# Asymmetric Effects of Renewable Energy Consumption, Trade Openness and Economic Growth on Environmental Quality in Nigeria and South Africa

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# Asymmetric Effects of Renewable Energy Consumption, Trade Openness and Economic Growth on Environmental Quality in Nigeria and South Africa

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## Abstract

The study investigates the asymmetric effects of renewable energy consumption (REC), trade openness (TOP) and GDP per capita (GDP) on environmental quality in Nigeria and South Africa using the Non-linear Autoregressive Distributed Lag (NARDL) model from 1990Q1-2014Q4. To ensure this, the Zivot-Andrews unit root test and nonlinear ARDL cointegration tests are employed. The empirical results based on the NARDL found that REC, TOP and GDP have asymmetric effects on environmental quality in Nigeria and South Africa in the long-run and the short-run dynamics. Specifically, the long-run effect of a negative change in REC and GDP is stronger than that of a positive change of the same magnitude. Similarly, the effect of a positive change in TOP is stronger than the negative change. The results of the short run for Nigeria indicates that the effect of a negative change in REC and GDP is stronger than that of the positive change, while the effect of a positive change in TOP is stronger than its negative change. For South Africa, the positive change in REC and GDP is stronger than the negative change while for TOP the negative change is stronger than the positive change. The policy implications of the findings are carefully discussed in the text.

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**Keywords:** Renewable energy consumption; Trade openness; Economic Growth; Environmental quality; Asymmetric effects

**Jel Codes:** Q2; Q5; Q56

## 1. Introduction

The global consensus about energy security and environmental quality has created concerns about the overdependence on fossil fuels, which is unsafe, exhaustible and non-renewable. Large consumption of energy from these non-renewable sources (oil, gas and coal) has been identified as the major source of environmental degradation through the emission of green house gases such as carbon dioxide. Several researches such as Apergis, Payne (2010), Menyyah & Wolde-Rafael, (2010); Stern, (2007); Adamantiades and Kessides (2009); DeCanio, (2009); Reddy and Assenza, (2009) have noted that unless serious actions are taken to reduce global warming, the world could face an environmental catastrophe in no distant time. To this effect, the Kyoto Protocol agreement 1997, the International Energy Agency (IEA) 2003 and 2009, the Doha agreement 2012 and the Paris agreement 2015 all emphasized the urgent need to limit global temperature increase by reducing carbon emissions. Consequently, many countries are making investments in renewable energy sources such as solar, wind, geo thermal and hydropower which have insignificant level of carbon content when compared to the conventional energy sources –

fossil fuels (Kannan & Marappan, 2011; Sambo, 2005). Similarly, the activities of environmental campaigners over the years have informed various governments and other institutions about the need to reduce fossil fuel consumption. These activists advocate for a shift from fossil fuel to renewable energy consumption in order to decrease carbon foot-print and mitigate climate change (Goshit et al., 2018; Ibeto et al., 2011; Parker and Blodgett, 2008). This is because, energy from renewable sources are clean, safe, inexhaustible and renewable. This most probably explains why investment in renewable energy all over the word is growing speedily and has assumed centre-stage in global energy investment. Rising from about US$22 billion in 2002 to about US$214 billion in 2013 (Agbongiarhuoyi, 2015) and US$286 billion in 2015, with countries like China and United States leading the way. Also, the contribution of renewable energy to total power generation in some biggest economies as at 2015 stood at 14% for the United States, 25.0% for China, 31.8% for Germany and 27.4% for the United Kingdom. For some countries, the contribution of renewable energy is above 50%. Iceland has achieved 100% of electricity production from renewable sources, Norway has 98.5%, Uruguay has 89.1. Brazil and Denmark have 75.0% and 69.2 % of their electricity from renewables respectively. In Nigeria and South Africa, the figure stood at 17.59% and 1.39% respectively (Word Development Indicators, 2018).

The choice of Nigeria and South Africa South Africa for this study is because; they are the two largest economies on the African continent with high level of energy endowment, which is the most internationally traded commodity. Nigeria is rich in energy resources and is currently the largest producer and exporter of petroleum and gas (Nnaji, Chukwu & Uzoma, 2017). The country is endowed with the world's tenth largest reserves of crude oil estimated to be approximately 36 billion barrels (about 4.896 tons of oil equivalents) Kalu, Mgbemena and Ekesiobi, 2017). While South Africa is the world's most carbon-intensive non-oil-producing developing country and as well, one of the 6 largest exporters of coal in the world (Hasson and Masih, 2017). Most of South Africa's liquid fuel requirements are imported in the form of crude oil. It has been listed as the largest emitter of Green-house gas (GHG) in Africa, emitting about 42 percent of the continent's GHG emissions. The country was ranked the seventh top emitter of GHG in the world and thirteenth emitter of fossil fuel $CO_2$ in 2008, emitting about 119 million metric tons of carbon from coal alone (See EIA, 2010). Despite the huge endowment in fossil energy (oil gas and coal) in these countries, the phenomenon of climate change has led to increased attention to alternative sources of energy that are renewable and environment-friendly (Alege *et al*. 2018). The climate change condition has worsened due to both human and industrial activities that have led to the increase in carbon dioxide ($CO_2$) emissions in the quest for economic development. According to IRENA (2016), one of the benefits of using energy from renewable sources rather than from non-renewables is that of global trade opportunities. The economic argument in support of global trade is that expanding trade from domestic markets to international market does not only increase market share of the trading countries but also introduces competition among the countries and improves efficiency in the utilization of scarce resources which leads to improvement in environmental quality (Shahbaz et al, 2013; Rafindadi, 2016; Hanif, 2017 and Hason & Masih, 2017).

On the contrary, environmental economists argue that the expansion of trade to international markets is associated with depletion of natural resources and can lead to increase in $CO_2$ emissions which ultimately deteriorate environmental quality (Baek & Choi, 2017; Zheng & Sheng, 2017; Halicioglu & Kentenci, 2015; Chaudhuri & Pfaff, 2002; Copeland & Taylor, 2001; Khalil & Inam, 2006). These findings however contradicts the findings of Shafik and Bandyopadhyay (1992) who noted that a country that is open to trade, will observe less pollution because higher levels of competition due to openness will results into investment in new efficient technologies that would lead to emission or pollution abatement.

