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# Renewable Energy Consumption Shocks on CO2 Emissions and Economic Growth of Nigeria

To cite this article: N Ezenwa *et al* 2021 *IOP Conf. Ser.: Earth Environ. Sci.* **665** 012013

# Renewable Energy Consumption Shocks on $CO_2$ Emissions and Economic Growth of Nigeria

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**Abstract:** The paper examines the nexus among economic growth, renewable energy consumption and CO2 pollution in Nigeria. The study tested for co-integration using the Johansen technique, which is evident and applied the vector error correction model (VECM) on the annual data for the period 1990-2015. The results indicate a bi-directional causality between renewable energy consumption (REC) and economic growth (GDP). REC positively granger causes GDP in both short-run and long-run, while GDP has an adverse effect on REC in the short run. Historical decomposition of shocks reveals the relative implications of renewable energy shocks on GDP to be mostly negative between period 1990 and 2007. This is as a result of inefficient renewable technologies during the period. However, there is persistent and positive influence of REC on economic growth in the period between 2009 and 2015. Increase use of renewable technologies due to its relative affordability and better efficiency contributes to the progressive influence on economic growth. The variance decomposition analysis predicts an increase in the use of renewable energy technologies in the five year forecast period, with CO2 emissions will increasing as a consequence of dependence fossil fuel energy resources. The paper suggests environmental and tax policy instruments, as well as, effective governance to enhance environmental quality and encourage sustainable/green economic growth. The key instruments include: grants, feed-in-tariffs (FIT), production tax credits, renewable portfolio standards (RPS), and loans to enable industrial sector invest in renewable energy.

***Keywords:*** Renewable Energy Consumption Shocks, CO2 emissions, Economic growth, VECM

## 1. INTRODUCTION

Energy is an indispensable factor for the economic progress of every country. It can be applied in multifarious ways in both household and industrial activities such as cooking, powering of automobiles and industrial machinery. Developed and developing countries are pursuing economic growth and sustainable development but there are environmental concerns, due to climate change, which are driving increased demand for renewable energy technologies [13].

In 2018, the global energy consumption has nearly doubled compared to the average growth rate in 2010 - surging as high as 32.5 gigatonnes (Gt) according to International Energy Agency (2019). This is as a result of growing demand in the world for advanced heating and cooling appliances. Electricity demand accounted for half the global energy demand. The demand for fossil fuel grew by 70%, in which natural gas accrued 45% having the largest share increase. In the same year, renewable consumption doubled, yet not enough to meet the growing global demand for electricity. The world-wide increase in non-renewable energy consumption has resulted to to a 1.7% increase in $CO_2$ emissions, where coal fired power plants contributed to 30% of the overall energy related CO2 emissions [16].

The benefits of renewable energy are innumerable for a developing economy like Nigeria considering the evidences of resource curse in parts of the country [11]. There are other reasons to encourage the use of clean energy technologies through policy measures, such as to boost energy security and to bridge energy gaps by creating sufficient and efficient energy mix. Furthermore, renewable energy could contribute in reducing environmental pollution associated with fossil fuel production and consumption, as well as, provide energy access to rural and remote areas, while simultaneously providing jobs for some of the populace [7].

Nigeria has a broad range of renewable energy sources which comprise of wind, hydro, sun and biomass. Biomass energy refers to energy gotten from organic materials from plant or animals, which are imbued with energy from the sun. Examples are fuelwood, animal waste, crops and agricultural residue, and even municipal waste. The fact that there is a vast potential for biomass energy to be gainfully utilized cannot be gainsaid. The rural areas alone comfortably provide all that is needed. Also, wind energy is a gift waiting to be tapped into. Nigeria has however failed to follow the trail of developed nations in this regard. Studies have shown that Nigeria has the potential to harness wind energy, particularly in the North where wind speed is remarkably high [3].

Nestled in the temperate equatorial region, Nigeria is exposed to a significant measure of solar radiation. This denotes enormous solar energy potentials. Solar energy can be utilized for agricultural purposes such as crop drying, domestic purposes such as cooking, and infrastructural purposes such as electricity and traffic lighting. The country has only gotten her foot in the door as far as harnessing solar energy is concerned. There are solar-powered street lamps and gadgets, but there is more work to be done.

Hydro power is by far the renewable energy source where Nigeria has harnessed renewable energy the most. Hydro provides 19% of Nigeria's National electrical grid supply [1]. The country has made considerable improvements in this sector, but still faced with government under-financed capital projects and routine maintenance operations putting pressure on the existing infrastructure that reduced the electricity supply in the grid. Hence, Nigeria has experience unstable electrical supply for the past two decades resulting to the increase in private producers using fossil fuel to generate electricity, which pollutes the environment with CO2 emissions and other greenhouse gases.

Nigeria, as the giant of Africa, is the subject of international concern due to its remarkable GDP growth as well as energy demand. The demand of energy is on the increase as the economy grows. The use of fossil fuel is on the high and is detrimental to the environment. Over the years the country has shifted its attention towards incorporating renewables in the energy mix through developing policies that encourage its use.

The growing use of renewable energy in Nigeria is the motivation for this study, because a nation's energy behaviour determines the level of impact on the economy, as well as, the environment. The aim of the study is to determine the causal link among renewable energy consumption (REC), CO2 emissions and economic growth (GDP) using the vector error correction model (VECM). The paper contributes to knowledge by discussing policy implications of results and proposing policies that can enhance environmental quality and encourage economic growth.

## 2. LITERATURE REVIEW

Several authors have studied the association between renewable energy consumption (REC), economic growth (GDP), and CO2 emissions, and employed different econometric methods: Autoregressive Distributed Lag ARDL), vector autoregressive (VAR), vector error correction (VECM), Johansen co-integration, and Granger causality methods and so on. Different literature has been discussed in several dimensions.

