclear energy and renewable energy. Commencing with nuclear energy, their findings validated a one-way causality flowing from nuclear energy consumption to economic growth in Spain and Belgium, a unidirectional causality flowing from economic growth to nuclear energy consumption was established in Sweden, Netherlands, Canada and Bulgaria and bidirectional causality between nuclear energy and economic growth was found for Argentina, Brazil, France, Pakistan, and the USA. No causality was established for Finland, Hungary, India, Japan, Switzerland and the UK. The results for renewable energy and economic growth suggested a unidirectional causality from renewable energy consumption to economic growth in Hungary, India, Japan, Netherlands, and Sweden. A unidirectional causality from economic growth to renewable energy consumption was evident in Argentina, Spain and Switzerland whereas bidirectional causality was found for Belgium, Bulgaria, Canada, France, Pakistan and the USA. No causality was found for Brazil and Finland. A feedback hypothesis between nuclear energy consumption and economic growth was realised for the panel while a conservation hypothesis was established between renewable energy consumption and economic growth.

The study by Halkos and Tzemes (2014) investigated the link between electricity consumption from renewable sources and economic growth for 36 countries covering the period between 1990 and 2011. The study used a non-parametric methodological technique. The study analysed the entire sample of countries and then grouped the countries into sub-samples. The results for the entire sample of countries established that the relationship increases only up to a certain level of economic growth. A highly non-linear relationship was realised for emerging and developing countries while for developed countries, an increasing non-linear relationship was observed.

Sebri and Ben-Salha (2014) studied the relationship between economic growth, renewable energy consumption, carbon dioxide emissions and trade openness for the Brics countries. The study was taken over a period between 1970 and 2010 using the ARDL bounds testing approach and the VECM technique. The results suggested an existence of a long run relationship between economic growth, renewable energy consumption, carbon dioxide emission and trade openness. The VECM model results supported bidirectional causality flowing between renewable energy consumption and economic growth.

Apergis and Payne (2014) investigated the relationship between renewable energy consumption, output, carbon dioxide emissions and fossil fuel prices for seven Central America countries for the period between 1980 and 2010. The results affirmed a long run relationship between renewable energy consumption, output, carbon dioxide emissions, coal prices and oil prices. The results further showed that these variables are positively and significantly related.

Ohlers and Fetters (2014) purposed to determine the causal linkage between electricity generated from different forms of renewables for the 20 OECD countries covering the period between 1990 and 2008. Their findings from the Pedroni panel co-integration test confirmed that electricity generated from the renewables and economic growth have a long run relationship. Furthermore, they established a feedback hypothesis between economic growth and hydroelectricity in the short run.

Zirimba (2013) aimed to determine the relationship between economic growth and hydroelectricity consumption for Algeria, Egypt and South Africa for the period 1980–2009. The findings from the Toda and Yamamoto technique suggested a feedback link between hydroelectricity consumption and economic growth in Algeria. Moreover, it was established that economic growth Granger-causes hydroelectricity in South Africa while no causality was observed for Egypt.

Apergis and Payne (2012) investigated the linkage between renewable energy consumption, non-renewable energy consumption and economic growth for 80 countries for the period 1990–2007. The study employed the Pedroni heterogeneous panel co-integration test and panel error correction model. Their findings confirmed an existence of a long run relationship between economic growth, renewable energy consumption and non-renewable energy consumption, capital formation and labor. The results further supported a feedback link between renewable energy consumption and non-renewable energy consumption and economic growth in the long run and short run.

Tugcu et al. (2012) explored the long run and causal relationship between renewable and non-renewable energy consumption and economic growth for G7 countries covering the period between 1980 and 2009. The ARDL bounds testing approach and the causality test by Hatemi-J (2012) were used to determine the long run relationship and direction of causality among the variables, respectively. The findings showed that either renewable energy consumption or non-renewable energy consumption have an impact on economic growth. The Causality results established that when the production function was augmented the results differ across the countries but in the case of a classical production function, all countries bear a feedback linkage between the variables.