Arising from the above therefore, the contribution of globalization, particularly trade openness, towards environmental quality ($CO_2$ emissions) has been a contentious and an important issue within the context of human induced climate change especially in the developing countries such as Nigeria and South Africa due to the composition of the traded commodities, which have varying emission intensities. Yet, there is paucity of country specific empirical investigations in this area in Nigeria and South Africa.

On the energy-environment nexus, there has been considerable attention in literature particularly on conventional energy sources (See Abraham, 2012; Pao & Fu, 2013; Kahia & Aissa, 2014; Al-Mulali, et al. 2015; Apergis and Ozturk, 2015; Bhattacharya, *et al.* 2016; Mesagan, *et al.* 2018; Katircioglu & Katircioglu, 2018). The results of these studies have produced mixed findings on the relationship between energy consumption and $CO_2$ emissions in the context of the conventional Environmental Kuznets Curve (EKC) hypothesis, which have contributed in keeping the problem unresolved. This is not strange given the obvious harmful effects of fossil fuels, which have been a significant part of total energy consumption (Ozatac, Gokmenoglu & Taspinar, 2017). More so, apart from the study of Riti and Shu (2016), most of the recent studies that focused specifically on renewable energy consumption dwelt more on its economic growth implications (see Alege *et al.* 2018, Kocak & Sarkgunesi, 2017, Armeanu et al. 2017, Thombs, 2017, Kocak & Sarkgunesi, 2017). These studies also did not account for the effect of trade openness, which according to Halicioglu and Kentenci (2015), Chaudhuri and Pfaff (2002); Copeland and Taylor (2001) and Khalil and Inam (2006) is a major determinant of environmental quality. Similarly, most of the studies that dwelt on the nexus between income and environment focused more on examining the EKC hypothesis (see Usman *et al,* 2019; Akbota and Baek, 2018; Shahbaz *et al.* 2013b; Rafindadi 2016, Shahbaz *et al*; Riti and Shu 2016) rather than on how positive and negative shocks in income affect the environment.

The objective of the study therefore, is to analyze the effect of renewable energy consumption, trade openness and economic growth on environmental quality in Nigeria and South Africa by moving out of the linear rut. The major contribution of this current study is the application of the Non-linear Autoregressive Distributed Lag (NARDL) model rather than the conventional Autoregressive Distributed Lag (ARDL) model to test the response of environmental quality to increase or decrease in renewable energy, trade openness and economic growth. None of the studies in this area used NARDL model, thereby assuming that, the relationship that exists among energy, trade, growth and environment related variables is symmetrical or linear (i.e. increases or decreases in energy, trade and growth variables have equal effect on environmental quality). This may not always be true. Similarly, the incorporation of renewable energy consumption rather than conventional energy use in the analysis of environmental quality is a departure from the existing literature especially in Africa. Another contribution of this study is the application of the structural breaks unit root tests developed by Zivot and Andrews (1992) and Clemente, Montanes and Reyes (1998) to test the unit root properties of the energy, trade, growth and environment related series. Unlike the conventional unit root tests such as Augmented Dickey Fuller (ADF), Philips Perron (PP) and KPSS tests, which do not account structural breaks in the series, Zivot-Andrews and Clemente Montanes Reyes unit root tests provide information about structural breaks points in the series. This circumvents the chances of obtaining spurious estimates.

The rest of the paper is presented as follows; section 2 focuses on the methodology which includes model specification, estimation techniques and data sources while the empirical results and conclusion and policy recommendations are presented in sections 3 and 4 respectively.

## 2. Methodology

### *2.1 Model specification*

The model for this study follows the framework in Aboagye (2017), Shahbaz et al (2015) and Naranpanawa (2011) in estimating the income – environmental degradation equation where $CO_2$ is used as a proxy for environmental quality. These studies augmented the income – environmental degradation equation with convention energy use. As a modification, this study incorporates renewable energy consumption (*REC*) and trade openness indicator (*TOP*) into the model in addition to the standard regressor of economic growth (*GDP*). All the variables are sourced from the World Bank Development Indicator (WDI) (2018). The functional form of the model with renewable energy consumption and trade openness indicators incorporated is expressed as;

$$CO_{2t} = f(REC, TOP, GDP) \tag{1}$$

To achieve harmony in the units of measurement of the variables and express the coefficients as elasticities, the linear specification of the stochastic model is converted into log-log specification. It is noted that log-log specification provides more appropriate and efficient results compared to linear-linear model. Therefore, the logarithmic form of the estimable model is specified as;

$$lnCO_{2t} = \alpha_0 + \alpha_1 \ln REC_t + \alpha_2 \ln TOP_t + \alpha_3 \ln GDP_t + \mu_t \tag{2}$$

Where $\alpha_0$ and $\mu_t$ are the constant term and white noise stochastic term respectively.

### 2.2 Asymmetric Autoregressive Distributed Lag (NARDL) Model

Under linear and symmetric ARDL, environmental quality ($CO_2$) response to the periods of increases in renewable energy consumption, trade openness and economic growth is no more than a mirror image of the periods of decreases in renewable energy consumption, trade openness and economic growth. To account for the impact of the two periods (increases and decreases) or positive and negative changes simultaneously, we employ the NARDL technique developed by Shin *et al*. (2009 and 2014). The NARDL model introduces nonlinearity by means of partial sum decompositions into the conventional ARDL model by Pesaran *et al.* (2001). Therefore, following Usman and Elsalih, (2018), the first step in the asymmetric cointegrating relationship under the NARDL specification method is to decompose the exogenous variables in Equation (2) into partial sum processes to account for the asymmetries in the relationship between renewable energy consumption, trade openness, economic growth and environmental quality; hence, our non-linear specification of Equation (2) is as follows;

$$\begin{aligned} lnCO_{2t} &= \alpha_0 + \alpha_1 lnREC_t^+ + \alpha_2 lnREC_t^- + \alpha_3 lnTOP_t^+ + \alpha_4 lnTOP_t^- \\ &\quad + \alpha_5 lnGDP_t^+ + \alpha_6 lnGDP_t^- + \mu_t \end{aligned} \tag{3}$$