The nexus between renewable energy consumption and economic growth has been broadly investigated in several literatures for the past three decades. This relationship is a persistent issue in present economic debates, due to the fact that existing outcomes varies. The work of [21] investigated the long-run and short-run correlation between renewable energy consumption and GDP using Autoregressive Distributed Lag co-integration technique on ten Central and Eastern European economies (CEE) from 1990-2014. They observe that in the short-run, the causality link between GDP and REC in Romania and Bulgaria is neutral while in Hungary, Lithuania and Slovenia is bi-directional, as is observed that increase in REC encourage economic growth and vice-versa. Similar results are observed in the long-run of seven countries: Bulgaria, Estonia, Latvia, Lithuania, Slovakia, Romania, Poland, and Slovenia. However, in Czech Republic and Romania there is a one-way causality from GDP to REC, while the nexus in Hungary exhibited neutral causality. The results also showed some countries surpassing the set goal on renewables as an effect of the major impact on policy implementation. Some of the most efficient and effective incentive programs are investments in power generation with hydro, biomass, and wind, introducing green certificates, and price regulation for the kind of renewable technology consumed.

The study of [5] investigates the time-varying bi-directional influence of renewable energy consumption (REC) on economic growth (GDP) for the G-7 economies from 1960-2015 using vector autoregressive model (VAR). The outcomes suggest that the impact of REC on economic growth indicates mixed results, indicating that a positive shock in renewable energy consumption is not consistent in the historical decomposition for the G-7 economies. The impact of GDP on REC shows time-changing effects and consistently positive in the historical decomposition for Germany, United States and Italy. However, positive and negative shocks is observed in United Kingdom, Canada, Japan, and France. The study identifies renewable energy consumption to be the major factor influencing economic growth, since the 1990s.

Another view of study is the causal relationship between economic growth and CO2 emissions. The study of [21] investigated this causal link for Nigeria in the period 1970 to 2013, adapting the error correction model (ECM). The findings suggest that economic growth has a positive relationship with CO2 emissions. The paper recommends adequate policies to promote green growth since is observed that the activities to reduce carbon emission have unfavourable effect on GDP in the short-run. The study suggests that Nigeria should focus on green investments that are efficient to promote economic growth and enhance environmental standard.

The work of [26] studies the long-run equilibrium relationship between economic growth and cabondioxide emission in EU countries, using the non-linear threshold co-integration. The nexus checks for the environmental Kuznets curve (EKC) assumption, which confirms that economic growth has a decoupling influence on carbon dioxide emissions. The observed result is categorized into three: high-level economies, middle-level economies, and low-level knowledge economies for easy discussion of causal links between economic growth and carbon dioxide emissions. The analysis ascertained that EKC hypothesis is evident for some high and middle knowledge-advanced nations. Also, introducing energy consumption in the model improves the causal relationship for the low-level knowledge economy. The paper confirms that the EU's policy is efficient for countries EKC hypothesis is evident and weak for low-level knowledge economy. Hence, suggests improvement in energy diversification through promoting renewables energy technologies will reduce environmental degradation.

The findings from previous studies, surrounding association among variables have emphasised on four hypotheses. The first postulation is the "neutrality *hypothesis*" which suggest that causal relationship does not exist between two variables; energy consumption and economic growth or carbondioxide emissions and energy consumption. The study [9] observed absence of causation in the short-run between energy consumption and real GDP for Cyprus, Egypt, Oman and Sudan. This hypothesis suggests that policies that pursue to reduce CO2 emissions through introduction of renewables or cutting down energy consumption will have no influence on economic output. This is a decoupling effect between energy consumption and economic growth.

The second postulation is the *"conservation hypothesis"* which suggest a unidirectional or one-way causality to which economic growth affects energy consumption. The scenario can be where economic activity can result to a rise in energy consumption or decline energy consumption. In a policy setting to reduce energy consumption, where real GDP increases energy consumption the economy will not be affected. This is because economic growth has no influence on energy consumption. [4] findings implementing the vector error correction model (VECM), show evidence of conservation assumption for BRICS countries.

The third postulation is the *"growth hypothesis"* which argues the unidirectional or one-way causality from energy consumption to economic growth. Energy consumption can have a positive or negative implications on the economy depending the macroeconomic structure. The policy implications imply that reducing energy consumption can positively impact economic output, if the economy increases its service industry that consumes less energy unlike the heavy industry. Findings of Chen, Chen, Hsu & Chen, [6] while investigating 188 economies using the vector error correction model, suggest that energy consumption has an unfavourable effect on real GDP of some developing economies but not in developed economies. The study observes a one-way causation that stems from energy consumption to carbon dioxide emissions for developing and developed economies.

The last postulation is the *"feedback hypothesis"* which proposes the two-way or bi-directional causality between two variables. Thus, cases exist where energy consumption positively influence economic growth, which in turn increases energy consumption in the country. The implication of this scenario is that environmental promotion strategies will reduce consumption and economic growth, and economic incentive policies can increase energy consumption and GDP growth. [19] examines the causal link for 10 CEE countries adapting the autoregressive distributed lag (ARDL) model, the results indicate two-way causation between renewable energy consumption and GDP growth in the long-run of seven CEE economies.

## 3. METHODOLOGY

The study investigates the causal nexus in the dataset of real GDP, renewable energy consumption (REC) and CO2 emissions applying the vector autoregressive model (VECM). The VECM is a restricted vector autoregressive model (VAR) constructed with first differenced variables, that are non-stationary and exhibited co-integration at levels.

The vector error correction model is validated in a three step process. The first step is testing for stationarity or unit root in the series. The series will be valid for the model if unit root is evident at level and are co-integrated, and the absence of unit root when first differenced. Two prominent technique for testing for stationarity in a series, namely [8] and [25] tests. These econometric techniques examine the stationarity properties of variables based on the order of integration. The rejection on the null hypothesis suggests that the variable is stationary. The analysis requires the null hypothesis to be accepted at level and rejected after first differencing.

The second step requires that all series are co-integrated or exhibit long-run relationship at level or $I(O)$ order. One of the methods used to test for co-integration in Eq. (1), is the [18] maximum likelihood method. The model selects the best lag by comparing the information [2] and [27] information criterion. The information with the lowest maximum likelihood is considered a better fit for lag selection. The technique adapts the maximum likelihood estimator for the vector autoregressive approach to obtain the number of R – co-integrating vectors which is determined by the trace statistics statistics. There is evidence of co-integration when the trace statistics is greater than the critical values. Hence, granger causes is present among the variables in at least one direction [24] and [28].