Apergis and Payne (2011) studied the link between renewable energy consumption and economic growth in six Central American countries covering the period from 1980 to 2016. The study employed the heterogeneous panel co-integration model and panel error correction model. Their findings confirmed an existence of co-integration between economic growth, renewable energy consumption, labor force and gross fixed capital formation. Furthermore, it was observed that there is a feedback relationship between renewable energy consumption and economic growth both in the long run and short run.

From the literature above, it can be realised that no study was done in South Africa to investigate the long run relationship and causal relationship between renewable energy consumption and economic growth using the ARDL bounds test and the VECM. Therefore, this study serves to fill the gap.

3. METHODOLOGY

3.1. Model Specification

This study investigates the causal relationship between renewable energy consumption and economic growth in South Africa for the period 1990-2014. To address the issue of omitted variables bias, the study incorporated trade openness, carbon dioxide emissions and capital formation as the additional variables to form a multivariate framework. All the variables were converted into logarithm form to avoid heteroskedasticity. The log linear quadratic form is employed to analyse the relationship between renewable energy consumption, economic growth, trade openness, carbon dioxide emissions and capital formation. The economic growth model is specified as follows:

$$LGDP_t = \alpha_1 + \alpha_{RE} LRE_t + \alpha_{TR} LTR_t + \alpha_{CO2} LCO2_t + \alpha_K LK_t + \varepsilon_t \quad (1)$$

LGDP represents the natural log of gross domestic product measured in millions of 2010 constant US dollars. LRE is the natural log of renewable energy consumption measured in million kilowatt-hours. LTR indicates the natural log of trade openness measured as the sum of exports and imports. LCO_2 denotes the natural log of carbon dioxide emissions measured in metric tones. LK represents the natural log of capital formation.

3.2. Data Sources

The study uses quarterly time-series data for the period between 1990 and 2014 for renewable energy consumption, economic growth, carbon dioxide emissions, trade openness and capital. Data for the mentioned variables was gathered from different sources. Gross domestic product (using constant prices of 2010) was sourced from the South African Reserve Bank. The data for renewable energy consumption and carbon dioxide emissions were sourced from International Energy Agency. The data for trade openness was collected from United Nations and Trade Development. Finally, the World Development Indicators was used to gather the capital formation data.

3.3. Data Analysis

3.3.1. Unit root test

The regression of two or more non-stationary variables results in spurious regression. Therefore, to avoid the problem of spurious regression, the characteristics of the time series data utilised for the estimation of the model will be examined. This study uses three unit root tests; Augmented Dickey Fuller (ADF) unit root test by Said and Dickey (1984), Phillips-Perron (PP) unit root test by Phillips and Perron (1988) and the Dickey Fuller Generalised Least Squares (DF-GLS) test proposed by Elliot et al. (1996). The ADF and the Phillips-Perron tests have been criticised for their low power when variables are stationary but with a root close to non-stationary boundary (Brooks, 2014). Elliot et al. (1996) argue that the DF-GLS test has more power in the presence of an unknown mean or trend compared to the ADF and the Phillips-Perron tests. The null of a unit root is tested against the alternative of stationarity in all tests.

3.3.2. Co-integration test

This study uses the ARDL bounds testing procedure to investigate the long run relationship between renewable energy consumption, economic growth, trade openness, carbon dioxide emissions and capital formation in South Africa. The ARDL bounds approach was originally introduced by Pesaran and Shin (1999) and extended by Pesaran et al. (2001). The ARDL technique was chosen over the conventional models such as Engle and Granger (1987) and Johansen (1988) for the research for the following reasons: Firstly, the ARDL technique uses a single reduced form of equation to examine the long term relationship of the variables as opposed to the conventional Johansen test that employs a system of equations. Secondly, it is suitable to use for testing co-integration when a small sample data is used. Thirdly, it does not require the underlying variables to be integrated of similar order e.g. integrated of order zero *I*(0), integrated of order one *I*(1) or fractionally integrated, for it to be applicable. Lastly, it does not rely on the properties of unit root datasets and this makes it possible for the Granger-causality to be applied in testing the long term relationships between the variables.