where $lnREC_t^+$ and $lnREC_t^-$; $lnTOP_t^+$ and $lnTOP_t^-$; $lnGDP_t^+$ and $lnGDP_t^-$ are the partial sums of positive and negative changes in $lnREC_t$ , $lnTOP_t$ and $lnGDP_t$ defined as;

$$lnREC_t^+ = \sum_{i=1}^{t} \Delta lnREC_i^+ = \sum_{i=1}^{t} max(\Delta lnREC_i, 0),\ lnREC_t^- = \sum_{i=1}^{t} \Delta lnREC_i^- = \sum_{i=1}^{t} min(\Delta lnREC_i, 0) \tag{4}$$

$$lnTOP_t^+ = \sum_{i=1}^{t} \Delta lnTOP_i^+ = \sum_{i=1}^{t} max(\Delta lnTOP_i, 0),\ lnTOP_t^- = \sum_{i=1}^{t} \Delta lnTOP_i^- = \sum_{i=1}^{t} min(\Delta lnTOP_i, 0) \tag{5}$$

$$lnGDP_t^+ = \sum_{i=1}^{t} \Delta lnGDP_i^+ = \sum_{i=1}^{t} max(\Delta lnGDP_i, 0),\ lnGDP_t^- = \sum_{i=1}^{t} \Delta lnGDP_i^- = \sum_{i=1}^{t} min(\Delta lnGDP_i, 0) \tag{6}$$

Following Shin *et al* (2014), Equation (2) is transformed into unrestricted NARDL specification as follows:

$$\begin{aligned} \Delta lnCO_{2t} &= \alpha_0 + \alpha_1 lnCO_{2t-1} + \alpha_2 lnREC_{t-1}^+ + \alpha_3 lnREC_{t-1}^- + \alpha_4 \ln TOP_{t\text{-}1}^+ + \alpha_5 \ln TOP_{t\text{-}1}^- \\ &\quad + \alpha_6 \ln GDP_{t-1} + \alpha_7 GDP_{t-1}^2 + \sum_{i=0}^{p} \rho_1 \Delta lnCO_{2t\text{-}i} + \sum_{i=1}^{q} \rho_{2,i} \Delta lnREC_{t\text{-}i}^+ + \sum_{i=0}^{m} \rho_{3,i} \Delta lnREC_{t\text{-}i}^- \\ &\quad + \sum_{i=0}^{n} \rho_{4,i} \Delta \ln TOP_{t-i}^+ + \sum_{i=0}^{d} \rho_{5,i} \Delta \ln TOP_{t-i}^- + \sum_{i=0}^{w} \rho_{6,i} \Delta GDP_{t-i}^+ + \sum_{i=0}^{z} \rho_{7,i} \Delta GDP_{t-i}^- + \varepsilon_t \end{aligned} \tag{7}$$

Where all the variables remain as earlier defined, *p, q, m, n, d, w* and *z* are the lag order. The long-run impact of positive and negative changes in renewable energy consumption, trade openness and economic growth on environmental quality are equivalent of $\varphi_2 = \frac{-\alpha_2}{\alpha_1}$ and $\varphi_3 = \frac{-\alpha_3}{\alpha_1}$ for renewable energy consumption, $\varphi_4 = \frac{-\alpha_4}{\alpha_1}$ and $\varphi_5 = \frac{-\alpha_5}{\alpha_1}$ for trade openness and and $\varphi_5 = \frac{-\alpha_7}{\alpha_1}$ for economic growth respectively. Similarly, the short-run impact of positive and negative changes in renewable energy consumption, trade openness and economic growth on environmental quality is shown by $\sum_{i=0}^{q} \rho_{2,i}$ and $\sum_{i=0}^{m} \rho_{3,i}$ for renewable energy consumption, $\sum_{i=0}^{n} \rho_{4,i}$ and $\sum_{i=0}^{d} \rho_{5,i}$ for trade $\varphi_4 = \frac{-\alpha_6}{\alpha_1}$ openness, and $\sum_{i=0}^{w} \rho_{6,i}$ and $\sum_{i=0}^{z} \rho_{7,i}$ respectively.

### 2.3 Cumulative Dynamic Multiplier

Similarly, the short-run asymmetric impact can be obtained by deriving the cumulative dynamic multiplier of a unit change in $lnREC_t^+$ and $lnREC_t^-$ $lnTOP_t^+$ and $lnTOP_t^-$ as well as $\mathrm{lnGDP}_t^+$ and $\mathrm{lnGDP}_t^-$ as;

$$dm_g^+ = \sum_{j=1}^{g} \frac{\partial CO2_{t+j}}{\partial REC_{t-1}^+}, \quad dm_g^- = \sum_{j=1}^{g} \frac{\partial CO2_{t+j}}{\partial REC_{t-1}^-}, \quad g = 0, 1, 2, ... \tag{8}$$

Note that as $g \to \infty$, $dm_g^+ \to \varphi_2$, and $dm_g^- \to \varphi_3$,

$$dm_g^+ = \sum_{j=1}^{g} \frac{\partial CO2_{t+j}}{\partial TOP_{t-1}^+}, \quad dm_g^- = \sum_{j=1}^{g} \frac{\partial CO2_{t+j}}{\partial TOP_{t-1}^-}, \quad g = 0, 1, 2, ... \tag{9}$$

Note here that as $g \to \infty$, $dm_g^+ \to \varphi_4$, and $dm_g^- \to \varphi_5$

$$dm_g^+ = \sum_{j=1}^{g} \frac{\partial CO_{2t+j}}{\partial GDP_{t-1}^+}, \quad dm_g^- = \sum_{j=1}^{g} \frac{\partial CO_{2t+j}}{\partial GDP_{t-1}^-}, \quad g = 0, 1, 2, ... \tag{10}$$

Note here that as $g \to \infty$, $dm_g^+ \to \varphi_6$, and $dm_g^- \to \varphi_7$