The final step is the application of the vector error correction model (VECM), when all series are integrated in the first differenced or $I$ (1) order. The model constrains the long-term performance of the endogenous variables to converge to their association which allows for short-term adjustment. The study specifies neo-classical model for developing the VECM, following the work of [24] Eq. (1), which allows the energy-associated variables as a proxy of technological progress.

$$lnGDP_t = \alpha_o + \alpha_1 lnREC + \alpha_2 lnCO2 + \mu_t \tag{1}$$

where the lnGDP, lnREC, and lnCO2 represent the natural logarithms of economic growth(GDP), renewable energy consumption(REC) and carbondioxide emissions (CO2). The natural logarithm form of variables allows the model to compute the elasticity estimates $\alpha_0, \alpha_1, and\ \alpha_2$.

The vector error correction model (VECM) is represented as:

$$\Delta lnGDP_t = \vartheta_1 + \sum_{i=1}^{m-1} \omega_i\, \Delta lnGDP_{t-i} + \sum_{j=1}^{m-1} \varphi_j\, \Delta lnREC_{t-j} + \sum_{k=1}^{m-1} \tau_k\, \Delta lnCO2_{t-k} + \lambda_1 ECT_{t-1} + \varepsilon_{1t} \tag{2}$$

$$\Delta lnREC_t = \vartheta_2 + \sum_{i=1}^{m-1} \omega_i\, \Delta lnGDP_{t-i} + \sum_{j=1}^{m-1} \varphi_j\, \Delta lnREC_{t-j} + \sum_{k=1}^{m-1} \tau_k\, \Delta lnCO2_{t-k} + \lambda_2 ECT_{t-1} + \varepsilon_{2t} \tag{3}$$

$$\Delta lnCO2_t = \vartheta_3 + \sum_{i=1}^{m-} \omega_i \,\Delta lnGDP_{t-i} + \sum_{j=1}^{m-1} \varphi_j \,\Delta lnREC_{t-j} + \sum_{k=1}^{m-1} \tau_k \,\Delta lnCO2_{t-k} + \lambda_3 ECT_{t-1} + \varepsilon_{3t} \quad (4)$$

where the error correction term (ECT) is expressed as:

$$ECT_{t-1} = \ln Y_{t-1} - C_1 X_{t-1} - \xi_1 R_{t-1} \quad (5)$$

$$Y_t = \sigma + C_1 X_{t-1} + \xi_1 R_{t-1} + \varepsilon_t \quad (6)$$

is derived from the lagged ordinary least squared (OLS) values of the residuals $R_t$ from the cointegrating association in Eq. (5) of the dependent variable ($Y_t$) on the independent variables ($X_t$) which contains the long memory information in Eq. (6). The ECT takes into account the previous periods deviation( $\xi_1$) from the long-run stable form, which affects the short-run dynamics in the dependent variable ($Y_t$). The symbol $\Delta$ in Eq. (2), (3), (4) is the first differenced operator and $(m-1)$ is the lag length reduced by 1. The $\omega_i$, $\varphi_j$, $\tau_k$ are the short-run coefficient of the VECM adjustment to the long run equilibrium. The coefficient of the error correction term, $\lambda$ is the speed of adjustment parameter which indicates the rate at which $Y_t$ returns to equilibrium after changes in $X_t$ and $R_t$. The stochastic error terms ($\varepsilon_t$) is the impulses or shocks.

The analysis uses the yearly data for Nigeria's real GDP, renewable energy consumption (REC), and CO2 emissions from 1990 to 2015 to investigate the co-integration and granger causation of Eq. (2), (3), (4). The variables GDP, REC, and CO2 are measured in US dollars, percentage (%) share of the total energy consumption, and million metric tonnes (mm tons) respectively. The data for GDP and REC are retrieved from the World Bank Website [30], and CO2 emissions from US energy Information Administration website [32]. The frequency of the renewable energy consumption time-series used for the research is based on data availability, which determined the selection of the periods. The data is converted to its natural logarithm, to compare the moments of probability density function (*pdf*) and allow the vector error correction model to estimate elasticity.

The dataset on EVIEWS 10 is presented in table 1, highlights the four moments of the probability density function (*pdf*); mean, standard deviation, skewness and kurtosis. The first two moments indicate that the mean is not zero and standard deviation lies between 0.99 and 0.02. Real GDP is considered to be the most volatile series and renewable energy consumption (REC) the least volatile series. Observing the third and fourth moment of the probability distribution, real GDP is skewed to the right while REC and CO2 emissions are skewed to the left. The statistics show evidence of asymmetry in the distribution around the mean. The probability density function (PDF) for the variables indicates no extreme changes for real GDP and and REC since the kurtosis less than three. However, the changes for CO2 emission is leptokurtic ($> 3$) , this indicates extreme changes which could not be contained in the distribution. This observation also indicate the normality assumption is violated for CO2 emissions, which is confirmed by the jarque-bera statistics.

Table 1: Descriptive Statistics of dataset

| | ln(GDP) | ln(REC) | ln(CO2) |
|---|---|---|---|
| Mean | 25.55602 | 4.457671 | 4.528438 |
| Median | 25.32879 | 4.459868 | 4.544944 |
| Maximum | 27.06627 | 4.486745 | 4.67483 |
| Minimum | 24.04658 | 4.418311 | 4.240979 |

| | | | |
|---|---|---|---|
| Std. Dev. | 0.986082 | 0.016974 | 0.095641 |
| Skewness | 0.185389 | -0.515589 | -1.119979 |
| Kurtosis | 1.514991 | 2.741067 | 4.376206 |
| jarque-bera | 2.537957 | 1.224571 | 7.487297 |
| Probability | 0.281119 | 0.54211 | 0.023668 |
| Observations | 26 | 26 | 26 |

Source: Authors' Computation with Eviews 10 (2020)

The jarque-bera rejects the null normality hypothesis for CO2 emissions and accepts the null hypothesis for GDP and REC. This shows that REC and GDP have a normal distribution, while the distribution for CO2 emission is non-normal.