The ARDL models employed in this study can be formulated as follows:

$$\Delta LGDP_t = \alpha_1 + \alpha_T T + \alpha_{GDP} LGDP_{t-1} + \alpha_{RE} LRE_{t-1} + \alpha_{CO2} LCO2_{t-1} + \alpha_K LK_{t-1} + \alpha_{TR} LnTR_{t-1} + \sum_{i=1}^{p} \alpha_i \Delta LGDP_{t-i} + \sum_{j=0}^{q} \alpha_j \Delta LRE_{t-j} + \sum_{k=0}^{r} \alpha_k \Delta LCO2_{t-k} + \sum_{m=0}^{t} \alpha_m \Delta LK_{t-m} + \sum_{n=0}^{u} \alpha_n \Delta LTR_{t-n} + \varepsilon_{1t} \quad (2)$$

$$\Delta LRE_t = \alpha_1 + \alpha_T T + \alpha_{RE} LRE_{t-1} + \alpha_{GDP} LGDP_{t-1} + \alpha_{CO2} LCO2_{t-1} + \alpha_K LK_{t-1} + \alpha_{TR} LnTR_{t-1} + \sum_{i=1}^{p} \alpha_i \Delta LGDP_{t-i} + \sum_{j=0}^{q} \alpha_j \Delta LRE_{t-j} + \sum_{k=0}^{r} \alpha_k \Delta LCO2_{t-k} + \sum_{m=0}^{t} \alpha_m \Delta LK_{t-m} + \sum_{n=0}^{u} \alpha_n \Delta LTR_{t-n} + \varepsilon_{2t} \quad (3)$$

$$\Delta LCO2_t = \alpha_1 + \alpha_T T + \alpha_{GDP} LGDP_{t-1} + \alpha_{RE} LRE_{t-1} + \alpha_{CO2} LCO2_{t-1} + \alpha_K LK_{t-1} + \alpha_{TR} LnTR_{t-1} + \sum_{i=1}^{p} \alpha_i \Delta LGDP_{t-i} + \sum_{j=0}^{q} \alpha_j \Delta LRE_{t-j} + \sum_{k=0}^{r} \alpha_k \Delta LCO2_{t-k} + \sum_{m=0}^{t} \alpha_m \Delta LK_{t-m} + \sum_{n=0}^{u} \alpha_n \Delta LTR_{t-n} + \varepsilon_{3t} \quad (4)$$

$$\Delta LTR_t = \alpha_1 + \alpha_T T + \alpha_{GDP} LGDP_{t-1} + \alpha_{RE} LRE_{t-1} + \alpha_{CO2} LCO2_{t-1} + \alpha_K LK_{t-1} + \alpha_{TR} LnTR_{t-1} + \sum_{i=1}^{p} \alpha_i \Delta LGDP_{t-i} + \sum_{j=0}^{q} \alpha_j \Delta LRE_{t-j} + \sum_{k=0}^{r} \alpha_k \Delta LCO2_{t-k} + \sum_{m=0}^{t} \alpha_m \Delta LK_{t-m} + \sum_{n=0}^{u} \alpha_n \Delta LTR_{t-n} + \varepsilon_{4t} \quad (5)$$

$$\Delta LK_t = \alpha_1 + \alpha_T T + \alpha_{GDP} LGDP_{t-1} + \alpha_{RE} LRE_{t-1} + \alpha_{CO2} LCO2_{t-1} + \alpha_K LK_{t-1} + \alpha_{TR} LnTR_{t-1} + \sum_{i=1}^{p} \alpha_i \Delta LGDP_{t-i} + \sum_{j=0}^{q} \alpha_j \Delta LRE_{t-j} + \sum_{k=0}^{r} \alpha_k \Delta LCO2_{t-k} + \sum_{m=0}^{t} \alpha_m \Delta LK_{t-m} + \sum_{n=0}^{u} \alpha_n \Delta LTR_{t-n} + \varepsilon_{5t} \quad (6)$$

$LGDP_t$ is the natural logarithm of Gross Domestic Product. LRE_t is the natural logarithm of renewable energy consumption. LCO_{2t} is the natural logarithm of carbon dioxide emissions. LTR_t is the natural logarithm of trade openness. LK_t is the natural logarithm of capital formation. T represents the time period while Δ represents the first difference operator. It is assumed that the residuals ($\varepsilon_{1t,}$ $\varepsilon_{2t,}$ $\varepsilon_{3t,}$ $\varepsilon_{4t,}$ $\varepsilon_{5t,}$) are normally distributed and white noise.