## 2.4 Unit Root Tests with Structural Breaks

Prior to the estimation of the NARDL model, we checked for the stationarity properties of the series using Zivot-Andrews (1992)[1] and Clemente Montanes Reyes (1998)[2] unit root tests to avoid spurious estimates. The choice of these tests is based on the fact that conventional unit root tests such as Augmented Dickey-Fuller (ADF), Phillips–Perron (PP) and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) tend to provide spurious results due to their inadequacies to accommodate information about structural breaks in the series, which lowers their predictive powers. Baum (2004) also observed that empirical evidence on the order of integration of the variable by ADF, PP, DF-GLS and Ng-Perron is not reliable. Therefore, attempts have been made to develop test of unit root which accounts for the presence of structural breaks in the null of unit root hypothesis (Nilsson, 2009). In addition, the period for this study is characterized by major changes in the global landscape which can potentially have spillover effects on Nigeria and South Africa and can cause structural breaks hence, the choice of structural breaks unit root is most appropriate. While the Zivot Andrews test identifies a single unknown structural break, the Clemente Montanes Reyes test can identify two structural breaks. This, according to (Shahbaz *et al.* 2013a, b, c) makes the Clemente Montanes Reyes test more power than the Zivot-Andrews test.

For Zivot-Andrews test, the null hypothesis is that $H_0 : \theta = 0$ and the alternative hypothesis is that $H_1 : \theta < 0$. Therefore, the Zivot-Andrews unit root test for this study includes Model X – a model with break in intercept; Model Y – a model with break in trend and Model Z – a model with break in intercept and trend.

Model X: $$\Delta x_t = \alpha_0 + \alpha_1 + \lambda x_{t-1} + \phi DU_t + \sum_{j=1}^{k} \theta_j \Delta x_{t-j} + v_t \qquad (11)$$

Model Y: $$\Delta x_t = \delta_0 + \delta_1 + \lambda x_{t-1} + \Phi DT_t + \sum_{j=1}^{k} \theta_j D x_{t-j} + v_t \qquad (12)$$

Model Z: $$\Delta x_t = \varphi_0 + \varphi_1 + \lambda x_{t-1} + \phi DU_t + \Phi DT_t + \sum_{j=1}^{k} \theta_j D x_{t-j} + v_t \qquad (13)$$

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[1] Here after referred to as Zivot-Andrews

[2] Here after referred to as Clemente Montales Reyes

Following equations 11, 12 and 13, $DU_t$ is the dummy variable, indicating the mean shift that occurs at each possible breakpoint ($T_j^b$), while the corresponding mean shift is the trend variable, which is denoted by $DT_t$. $DU_t = 1$ if t $> T_j^b$, and 0 if otherwise. Similarly, $DT_t = t - T_j^b$ if t > $T_j^b$, and 0 if otherwise. Note that $T_j^b$ represents the possible break point in the series. The null hypothesis indeed states that $H_0 : \theta = 0$. This signifies that there is a unit root in the presence of a single breakpoint. Whereas, the alternative hypothesis is stated as $H_1 : \theta < 0$, indicating that in the presence of a single breakpoint, no unit root is found.

For Clemente Montanes Reyes test which is an extension of the Perron and Vogelsang (1992) statistic to the case of two changes in the mean, the hypothesis is that;

$$H_0 : y_t = y_{t-1} + \delta_1 DTB_{1t} + \delta_2 DTB_{2t} + \mu_t \tag{14}$$

$$H_1 : y_t = \mu + d_1 DU_{1t} + d_2 DTB_{2t} + e_t \tag{15}$$

Where $DTB_{1t}$ is a pulse variable equal to 1 if $t = TB_1 + 1$ and zero if otherwise; $DU_{it} = 1 \; if \; t > TB_i (i = 1, 2)$ and zero if otherwise; $TB_1$ and $TB_2$ are the two times when the mean is being modified.

### 2.5 Asymmetric Cointegration Test

To investigate the asymmetric long-run and short-run cointegration among the variables, Shin *et al.* (2014) proposed two operational tests, which include the bounds testing procedure of Pesaran *et al.* (2001) through a modified F-statistic ($F_{PSS}$) and the t-statistic ($t\text{-}_{BDM}$) proposed by Banerjee *et al.* (1998). The cointegration test is conducted using the level variables. If the computed statistic is greater than the upper bound critical value, the null hypothesis is rejected indicating the existence of a long-run relationship among variables.

## 3. Results and Discussions

### 3.1 Unit root tests

First, we began the estimation and analysis by conducting Zivot-Andrews unit root test and Clemente-Montanes-Reyes unit root tests to identify the unknown structural breaks in the series or variables and the results is presented on Table 1. The results of this test using only intercept as suggested by Balcilar, *et al.* (2013) is presented in Table 1. The results reveal the presence of structural break(s) in the variables, even though all the variables are integrated of order one for both countries.

**Table 1: Results of Zivot-Andrews Unit Root Test with Single Structural Break**

| | *At level* | | *At first difference* | |
|---|---|---|---|---|
| | *Statistic* | *Time Break* | *Statistic* | *Time Break* |
| **Nigeria** | | | | |
| *lnCO2* | -2.289(3) | 2004 | -4.537*(2) | 2001 |
| *REC* | -4.401(3) | 2003 | -6.609**(1) | 2000 |
| *TOP* | -4.396(4) | 2009 | -6.989**(2) | 1998 |
| *lnGDP* | -2.387(2) | 1996 | -5.227**(3) | 2005 |
| **South Africa** | | | | |
| *lnCO2* | -3.654(2) | 2003 | -5.854**(2) | 2003 |
| *REC* | -3.175(3) | 1999 | -6.273**(2) | 2003 |
| *TOP* | -3.899(3) | 2009 | -5.139**(2) | 2009 |
| *lnGDP* | -3.136(2) | 2004 | -5.764**(1) | 2009 |
| **Sig. Level** | **Critical Values** | | | |
| 1% | -4.80 | | | |
| 5% | -4.42 | | | |