This situation is due to limited number of observations based on data availability of renewable energy consumption. Although, not part of the study, the CO2 data set is tested in the periods from 1980 and 2016. It is observed that there are no extreme changes and the jaque-bera statistics is not violated at the 5% significance level. Nevertheless, stationarity and co-integration tests among variables using the available dataset for all variables from 1990 to 2015 was conducted.

The vector error correction model (VECM) requires the dataset to be stationary when first differenced $I(1)$. Table 2 shows the logarithm variables tested in the $I(0)$ order or level, without any intercept indicate the presence of unit root (non-stationary), while including an intercept shows evidence of stationarity for REC at 10% significance level and CO2 emissions at 5% significant level. The logarithm variables real GDP, renewable energy consumption, and CO2 emissions show absence of unit root after first differencing for both tests. Therefore, we check for co-integration among variables.

Table 2: Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests

| | ADF tests | | | | PP tests | | | |
|---|---|---|---|---|---|---|---|---|
| Variable | Level | | First difference | | Level | | First difference | |
| | None | Intercept | None | Intercept | None | Intercept | None | Intercept |
| ln(GDP) | 2.4722 | 0.2532 | -3.4081** | -4.1317** | 2.3531 | 0.2003 | -3.3606** | -4.1171** |
| ln(REC) | -0.1733 | -2.6364* | -5.2377*** | -5.1218*** | -0.2109 | -2.6365* | -5.4009*** | -5.26218*** |
| ln(CO2) | 0.3174 | -3.1886** | -5.4774*** | -5.3729*** | 0.6577 | -3.2517** | -6.1847*** | -6.0273*** |

***, **, * signify 1%, 5%, and 10% significance level respectively.
Source: Authors' Computation with Eviews 10 (2020)

Table 3 indicate that long-run relationship exist among variables at the 5% significance level from the trace statistics. The trace statistics is greater than the critical value, which indicates that no co-integration exists at the 5% significance level for the alternative, co-integration exists or long-run relationship exists. This follows the work of [24], that there is granger causality is evident among variables at least in one direction. The result of the stationarity and co-integration test validates the use of the vector error correction model to investigate the short-run and long-run nexus among variables.

Table 3: Johansen Co-integration Test

| Hypothesized | | Trace | 0.05 | |
|---|---|---|---|---|
| No. of CE(s) | Eigenvalue | Statistic | Critical Value | Prob.** |
| | | | | |
| None * | 0.541526 | 33.30101 | 29.7971 | 0.019 |

| | | | | |
|---|---|---|---|---|
| At most 1 | 0.431506 | 15.36442 | 15.4947 | 0.0523 |
| At most 2 | 0.098102 | 2.374832 | 3.8415 | 0.1233 |

* signifies rejection of the hypothesis at the 0.05 level
** Significance threshold at 5%
Source: Authors' Computation with Eviews 10 (2020)

## 4. Results and Discussion

The Vector error correction model (VECM) requires that the best lag of dataset is selected. The selection of the number of lag order $(l)$ that is required by the linear model depends upon the model selection criteria. This is tested on the unrestricted vector autoregressive system (VAR) which allows for the optimum selection of lag applying the Akaike information criterion (AIC) or the Schwarz information criterion (SIC).

The two information criterion is presented in Table 4 under the unrestricted VAR system. The value for the AIC is lower than the SIC, which considers the selection of lag length based on the AIC. The best lag length for the annual data series under the unrestricted VAR system is two. The restricted VAR, which is the VECM reduces the lag length by 1, which is represented as $VECM(1,1)$.

Table 4: Model Lag Selection Criteria using the AIC and SIC

| Lag | logarithm Likelihood | AIC | SC |
|---|---|---|---|
| 0 | 49.2994 | -4.209 | -4.0603 |
| 1 | 112.8566 | -9.1688 | -8.5737* |
| 2 | 122.244 | -9.2034* | -8.1626 |
| 3 | 129.9781 | -9.0889 | -7.6011 |
| 4 | 137.2881 | -8.9353 | -7.0012 |
| Log likelihood | | 112.0026 | |
| Akaike information criterion (AIC) | | -8.0002 | |
| Schwarz information criterion (SIC) | | -7.4151 | |

*Selected Lag

Source: Authors' Computation with Eviews 10 (2020)

Model lag selection is essential because the optimum estimate to study the co-integrating relationship and simulate impulse responses that reflect the macroeconomic framework in the best way.

The study investigates the way of causality for economic growth(GDP), renewable energy consumption (REC), and CO2 emissions. The results for causality are presented in Table 5. The causality tests for REC on GDP suggest the dismissal of the null hypothesis at 1% significance level. Also, granger causes run from GDP to REC for Nigeria. This shows a bi-directional causality between REC and GDP, which support the feedback hypothesis. The result is similar with the findings of [19] on seven central and european economies(CEE) (Bulgaria, Estonia, Latvia, Lithuania, Poland, Romania, Slovakia, and Slovenia) in the long-run and three economies (Hungary, Lithuania and Slovenia) in the short-run. There is a unidirectional causality that runs from REC to CO2 emissions for Nigeria at 10% significance level. This is similar to findings of [6] investigating 188 countries.

IOP Conf. Series: Earth and Environmental Science **665** (2021) 012013 doi:10.1088/1755-1315/665/1/012013

Table 5: Vector Error Correction(VEC) Granger Causality result

| Period: 1990 2015 | |
|---|---|
| Observations: 24 | |
| Lag: 1,1 | |
| Null Hypothesis: | Chi-square |
| ln(REC) does not affect ln(GDP) | 7.5035*** |
| ln(CO2) does not affect ln(GDP) | 1.8548 |
| ln(GDP) does not affect ln(REC) | 3.457* |
| ln(CO2) does not affect ln(REC) | 0.2082 |
| ln(GDP) does not affect ln(CO2) | 1.0714 |
| ln(REC) does not affect ln(CO2) | 3.6971* |

***, **, * 1%, 5%, and 10% significance level respectively.
Source: Authors' Computation with Eviews 10 (2020)

This supports the growth hypothesis for developing and developed countries. There is no causality that runs from CO2 emission to REC and between economic growth and CO2 emissions. Also, presents are estimates for the VECM to identify causality and magnitude in both short-run and long-run.