The bounds testing procedure is based on the joint F-statistics (or Wald test) to determine existence of co-integration among the variables. The null hypothesis of the non-existence of cointegration for equations 2-6 are as follows; H_0: $\alpha_{GDP} = \alpha_{RE} = \alpha_{CO2} = \alpha_{TR} = \alpha_K = 0$ tested against the alternative hypothesis H_1: $\alpha_{GDP} \neq \alpha_{RE} \neq \alpha_{CO2} \neq \alpha_{TR} \neq \alpha_K \neq 0$. The two sets of critical values for a given significance level are reported by Pesaran and Pesaran (1997) and Pesaran et al. (2001). The one assumes that all the variables incorporated in the ARDL model are *I*(0) and the other one assumes that the variables are *I*(1). If the calculated F-statistics exceeds the upper critical bound value, then the H_0 is rejected and the results conclude in favor of co-integration. If the F-statistics falls below the lower critical bound value, H_0 cannot be rejected. If the F-statistics falls within the two bounds, then the co-integration test becomes inconclusive.

3.2.3. Granger-causality

The existence of a long run relationship between the variables does not show which variable causes the other. As a result, the Granger-causality is applied to find the direction of causality among the variables. Granger-causality works in a way that, a time series X_t causes another time series Y_t, if Y_t can be predicted better utilising the past values of X_t than by not doing so. This means that if the past values of X_t significantly contribute to forecasting Y_t, then it implies that X_t Granger-causes Y_t. Causality from Y_t to X_t can be explained in the same way. The VECM is used to determine the long run and short run relationship between the variables and can detect sources of causation. The VECM is moulded by Eq. (7) – Eq.(11). In each equation, the dependent variable is explained by itself, the independent variables and the error correction term

$$\Delta LGDP_t = \alpha_{10} + \sum_{i=1}^{q}\alpha_{11}\Delta LGDP_{t-i} + \sum_{i=1}^{r}\alpha_{12}\Delta LRE_{t-i} + \sum_{i=1}^{s}\alpha_{13}\Delta LCO2_{t-i} + \sum_{i-1}^{t}\alpha_{14}\Delta LTR_{t-i} + \sum_{i-1}^{u}\alpha_{15}\Delta LK_{t-i} + \psi_1 ECT_{t-1} + \varepsilon_{1t} \quad (7)$$

$$\Delta LRE_t = \alpha_{20} + \sum_{i=1}^{q}\alpha_{21}\Delta LRE_{t-i} + \sum_{i=1}^{r}\alpha_{22}\Delta LCO2_{t-i} + \sum_{i=1}^{s}\alpha_{23}\Delta LGDP_{t-i} + \sum_{i-1}^{t}\alpha_{24}\Delta LTR_{t-i} + \sum_{i-1}^{u}\alpha_{25}\Delta LK_{t-i} + \psi_2 ECT_{t-1} + \varepsilon_{2t} \quad (8)$$

$$\Delta LCO2_t = \alpha_{30} + \sum_{i=1}^{q}\alpha_{31}\Delta LCO2_{t-i} + \sum_{i=1}^{r}\alpha_{32}\Delta LRE_{t-i} + \sum_{i=1}^{s}\alpha_{33}\Delta LGDP_{t-i} + \sum_{i-1}^{t}\alpha_{34}\Delta LTR_{t-i} + \sum_{i-1}^{u}\alpha_{35}\Delta LK_{t-i} + \psi_3 ECT_{t-1} + \varepsilon_{3t} \quad (9)$$