*Note: Values in parentheses are the lag length of variables*

*** and * denotes rejection of null hypothesis,* $H_0 : \Phi = 0,$ *at 1% and 5% level respectively.*

**Table 2: Result of Clemente–Montanes-Reyes Unit Root with Two Structural Breaks**

| | *At level* | | | *At first difference* | | |
|---|---|---|---|---|---|---|
| | *Statistic* | *Time Break 1* | *Time Break 2* | *Statistic* | *Time Break 1* | *Time Break 2* |
| **Nigeria** | | | | | | |
| *lnCO2* | -3.716(3) | 1997 | 2001 | -5.565*(2) | 1997 | 2002 |
| *REC* | -2.266(4) | 1991 | 2002 | -6.087*(2) | 1992 | 2000 |
| *TOP* | -3.722(4) | 1997 | 2001 | -7.898*(3) | 2005 | 2007 |
| *lnGDP* | -3.808(3) | 2001 | 2005 | -5.684*(2) | 2000 | 2006 |
| **South Africa** | | | | | | |
| *lnCO2* | -5.265(2) | 1994 | 2004 | -6.180*(2) | 1990 | 2006 |
| *REC* | -5.033(3) | 1995 | 2000 | -5.890*(2) | 1991 | 1994 |
| *TOP* | -3.653(2) | 1997 | 2007 | -5.796*(2) | 2000 | 2006 |
| *lnGDP* | -3.767(4) | 2001 | 2006 | -6.269*(3) | 2001 | 2007 |
| **Sig. Level** | **Critical Values** | | | | | |
| 5% | -5.490 | | | | | |

*Note: Values in parentheses are the lag length of variables*
** denotes rejection of null hypothesis,* $H_0 : \Phi = 0,$ *at 5% level respectively.*

### 3.2 Asymmetry Test

Further to this analysis, we conducted the asymmetry test to investigate the long-run and short-run asymmetric properties of the variables under study and the result is presented on Table 3. The null hypothesis of the test is that the inclusion of partial sums of positive and negative changes in renewable energy, trade openness and economic growth, is not significant (i.e. no asymmetries), and the alternative is that the decomposition of the changes matters (i.e. there is asymmetries). The result of the Wald asymmetry test on Table 3 show that the null hypothesis of no asymmetry in the long-run coefficients ($\alpha_X^+ = \alpha_X^-$) is rejected for all the cases in Nigeria and South Africa, while for the short-run, the results show that the null hypothesis of no asymmetry in the short-run coefficients ($\rho_X^+ = \rho_X^-$) is rejected for GDP in Nigeria and TOP and GDP in South Africa respectively. These findings uphold the specification of the NARDL model in Equation 7. The results also reveal that variations in renewable energy consumption, trade openness and economic impose varying long-run equilibrium relationships on CO$_2$ emissions in real terms. This impact is captured by the patterns of the dynamic adjustment from initial equilibrium to the new equilibrium as shown in the cumulative dynamic multiplier on Figures 1 and 2 for Nigeria and South Africa respectively.

**Table 5: Results of the Asymmetry Wald Test**

| | Wald Statistic | | Is there Asymmetry? | |
|---|---|---|---|---|
| | Long-run | Short-run | Long-run | Short-run |
| **Nigeria** | | | | |
| *LnREC* | 8.843(0.005)*** | 8.333(0.006)*** | Yes | Yes |
| *LnTOP* | 39.00(0.000)*** | 3.665(0.063)* | Yes | Yes |
| *LnGDP* | 4.118(0.049)** | 0.061(0.807) | Yes | No |
| **South Africa** | | | | |
| *LnREC* | 5.232(0.030)** | 3.732(0.064)* | Yes | Yes |
| *LnTOP* | 5.719(0.024)** | 0.757(0.392) | Yes | No |
| *LnGDP* | 4.314(0.047)** | 0.432(0.517) | Yes | No |

Notes: ***, ** and * denote rejection of the null hypothesis at 1%, 5% and 10% significance level respectively. Values in parenthesis are the probabilities

### 3.3 Cointegration Test using Asymmetric Bounds Test

Since all the series are integrated of order and none is integrated of order two, we proceed to investigate the cointerating relationship using the asymmetric bounds tests and the results is presented on Table 4. The results show evidence of non-linear cointegration in the long-run and in the short-run using $F_{PSS}$ and $t_{BDM}$ respectively.

**Table 4: Asymmetric Bounds Test**

| | Statistic | Lower Bound | Upper Bound | Cointegration |
|---|---|---|---|---|
| **Nigeria** | | | | |
| $F_{PSS}$ *(non-linear)* | 3.8919* | 2.72 | 3.77 | Yes |
| $t_{BDM}$ *(non-linear)* | -4.4489* | -2.57 | -3.46 | Yes |
| **South Africa** | | | | |
| $F_{PSS}$ *(non-linear)* | 14.0836* | 2.72 | 3.77 | Yes |
| $t_{BDM}$ *(non-linear)* | -5.3040* | -2.57 | -3.46 | Yes |

Notes: * denote rejection of the null hypothesis at 10%, significance level. For K=3, the upper bounds of the critical values in Pesaran, et al. (2001) with unrestricted intercept and no trend (case III).