Table 6 displays the results of the vector autoregressive model estimates in the long-run and short-run. The analysis selects the natural logarithm (ln) of real GDP to be the target variable.

The target variable is the variable on which normalization of co-integration is conducted upon. The lnGDP is the placed as the dependent variable in the long-run co-integrating equation. The sign of the constants is reversed in the long-run as in $Eq.(6)$. In the long-run and short-run, renewable energy has a positive influence on CO2 emission at 1% and 10% significance level respectively, given that the speed of adjustment is negative and significant. This confirms the growth hypothesis. In the long-run, REC has a positively influence on economic growth at 1% significance level.

Table 6: VECM Results

| Sample (Adjusted) : 1992 to 2015 | | | |
|---|---|---|---|
| Observations after adjustments: 24 | | | |
| VECM(1,1) | | | |
| Dependent Variable: $ln(GDP)$ | | | |
| Long-run estimates (co-integrating equation) | | | |
| Independent Variables | Coefficient | Standard Error | t-statistics |
| $\Delta lnREC(-1)$ | -10.5801*** | 63.6688 | -0.1662 |
| $\Delta lnCO2(-1)$ | 59.2365 | 13.2667 | 4.46503 |
| Short-run estimates | | | |
| Dependent Variable: $\Delta ln(GDP)$ | | | |
| $\lambda_1$ | -0.0117 | 0.008 | -1.4624 |
| $\Delta GDP(-1)$ | 0.2638 | 0.208 | 1.2681 |
| $\Delta REC(-1)$ | 7.3663*** | 2.6892 | 2.7392 |

| | | | |
|---|---|---|---|
| $\Delta CO2(-1)$ | 0.6568 | 0.4822 | 1.36192 |
| $\vartheta_1$ | 0.06675* | 0.03954 | 1.6883 |
| Dependent Variable: $\Delta ln(REC)$ | | | |
| $\lambda_2$ | 0.0019*** | 0.0007 | 2.857 |
| $\Delta GDP(-1)$ | -0.0324* | 0.0174 | -1.8593 |
| $\Delta REC(-1)$ | -0.2005 | 0.2252 | -0.8903 |
| $\Delta CO2(-1)$ | -0.0184 | 0.0404 | -0.4564 |
| $\vartheta_2$ | 0.0033 | 0.0033 | 1.009 |
| Dependent Variable: $\Delta ln(CO2)$ | | | |
| $\lambda_3$ | -0.016*** | 0.00421 | -3.7936 |
| $\Delta GDP(-1)$ | 0.1133 | 0.1095 | 1.0351 |
| $\Delta REC(-1)$ | 2.721* | 1.4152 | 1.9228 |
| $\Delta CO2(-1)$ | 0.5152** | 0.2538 | 2.0301 |
| $\vartheta_3$ | -0.0094 | 0.0208 | -0.4524 |

***, **, * indicate 1%, 5%, and 10% significance level respectively.
$\lambda_i$ ; $i = 1,2,3$ represent the speed of adjustment parameter
$\Delta$ is the first difference operator
$\vartheta_i, i = 1,2,3$ represent the constant parameters
$(-1)$ indicate lag length reduced by 1

Source: Authors' Computation with Eviews 10 (2020)

In terms of magnitude, an increase in REC by 1% will lead to an increase in 7.3663 USD. In the short-run, there is a negative impact of GDP on REC at 10% significance level. This is consistent with the results of [21] in Nigeria, which suggested adequate policies to promote green growth by promoting green investments that are efficient. This is similar with the conservation hypothesis of [4] for BRICS countries.