$$\Delta LTR_t = \alpha_{40} + \sum_{i=1}^{q}\alpha_{41}\Delta LTR_{t-i} + \sum_{i=1}^{r}\alpha_{42}\Delta LRE_{t-i} + \sum_{i=1}^{s}\alpha_{43}\Delta LCO2_{t-i} + \sum_{i-1}^{t}\alpha_{44}\Delta LGDP_{t-i} + \sum_{i-1}^{u}\alpha_{45}\Delta LK_{t-i} + \psi_5 ECT_{t-1} + \varepsilon_{4t} \quad (10)$$

$$\Delta LK_t = \alpha_{50} + \sum_{i=1}^{q}\alpha_{51}\Delta LK_{t-i} + \sum_{i=1}^{r}\alpha_{52}\Delta LRE_{t-i} + \sum_{i=1}^{s}\alpha_{53}\Delta LCO2_{t-i} + \sum_{i-1}^{t}\alpha_{54}\Delta LGDP_{t-i} + \sum_{i-1}^{u}\alpha_{55}\Delta LTR_{t-i} + \psi_5 ECT_{t-1} + \varepsilon_{5t} \quad (11)$$

Δ denotes the difference operator, α_{it} is the constant term and ECT represents the error correction term derived from the long run cointegrating relationships. The t-statistics is employed to test the significance of the speed of adjustment in ECT terms. The statistical significance of ECT_{t-1} with a negative sign validates the existence of a long run causality flowing among the variables.

To investigate the short run causality, the Wald test is applied on differenced and lagged differenced terms of the independent variables.

4. FINDINGS OF THE STUDY

4.1. Unit Root Tests

The study conducted the unit root test to check the level of stationarity using ADF test, Phillips and Perron and DF-GLS unit root tests. The results of these tests are reported in Table 1. Table 1 shows that economic growth, renewable energy consumption, trade openness, carbon dioxide emissions and capital formation are non-stationary at levels. After taking the first difference, all the variables show the same level of integration. This implies that all the series are stationary at *I*(1).

4.2. Co-integration

The unique order of integration shows that the cointegration tests can be investigated. But it is necessary to first find the maximum lag length. The results for the selection order criteria are illustrated in Table 2. Table 2 shows that the optimal lag length of p*=2 is chosen.

The results for the ARDL bounds test are disclosed in Table 3. Table 3 shows that there is an existence of a long run relationship between economic growth, renewable energy consumption, trade openness, carbon dioxide emissions and capital formation in South Africa. This is on account that when economic growth, carbon dioxide emissions, trade openness, and capital formation are used as the dependent variables, their F-statistics exceed the upper critical values at 5% level of significance. These results are consistent to the findings of Sebri and Ben-Salha (2014), Apergis and Payne (2014) and Apergis and Payne (2012).

After confirming the existence of a long run relationship among the variables, the study estimates the long run effect of renewable energy consumption, trade openness, carbon dioxide emissions and capital formation on economic growth. The long run estimations are conducted using the ARDL method. The results are presented in Table 4. All the estimated coefficients suggested correct signs as expected but not all are significant at 5% level of significance. The results show that renewable energy consumption contributes positively to economic growth and this relationship is significant at 5% level of significance. All else held constant, a 1% increase in renewable energy consumption increases economic growth by approximately 1.37%. Furthermore, it was established that carbon dioxide negatively affects economic growth and it is significant

Table 1: Unit root tests

Variable	Levels			First difference		
	ADF	PP	DF-GLS	ADF	PP	DF-GLS
LGDP	0.898	0.667	−0.619	−3.057**	−2.958**	−2.518**
LRE	−2.582	−2.582	0.331	−2.901***	2.901***	−2.735*
LTR	−1.252	−1.260	−0.159	−4.202*	−4.208*	−4.088*
LCO_2	−1.991	−2.046	−2.031	−4.876*	−4.923*	−4.982*
LK	−2.776	−2.792	−2.015	−3.443***	−3.390***	−2.952***