### 3.4 Long-run and Short-run NARDL Estimates

The results of the long-run and short-run estimates of the NARDL model for Nigeria on Table 5 indicate that the long-run effect of a positive shock in REC on $CO_2$ emission is positive and statistically significant at 10% significance level while the long-run effect of a negative shock in REC on $CO_2$ emissions is negative and statistically significant at 1% significance level. That is, $(\alpha^{+} = 0.510, P < 0.056)$ and $(\alpha^{-} = -1.341, P < 0.000)$, suggesting that a 1% increase in REC would bring about 0.51% increase in $CO_2$ emissions while a 1% decrease in REC will lead to about 1.34% decrease in $CO_2$ emission. This finding is contrary to expectations and inconsistent with the findings of Riti and Shu (2016). The results also show that the long-run effect of positive and negative shocks in TOP on $CO_2$ emission is positive and statistically significant. That is, $(\alpha^{+} = 0.901, P < 0.003)$ and $(\alpha^{-} = 0.781, P < 0.008)$, implying that a 1% increase in TOP would bring about 0.90% increase in $CO_2$ emissions, indicating that foreign trade is harmful to environmental quality in Nigeria. This finding is consistent with the findings of Nnaji, Chukwu and Uzoma (2013); Chaudhuri and Pfaff (2002); Copeland and Taylor (2001) and Khalil and Inam (2006). Also, a 1% decrease in TOP will lead to about 0.78% increase in $CO_2$ emission. This finding conforms to expectations and is consistent with the findings of Inglesi-Lotz and Nakumuryango (2013). The results also show that $CO_2$ emission responds positively to positive change in GDP per capita and negatively to negative change in GDP per capita in the long-run. That is $(\alpha^{+} = 0.749, P < 0.025)$ and $(\alpha^{-} = -3.225, P < 0.084)$. Both effects are statistically significant at 5% and 10% significance level respectively. A 1% increase in come would lead to about 0.749% rise in $CO_2$ emission while a 1% decrease in income would bring about a reduction in CO2 emission by 3.23% in the long-run. This finding is consistent with the findings of Rafinidadi (2016) and Riti and Shu (2016) who established that economic growth leads to increase in $CO_2$ emission and deteriorates environmental quality.

For the short-run, the results show that positive and negative shocks in REC lead to statistically significant increase in $CO_2$ emissions, that is, $(\rho^{+} = 0.305, P < 0.094)$ and $(\rho^{-} = 0.821, P < 0.002)$, suggesting that a short-run positive shock in REC would bring about 0.31% increase in $CO_2$ emission and a short-run negative shock in REC will results to about 0.821% increase in $CO_2$ emissions in Nigeria. For TOP, the results show that $CO_2$ emission responds positively to positive change in TOP and negatively to negative change in TOP. That is, $(\rho^{+} = 0.254, P < 0.019)$ and $(\rho^{-} = -0.044, P < 0.017)$. A 1% increase in TOP leads to about 0.25% increase in $CO_2$ emission which is in line with the study of Rafindadi (2016), while a 1%

decrease in TOP results to 0.04% decrease in $CO_2$ emission. Both effects are statistically significant at 5% level. Also, the short-run results show that both positive and negative shocks in GDP per capita lead to statistically significant increase in $CO_2$ emission by 0.60% and 10.95% respectively.

For the case of South Africa, the results suggest that $CO_2$ emission responds negatively and statistically significant to positive change in REC, while it responds positively and statistically significant to negative change in REC. That is, $(\alpha^{+} = -0.180, P < 0.026)$ and $(\alpha^{-} = 0.744, P < 0.018)$. A 1% increase in REC brings about 0.18% reduction in $CO_2$ emission while a 1% decrease in REC causes a rise in $CO_2$ emission by 0.74%. This finding suggest that renewable energy consumption is beneficial to environmental quality in South Africa which goes to explain why the South African government is investing heavily in renewables as a way of decoupling $CO_2$ emission and improving environmental quality. Contrary to the case for Nigeria, $CO_2$ emission in South Africa responds negatively to both positive and negative shocks in TOP, though only the negative effect is statistically significant. That is, $(\alpha^{+} = -0.728, P < 0.289)$ and $(\alpha^{+} = -1.342, P < 0.001)$ respectively. A 1% increase or decrease in TOP reduces $CO_2$ emissions by 0.73% and 1.34% respectively. This finding suggests that, foreign trade is beneficial to South African environmental quality and is consistent with the finding of Shahbaz et al (2013). Similarly, the results show that $CO_2$ emission responds negatively to both positive and negative changes in GDP per capita in the long-run. That is, $(\alpha^{+} = -0.998, P < 0.424)$ and $(\alpha^{+} = -20.997, P < 0.038)$. A 1% increase or decrease in GDP leads to reduction in $CO_2$ emissions by 0.998% and 20.997% respectively. This finding concurs with the findings of Shahbaz et al (2013), Hanif (2017) and Hasson and Masih (2017) for South Africa. That is, the country may have to sacrifice growth to achieve pollution free environment in the long-run.

For the short-run, the results indicate that $CO_2$ emission responds negatively to both positive and negative changes in REC though only the effect of a positive change is statistically significant. That is, $(\rho^{+} = 0.028, P < 0.038)$ and $(\rho^{-} = -0.009, P < 0.0433)$, suggesting that a 1% positive and negative change in REC would lead to 0.028% and 0.009% reduction in $CO_2$ emission in the short-run. Conversely, $CO_2$ emission responds positively to both positive and negative changes in TOP. That is, $(\rho^{+} = 0.839, P < 0.000)$ and $(\rho^{-} = 0.073, P < 0.209)$, indicating that a 1% positive and negative change in TOP lead to 0.84% and 0.07% increase in $CO_2$ emission, which implies that foreign trade is harmful to environmental quality in South Africa in the short-run. Also evident from the result is that $CO_2$ emission responds negatively to increase in GDP per capita and positively to decrease in GDP per capita. That is a 1% increase in GDP per capita causes $CO_2$ emission to decrease by 3.33% in the short-run while a 1% decrease in GDP per capita leads to about 1.27% increase in $CO_2$ emission. This suggests that, since the consumption of energy from renewable sources is on the rise in South Africa, the South African economy can grow in the short-run without necessarily hurting the environment.