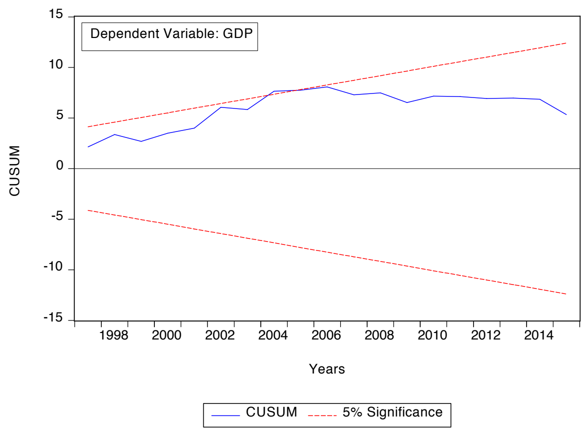


Figure 1: VECM Stability Diagnostic Test when GDP is the Dependent Variable

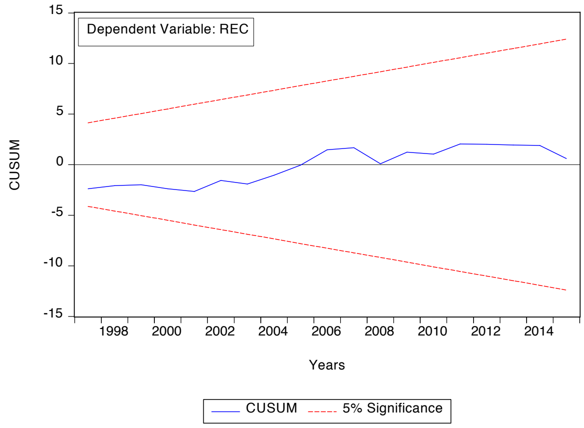


Figure 2: VECM Stability Diagnostic Test when REC is the Dependent Variable

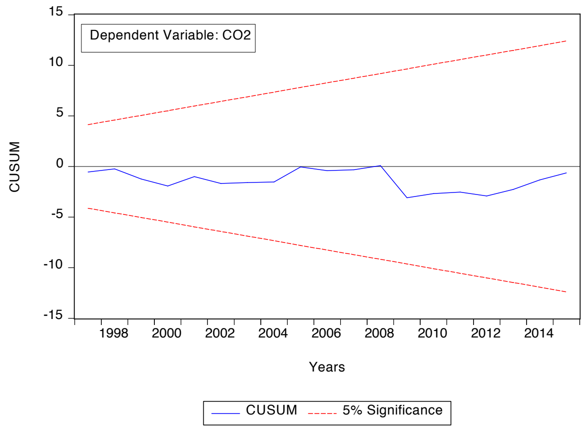


Figure 3: VECM Stability Diagnostic Test when CO2 is the Dependent Variable

The study employed the CUSUM tests to estimate equations (2), (3), (4), for parameter consistency for the VECM. The error correction term ($\lambda$) in Eq. (1)is not significant , where GDP is the dependent variable, but the REC variable in the short-run is significant. Although, is significant for in equations (2) and (3), where REC and CO2 are the dependent variables respectively. Figures 1, 2, and 3 display the CUSUM plots of these equations. The CUSUM test statistics in figure 1, slightly exceeds the 5% significance level. Although, in the study, assume the threshold significance level to be at 10%. Therefore, conclude that the regression model is stable. The CUSUM plot in figures 2 and 3 reveal that the regression equations are stable. Furthermore, the residual diagnostics of the vector error correction model (VECM) are observed.

Table 7: Serial Correlation LM and Heteroscedasticity Test

| Equations | Breusch-Godfrey Serial Correlation LM Test | Heteroscedasticity Test: ARCH |
|---|---|---|
| | F-Stat (Probability) | F-Stat (Probability) |

| | | |
|---|---|---|
| 2 | 1.4743 (0.2568) | 0.2993 (0.5901) |
| 3 | 1.1729 (0.3333) | 0.7865 (0.3852) |
| 4 | 0.4101 (0.67) | 0.0679 (0.797) |

Source: Authors' Computation with Eviews 10 (2020)

Table 7 show the serial correlation LM and heteroscedasticity tests of residuals in the model. The F-statistics result for serial correlation accepts the null hypothesis in all equations, which indicate that there is no evidence of autocorrelation of the error terms in the system. The heteroscedasticity tests indicate that the variance of the error terms is the same, judging by the F-statistics which is not significant. This shows the evidence of homoscedasticity.

Variance decomposition of the forecast error shows the proportion of unexpected variation in each variable that is produced by shocks from its own variable and other variables. This reveals the relative impact a variable has on another as in [14]. Presented in Table 8 are the results of variance decomposition of variables. The study forecasts a period of five years ahead, assuming the first two years and last three years are short-run and long-run periods.

The study observes that in the short-run where GDP is the dependent variable, 100% and 86% of forecast error variance in GDP are influenced by its own variable (strongly exogenous), showing that other explanatory variables have a weak influence on GDP (strongly exogenous) by 0% and 14% for REC and CO2 respectively. In the long-run, the real GDP is also strongly endogenous and other variables have less influence on GDP. In addition, renewable energy consumption (REC) is shown to be strongly endogenous in the short-run and weakly endogenous for the long-run periods implying strong influence from CO2 emissions with 36%, 42%, and 43% percentile. The GDP has a weak influence REC in both short-run and long-run periods.

The CO2 emissions has a strong influence from its own variable (strongly endogenous) in both short-run and long-run where REC is rising over the years, suggesting a continuous dependence in oil and gas consumptions in industrial sector, transport sector, and household.

Table 8: Variance Decomposition Analysis of Variables

| Cholesky Ordering: ln(GDP) ln(REC) ln(CO2) | | | | |
|---|---|---|---|---|
| Variance Decomposition of ln(GDP): | | | | |
| Period | S.E. | ln(GDP) | ln(REC) | ln(CO2) |
| 1 | 0.1646 | 100 | 0 | 0 |
| 2 | 0.2815 | 86.3811 | 13.6067 | 0.0123 |
| 3 | 0.3477 | 81.6200 | 18.3711 | 0.0089 |
| 4 | 0.3952 | 80.8296 | 19.1608 | 0.0096 |
| 5 | 0.4397 | 80.5335 | 19.4555 | 0.0111 |
| Variance Decomposition of LOG(REC): | | | | |
| Period | S.E. | LOG(GDP) | LOG(REC) | LOG(CO2) |
| 1 | 0.0138 | 0.0600 | 99.9400 | 0 |
| 2 | 0.0190 | 6.8165 | 75.2466 | 17.9369 |
| 3 | 0.0248 | 5.6154 | 58.2323 | 36.1523 |
| 4 | 0.0304 | 4.2543 | 54.0799 | 41.6658 |
| 5 | 0.0351 | 3.9857 | 53.1278 | 42.8866 |
| Variance Decomposition of LOG(CO2): | | | | |
| Period | S.E. | LOG(GDP) | LOG(REC) | LOG(CO2) |
| 1 | 0.0866 | 0.1537 | 4.0588 | 95.7875 |
| 2 | 0.1049 | 2.7215 | 10.8928 | 86.3857 |
| 3 | 0.1081 | 2.7255 | 15.5373 | 81.7372 |

| | | | | |
|---|---|---|---|---|
| 4 | 0.1091 | 4.0746 | 15.2692 | 80.6562 |
| 5 | 0.1096 | 4.3979 | 15.5542 | 80.0478 |

Source: Authors' Computation with Eviews 10 (2020)

The GDP is strongly exogenous on CO2 emissions in both short-run and long-run periods. The variance decomposition analysis predicts promotion in the use of renewable energy technologies in the five year forecast period, although CO2 emissions will be on the high as a consequence of strong dependence in fossil fuel consumption.

This empirical study extends a recent view point in the work of Balcilar, Ozdemir, Ozdemir, & Shahbaz [5] that examines the historical time-varying effects of shocks from vector error correction model. This concept aids in explaining the effects of shocks for renewable energy consumption on economic growth and CO2 emission. This pattern of analyses has an advantage over using the coefficient estimate from the entire analysis period. The observation of shocks is done at each time period using EVIEWS 10, which has energy policy implications in explaining real events that has occurred over the years due to volatile interactions of variables.