ADF: Augmented dickey fuller, PP: Phillips-Perron, DF-GLS: Dickey Fuller Generalised Least Squares

Table 2: Selection order criteria

Lag	LogL	LR	FPE	AIC	SC	HQ
0	1126.803	N/A	2.96e−17	−23.86816	−23.73288	−23.81351
1	2164.316	1942.577	1.31e−26	−45.41099	−44.59930	−45.08312
2	2271.641*	189.5313*	2.28e−278*	−47.16258*	−45.67448*	−46.56150*
3	2282.346	17.76476	3.12e−27	−46.58542	−44.69391	−45.98412
4	2286.479	6.419597	4.97e−27	46.41444	−43.57353	−45.26692

Source: Own calculation

at 5% level of significance. The relationship is such that a 1%% increase in carbon dioxide emissions leads a fall in economic growth by 0.09% ceteris paribus. The results also showed that trade openness and capital formation have a positive effect on economic growth but are not significant at 5% level of significance.

The short run estimations are illustrated in Table 5. The coefficient on the lagged error correction term is significant with a negative sign. This confirms the existence of a stable long run relationship between the variables. This coefficient indicates that a deviation from the long run equilibrium level of output in one quarter is corrected by 43% over the following quarter. The elasticity of output with respect to renewable energy consumption, trade openness and capital formation are positive and significant at 5% level of significance. This implies that renewable energy consumption, trade openness and capital formation contribute to economic growth in the short run.

The results for the short-run diagnostic are reported in Table 6. The results suggest that the error terms of the short run models have no serial correlation, they are free of heteroskedasticity and are normally distributed. It established that the short run models are not spurious because the Durban-Watson statistics was found to be greater than the R^2. The Ramsey RESET test validated that the functional form of the model is well specified.

The stability of the long run parameters were estimated using the cumulative sum of recursive residuals. The results are shown in Figure 1. Our selected ARDL model is found to be stable. This is on account that the results fail to reject the null hypothesis at 5% level of significance because the plot of the tests fall within the critical limits.

4.3. Granger Causality

If a set of variables are found to have one or more co-integrating vectors, then a suitable estimation technique to determine the direction of causality is the VECM. This technique adjusts to both short changes in variables and deviations from equilibrium. The results of both the short run and long run causalities are illustrated in Table 7. The results in Table 7 present the coefficient of the lagged error term which is used to determine the existence of the long run causality between the variables. The coefficient of the lagged error term shows the speed of adjustment of the endogenous variables to explanatory variables and determines the long run causality.

Table 7 reported that the sign of ECT (−0.07) coefficient is significant and negative, in line with the a priori expectation. This validates that there is a long run causality flowing from renewable energy consumption, carbon dioxide emissions, trade openness and capital formation to economic growth. The long run results further suggested a long run causality flowing from economic

Table 3: ARDL Co-Integration Test

Critical value bound of the F-statistic						
K	90% level		95% level		99% level	
	I (0)	I (1)	I (0)	I (1)	I (0)	I (1)
3	2.022	3.112	2.459	3.625	3.372	4.797
4	1.919	3.016	2.282	3.340	3.061	4.486
Calculated F-statistics						
F_{GDP} (GDP/RE, TR, CO2, K) =3.81						
F_{RE} (RE/GDP, TR, CO2, K) = 3.06						
F_{CO2}(CO2/GDP, RE, TR, K) = 3.72						
F_{TR} (TR/GDP, RE, CO2, K) = 4.31						
F_K (INV/GDP, RE, CO2, TR) = 4.16						

Source: Own calculation. The critical bound values were taken from Narayan and Smyth (2005: 470). ARDL: Autoregressive distributed lag

Table 4: Long run results

Dependent variable=LGDP				
Long term results				
Variable	Coefficients	Standard error	T-statistics	P
C	1.470	1.232	1.194	0.236
RE	1.372	0.341	4.012	0.000
CO2	−0.091	0.205	−0.446	0.007
TR	0.014	0.181	0.079	0.937
K	0.197	0.179	1.102	0.237
R^2	0.999			
D.W test	2.06			