**Table 5: Long-run and Short-run NARDL Results**

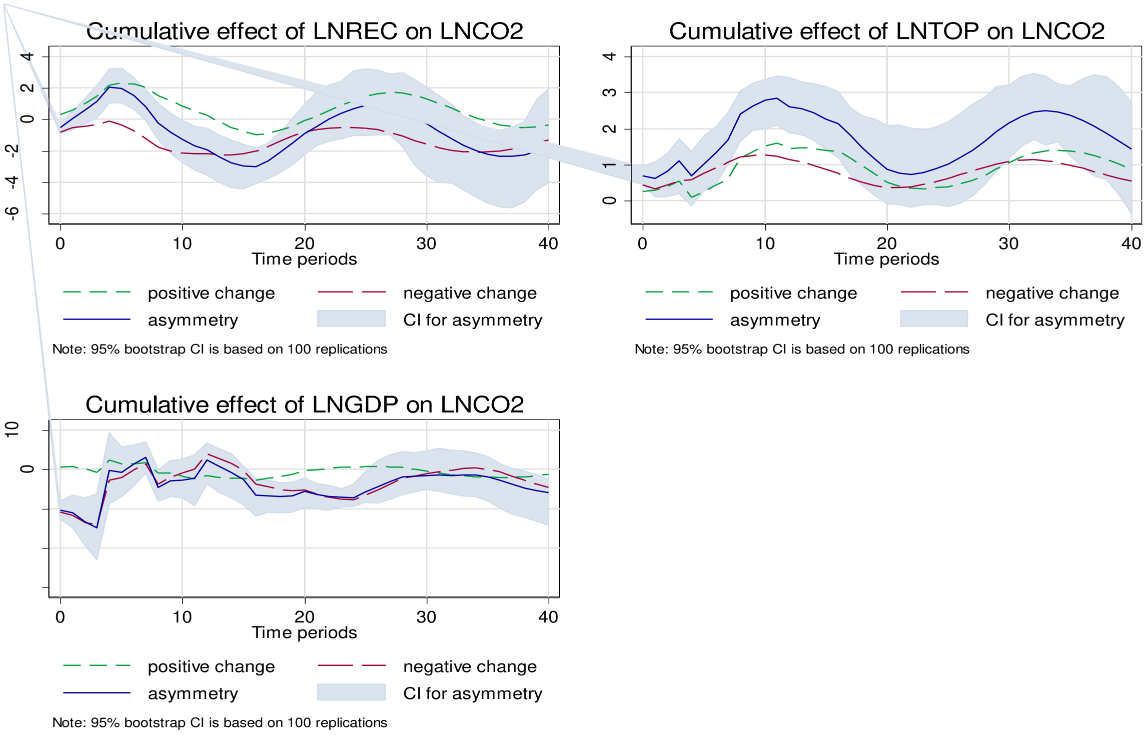
| Dep. Var. | **Nigeria** | | **South Africa** | |
|---|---|---|---|---|
| $\Delta lnCO2$ | Coefficient | P-value | Coefficient | P-value |
| $lnREC^{+}$ | 0.510 | 0.056 | -0.180 | 0.026 |
| $lnREC^{-}$ | -1.341 | 0.000 | 0.744 | 0.018 |
| $lnTOP^{+}$ | 0.901 | 0.003 | -0.728 | 0.289 |
| $lnTOP^{-}$ | 0.781 | 0.008 | -1.342 | 0.001 |
| $lnGDP^{+}$ | 0.749 | 0.025 | -0.998 | 0.424 |
| $lnGDP^{-}$ | -3.225 | 0.084 | -20.997 | 0.038 |
| *Constant* | 2.571 | 0.000 | 8.839 | 0.000 |
| $\Delta lnREC^{+}$ | 0.305 | 0.094 | -0.028 | 0.038 |
| $\Delta lnREC^{-}$ | 0.821 | 0.002 | -0.009 | 0.433 |
| $\Delta lnTOP^{+}$ | 0.254 | 0.019 | 0.839 | 0.000 |
| $\Delta lnTOP^{-}$ | -0.044 | 0.017 | 0.073 | 0.209 |
| $\Delta lnGDP^{+}$ | 0.604 | 0.220 | -3.330 | 0.000 |
| $\Delta lnGDP^{-}$ | 10.951 | 0.000 | 1.272 | 0.066 |
| $\chi^2_{SC}$ | 4.581 | 0.244 | 4.518 | 0.264 |
| $\chi^2_{H}$ | 1.34 | 0.342 | 1.067 | 0.302 |
| $\chi^2_{FF}$ | 1.95 | 0.288 | 1.383 | 0.135 |
| $\chi^2_{N}$ | 4.062 | 0.072 | 1.219 | 0.544 |

Note: $\chi^2_{SC}$, $\chi^2_{H}$, $\chi^2_{FF}$, and $\chi^2_{N}$ are tests for serial correlation, heteroscesdasticity, functional form and normality respectively

### 3.5 Cumulative Dynamic Multiplier Tests

The results of the cumulative dynamic multiplier shown on Figures 1 and 2 respectively indicate the pattern of adjustment of environmental quality ($CO_2$ emissions) to changes in renewable energy consumption, trade openness and economic growth in Nigeria and South Africa. The dotted green and red lines represent positive and negative changes respectively, while the blue line indicates the trend of asymmetry at 95% bootstrap confidence interval shown by the solid grey area. We performed the cumulative multiplier effect using 40 horizons, which is equivalent to 40 quarters. The result on Figure 1 reveal that a positive change or increase in LNREC (renewable energy consumption) has positive effect on $LNCO_2$ ($CO_2$ emission) as shown by the green line, while negative change or decrease in renewable energy consumption has negative effect on carbon emission as shown by the red line. Furthermore, the results indicate that the effect of a positive change dominates the effect of a negative change in Nigeria. Also, the result shows that both positive change and negative change in LNTOP (trade openness) have positive long-run effect on carbon emission in Nigeria. Although, the short-run effect of a positive change is negative but we can conclude that the cumulative effect is positive. However, the cumulative positive effect of a positive change in trade openness outweighs the cumulative positive effect of a negative change in Nigeria. The results further show that the effect of a positive change in GDP is positive and a negative change of GDP is negative. The fact that the effect of a negative change is larger than a positive effect, the cumulative effect becomes negative.

For South Africa, the result as presented on Figure 2 show that, both cumulative positive and negative changes in renewable energy consumption have positive effect on carbon emission. Although the effect of a negative change is more than the effect of a positive change in South Africa. Hence, the cumulative effect of renewable energy consumption is negative. Furthermore, the effect of a positive change in TOP on $CO_2$ emission is positive and asymmetric while the effect of the negative change is also positive. However, the effect of a negative change is stronger compared to the effect of a positive change, hence the cumulative effect of the positive and negative changes in TOP is negative. In addition, the cumulative effect of positive and negative changes in GDP on $CO_2$ emission is negative. This is because the effect of a negative change in GDP is stronger than the effect of a positive change in GDP. These findings corroborate the results of the NARDL estimations.