Vector error correction model (VECM) assumes parameter to be constant over the entire period of observation, which does not account for regime shift or structural breaks in times of extreme events. VECM analyses in existing literature depends on a single positive shock of the endogenous variables. Thus, the business cycle fluctuations in the real world is as a result of impulses or shocks in which the magnitude and signs vary. Therefore, it is inefficient to justify the business cycle centred on a single shock applied on a system to effect a change on a variable or itself. This is common in the real world, that a negative shock can interrupt the stability of a positive shock applied to a system, which occur during crisis period. The historical decomposition analysis reveals the effects of relative shocks on the business cycle on real GDP, REC, and CO2 emissions over the time period from 1990 to 2015 for Nigeria.

The study's outcome indicates that the effects log(REC) shocks on log(GDP) to be mostly negative between 1990 and 2007. This can be as result of inefficient renewable technologies during these years. The period (1990 – 2007) could be called the learning period for development of renewable energy technologies. Nigeria's investment in renewable energy, during this period, had adverse effect on the economy considering the efficiency of the technology, exchange rate, and payback period. However, the effect of renewable energy consumption shocks on GDP causes a slight positive increase between 2007 and 2008. Consequently, GDP experienced a sharp decline from 2008 to 2009, which could be from the global financial crisis that affected most economies. This aligns with the growth hypothesis of [6] for developing countries. The response of GDP from REC experienced a persistent increase and positive impact from 2009 to 2015. This period is recovery in the financial world and subsequent fall in oil prices. In addition, the increase in the use of renewables technologies due to its availability, affordability and better efficiency contributed to the positive shocks in GDP.

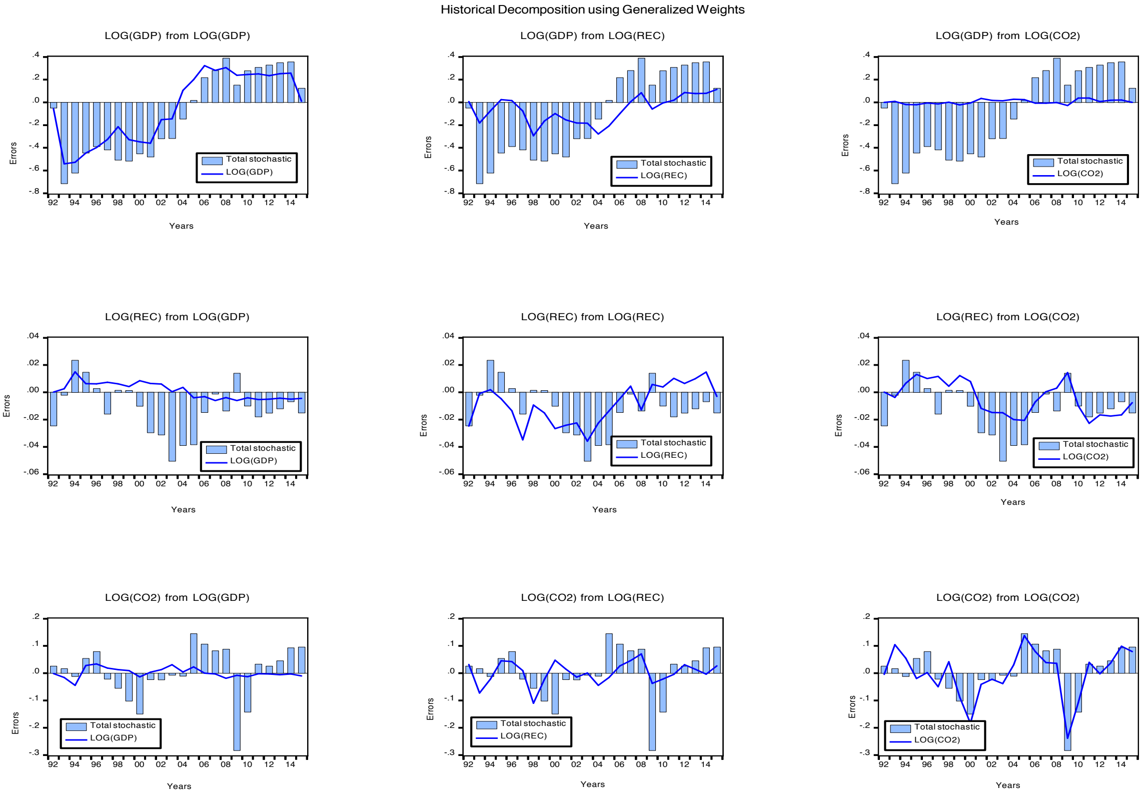


Figure 4: Historical Decomposition for Generalized Impulses: Shock Variations of log(REC), and log (CO2) from 1990 to 2015

Log = natural logarithm
Source: Authors' Computation with Eviews 10 (2020)

Moreover, some strategic policy initiatives contributed significantly to the REC growth hypothesis over the last two decades. For instance, the National Energy Policy in 2006 and 2013, focused on increasing energy security through diversification of the supply mix [23]. Before then, the National Economic Empowerment and Development Strategy (NEEDS) in 2004, sought to improve the living standards of the poor, through government financing of renewable energy projects for rural electrification [17] [31]. Furthermore, the Renewable Electricity Policy Guidelines (REPG) and Renewable Electricity Action Programme (REAP) in 2006, were established by the Federal Ministry of Power and Mining to increase competition for renewable energy producers, and joint ventures to finance projects [10]. The Nigerian National Petroleum Commission (NNPC) spearheaded the Nigerian Biofuel Policy and Incentives (NBPI) in 2007, which focused on the growth and development of domestic biofuel industry, reduce dependence on fossil fuel to reduce fossil fuel associated greenhouse gases that have adverse effect on the environment [12]. In addition, the Renewable Energy Master Plan is a policy action established by the Energy Commission of Nigeria, to promote the integration of renewable technologies in building, to on and off-grid electrical infrastructures [22]. The main goal is to increase the proportion of renewable energy in total electricity generation, from 13% in 2015 to 30% by 2030 [15].