Source: Own calculations

Table 5: Short run analysis

Variable	Coefficient	Standard error	T-statistics
Constant			
LREC	0.919*	0.159	5.980
LTR	0.140*	0.016	8.746
LK	0.071*	0.020	3.671
ECM_{t-1}	−0.438*	0.009	−4.921
R^2	0.86		
D.W test	2.06		

*represent 1%, significance level

Source: Own calculation

Table 6: Short-run diagnostics

Short run diagnostics		
Test	F-statistics	P
Normality	117	0.165
Heteroskedasticity	1.127	0.352
Serial correlation	0.605	0.548

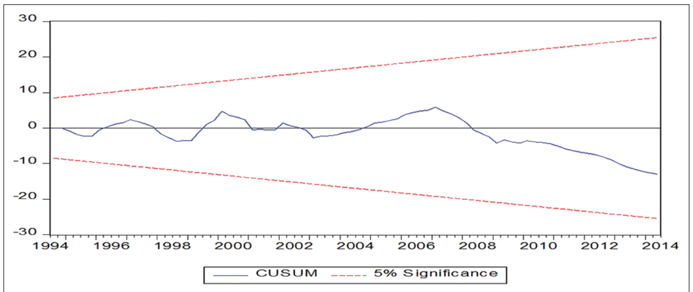
Source: Own calculation

Table 7: VECM

Dependent variable	Types of causality					
	Short run					Long run
	$\sum\Delta LGDP$	$\sum\Delta IRE$	$\sum\Delta ICO_2$	$\sum\Delta ITR$	$\sum\Delta IK$	ECT_{t-1}
ΔLGDP	-	0.013	0.045	0.134	0.087	−0.07*
ΔIRE	0.240*	-	0.075	0.236	0.088	−0.001
ΔICO_2	2.099	0.040	-	0.425	0.334	−0.118*
ΔITR	0.980	0.037*	0.080*	-	0.479	−0.062
ΔIK	0.460	0.078	0.052	0.334	-	−0.037

Source: Own calculation, VECM: Vector error correction model

Figure 1: Cumulative sum of recursive residuals



growth, renewable energy consumption, trade openness and capital formation to carbon dioxide emissions. This is because the coefficient of the lagged error term (−0.118) was found to be negative and significant. The existence of a long run causality flowing from renewable energy consumption to economic growth suggest that the energy policies such as energy conservation cannot be applied in the long run as this will have adverse effect economic growth. It agrees with the studies conducted by Omri et al. (2015) for Hungary, India, Japan, Netherlands, and Sweden.

Furthermore, the findings confirmed a short run causality flowing carbon dioxide and renewable energy consumption to trade openness and from economic growth to renewable energy consumption. The existence of a short run causality flowing from economic growth to renewable energy consumption in the short run imply that environmentally friendly policies like energy conservation, the demand-side management policies and efficiency improvement measures, can be implemented without adversely affecting economic growth.

5. CONCLUSION

The study focuses on the causal relationship between renewable energy consumption and economic growth in South Africa for the period between 1990 and 2014 using quarterly data. The study employs the ARDL model to explore the long run relationship among the variables and the VECM to determine the direction of causality between the variables. The results confirm that all the variables are co-integrated. Furthermore, the results suggest a growth hypothesis in the long run and a conservation hypothesis in the short run.

These results have important implications for South Africa for managing the objectives of energy conservation policies that lead to increase in economic growth in the short run and the long run energy-growth reforms. In particular, based upon the empirical findings, the following policy implications can be drawn: A unidirectional causality flowing from economic growth to renewable energy consumption means that in the short run, energy conservation policies may not harm the economic growth. But a unidirectional causality flowing from renewable energy consumption to economic growth found in the long run suggests that South Africa is energy dependent in the long run. As a result, renewable energy consumption leads to economic growth in the long run.

The results of the study motivate that the policies should be focused on increasing energy efficiency and increasing the share of green energy from their total energy use. It further recommends that energy conservation policies should only be applied in the short run to curb unnecessary waste of energy.

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