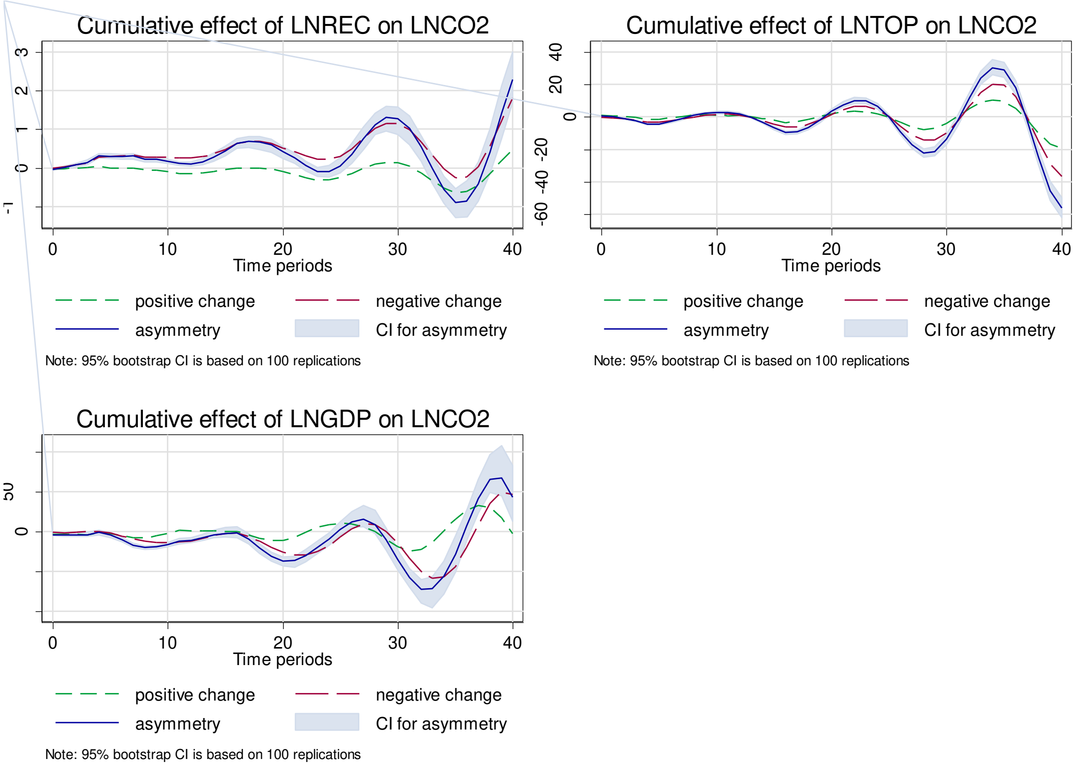

Cumulative effect of LNREC on LNCO2

Cumulative effect of LNTOP on LNCO2

Cumulative effect of LNGDP on LNCO2

Note: 95% bootstrap CI is based on 100 replications

**Figure 1: Cumulative Dynamic Multiplier Effect for Nigeria**


Cumulative effect of LNREC on LNCO2

Cumulative effect of LNTOP on LNCO2

Cumulative effect of LNGDP on LNCO2

Note: 95% bootstrap CI is based on 100 replications

**Figure 2: Cumulative Dynamic Multiplier Effect for South Africa**

## 4. Conclusion and Policy Implications

This present paper investigates the effects of renewable energy consumption, trade openness and economic growth on environmental quality in Nigeria and South Africa using asymmetric ARDL on quarterly data over the period 1990Q1 – 2014Q4. To avoid spurious estimates, we tested for stationarity properties of the data using structural breaks unit root tests of Zevot-Andrews and Clemente Montanes Reyes for single and two structural breaks respectively. Both tests reveal non-stationary process for all the series in levels but found all the series stationary at first difference implying that all the series are integrated of order one [I(1)]. To test for cointegration, we employed the asymmetric bounds test using both the F-statistic ($F_{PSS}$) and the t-statistic ($t_{BDM}$). The results reveal the presence of cointegration among the variables for both countries. We also conducted asymmetry test using the asymmetric Wald test and found the presence of long-run asymmetry for all the variables in both countries. Furthermore, the study estimated the NARDL model for Nigeria and South Africa. The results for Nigeria indicate that positive and negative long-run changes in renewable energy consumption have increasing and decreasing effects on $CO_2$ emission respectively, while positive and negative long-run changes in trade openness lead to increase in $CO_2$ emission. More so, the results reveal that $CO_2$ emission responds positively to increase in per capita income and responds negatively to decrease in per capita income.

For the case of South Africa, the study found that $CO_2$ emission responds negatively to increase in renewable energy consumption in the long-run and positively to decrease in renewable energy consumption. Also, the study found that $CO_2$ emission responds negatively to both increase and decrease in trade openness and per capital income in the long-run. Turning to the short-run, we found that both positive and negative changes in renewable energy consumption lead to positive effect on $CO_2$ emission in Nigeria. The same holds for income per capita, while a positive change in trade openness causes positive effect on $CO_2$ emission and a negative change causes negative effect on $CO_2$ emission in Nigeria. Conversely, both positive and negative changes in renewable energy consumption lead to negative short-run effect on $CO_2$ emission in South Africa, while positive and negative changes in trade openness lead to positive short-run effect on $CO_2$ emission. Regarding the effect of income per capital, we found that positive change in income per capita leads to negative effect on $CO_2$ while negative change in it brings about positive short-run effect on $CO_2$ emission in South Africa.

The findings for both Nigeria and South Africa are juxtaposed by the cumulative dynamic multiplier effect on Figures 1 and 2 respectively. On the basis of the findings therefore, we recommends energy and trade related policies that promote the consumption of renewable energy on one hand, and ensure that international trade is not harmful to the environment on the other hand. Some of these policies include subsidizing investment in renewable energy development and imposition of energy or carbon taxes on the consumption of fossil fuels in order to discourage its consumption and facilitates a shift to the consumption of energy from renewable energy sources.

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