The effect of REC shocks on CO2 emission is characterized with both negative and positive shocks that are not persistent, showing high level of inconsistency in reducing CO2 pollution. This is as a result of factors that generally affect CO2 emission in Nigeria. The factors are fossil fuel consumption, availability and efficiency of renewable energy technologies, and energy demand. The increase in green technologies to meet energy demand has led to decrease in CO2 emission.

There are slight historical shock effects between GDP and CO2 which are not significant. This presents evidence of the neutrality hypothesis between variables. Renewable energy shocks from historical GDP decomposition is negative from 2005 to 2015. Increased financial investments, research, relevant policies, and infrastructural development activities towards the deployment of renewable energy technologies will result in increased REC and reduction of CO2 emission in the Nigerian economy. Renewable energy (RE) projects require high investment and operational maintenance. As such, stakeholders and potential consumers are usually faced with issues of finance, high cost of acquiring RE technologies and unfavourable conditions to access credits. in this regard, some other factors that hinder RE market development are high interest rates, unsupportive business climate, and small number of skilled RE experts.

Renewable energy technologies such as solar photovoltaic (PV) panels, mini hydropower stations, and wind vane require research and training of energy engineers, scientist and marketers. Public and private sector grants are needed to encourage research in renewable energy technologies. The increase in skilled labour for renewables will encourage the development of renewables in Nigeria.

The study presents key policy instruments that will help tackle barriers to renewable energy development, while maintaining economic growth and reducing environmental degradation in Nigeria. Hence, key policy instruments include; subsidy and grants, feed-in-tariffs (FIT), production of tax credits, renewable portfolio standards (RPS), and loans.

Subsidies and grants does not only involve monetary support, but also a functional recovery cost mechanism that are sustainable for driving economic growth. Recovery funds are important to finance future RE projects and overhaul existing RE infrastructures. Grants given to research and development institution encourage innovations in RE technologies and skilled labour that creates employment opportunities.

Feed-in Tariffs (FIT) are payments made to end consumers for the renewable electricity generated and supplied on the grid. This policy encourages the supply of RE electricity. The government have to guarantee swift payback on investments and promote market competition to allow a level playing field for small investors. Thus, is important that the policy sustainable for the economy in the long-run.

Production of tax credits is akin to the feed-in tariff, although instead of cash payment, the RE producer accepts tax credit for each KWH generated. Another form of this is accelerated depreciation, which allows RE investments to be fully or partially deducted from tax obligations for a period of time. In some cases, tax exemptions are given to RE producers over a period of time, to help them recoup initial investment.

Renewable electricity standards (RES) are policies designed to encourage the production electricity from renewable energy sources. This policy promotes energy security and environmental quality by reducing dependence on fossil fuel. The government should ensure flexible price mechanism for different locations because natural endowments differ from location to location. Some regions can have more comparative advantage in price for renewable electricity than others.

Loans can make RE investors risk adverse due to high interest rates. The government can encourage borrowing to finance RE projects by offering low interest. Also, loan recovery mechanism is essential to ensure the finance sustainability of existing and future projects.

## 5. Conclusion

The paper examines the nexus among economic growth, renewable energy consumption and CO2 pollution. Recently, concerns of global warming and climate change are subject of global discussion. Nigeria as an energy dependent economy, is faced with energy demand increase as the economy develops. The use of fossil fuel is on the high and is detrimental to the environment. Over the years the country has shifted its attention towards incorporating renewables in the energy mix through developing policies and regulatory framework that encourages its use.

The research applied VECM on annual data for the period 1990-2015, since the variables indicate evidence of co-integration or long-run relationship among them. The study tested for co-integration using the Johansen technique. Furthermore, granger causality was tested between variables based on four principal hypotheses: neutrality, conservation, growth, and feedback hypothesis. The study also observed the historical decomposition of shocks in the vector autoregressive model (VECM), to examine the historical time-varying effects of shocks following similar work of [5]. Empirical findings indicate evidence of these hypothesis, thus present key policy instruments that can help enhance environmental standards and encourage economic growth through the development of renewables in Nigeria.

The study from the VECM estimates, indicates bi-directional causality between renewable energy consumption (REC) and economic growth (GDP). REC positively influence GDP in both the short-run and long run, while in the short-run GDP has a negative impact on REC. This confirms the feedback hypothesis similar to the results of [20] for seven CEE countries in the long-run and three CEE countries in the short-run. Renewable energy consumption has a positive influence on CO2 emission in both short-run and long-run. This is consistent with the findings of [21] that adapts the EKC methodology in Nigeria, and similar to the conservation hypothesis of [4] for BRICS countries.

Historical decomposition of shocks reveals the relative implications of renewable energy shocks on GDP to be mostly negative between period 1990 and 2007. This is as a result of inefficient renewable technologies during the period. However, there is persistent and positive influence of REC on economic growth in the period between 2009 and 2015. Increased use of renewable technologies due to its relative affordability and better efficiency contributes to the progressive influence on economic growth. The study revealed that the effect of REC shocks on CO2 emissions is characterized by negative and positive shocks that are not persistent, showing high level of inconsistency in reducing CO2 pollution. The variance decomposition analysis predicts an increase in the use of renewable energy technologies in the five year forecast period, with CO2 emissions increasing as a consequence of dependence fossil fuel energy resources.

The study finally recommends key policy instruments that will help tackle barriers to renewable energy development, simultaneously encourage economic growth and promote environmental quality in Nigeria. These key policy instruments are: renewable energy subsidy and grants for private universities and hospitals, renewable energy production tax credits, renewable portfolio standards (RPS), and loans to enable SMEs invest in renewable energy.

Renewable energy (RE) projects require high financial investments and operational maintenance costs borne most times by end consumers. Thus, it will be interesting to examine the relationship between income effects and development of renewable energy technologies in low, middle and high income economies.

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