Nyoni, Bothwell; Phiri, Andrew

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Renewable Energy - Economic Growth Nexus in South Africa: Linear, Nonlinear or Non-existent?

Bothwell Nyoni[1], Andrew Phiri[2]*

[1]Innoventon and the Downstream Chemicals Technology Station, Nelson Mandela University, South Africa, [2]Department of Economics, Faculty of Business and Economic Studies, Nelson Mandela University, Port Elizabeth, South Africa. *Email: phiricandrew@gmail.com

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ABSTRACT

With escalating fears of climate change reaching irreversible levels, much emphasis has been recently placed on shifting to renewable sources of energy in supporting future economic livelihood. Focusing on South Africa, as Africa's largest energy consumer and producer, our study investigates the short-run and long-run effects of renewable energy on economic growth using linear and nonlinear autoregressive distributive lag (ARDL) models. Working with data availability, our empirical analysis is carried out over the period of 1991-2016, and our results unanimously fail to confirm any linear or nonlinear cointegration effects of the consumption and production of renewable energy on South African economic growth. We view the absence of cointegration relations as an indication of inefficient usage of renewable energy in supporting sustainable growth in South Africa and hence advise policymakers to accelerate the establishment of necessary renewable infrastructure in supporting future energy requirements.

Keywords: Renewable Energy, Economic Growth, Autoregressive Distributive Lag, Nonlinear Autoregressive Distributive Lag, South Africa, Sub-Sahara Africa

JEL Classifications: C13, C32, C52, Q43

1. INTRODUCTION

In advancing its cause towards a globally cleaner energy environment, the International Renewable Energy Agency (IRENA) has recently released "The Global Energy Transformation: A Roadmap to 2050" (IRENA, 2015). The document mandates that "…renewable energy needs to be scaled up to at least 6 times faster for the world to start to meet the goals set out in the Paris (climate change) agreement…". In order to reach these targets, the report predicts that (i) the total share of renewable energy must more than triple from its current levels of 18% of total final energy consumption to around two-thirds or 67% by 2050, and (ii) the share of renewables in the power sector are required to be boosted from its current level of 25% to a four-fold increase of 85%. It is firmly believed that such a transition towards a renewable energy dominated world will also accelerate global progress towards the United Nations (UN) Sustainable Development Goal (SDP7) of providing access to affordable, reliable, sustainable and modern energy for all people across the global.

However, for IRENA to attain these objectives, much investment expenditure in corresponding infrastructure as well as technology is necessary, and it is predicted that the global economy would have to sacrifice approximately 2% of global GDP per annum to finance such developments. Despite such expected significant losses in future global GDP growth being required for the transition towards increased usage of renewable energies, IRENA predicts that economic benefits of investment in renewable energies outweigh their associated economic costs. The document particularly projects an additional increase in global welfare by 15%, in GDP by 1% and in employment by 1%, in comparison to forecasts derived from a reference case experiment where investment in such energy technologies were not implemented. Another striking feature of the document is its particular reference to and acknowledgement of the South African economy as the main representative country of the African continent. With South African simultaneously standing as the largest producer of energy as well as the largest emitter of carbon emissions in Africa, IRENA predicts that South Africa will benefit through increased renewable energy usage via three main channels.

Firstly, increased reliance on renewable energy is expected to immensely decrease South Africa's greenhouse gas emissions, and this decrease in carbon emissions is expected to be greater in comparison to that expected to be experienced by other countries or regions globally. Secondly, it is believed that the transition towards cleaner energy usage is expected to decrease South Africa's imports of fossil fuels and consequentially increase consumption of domestic goods and services. This, in turn, will assist in boosting the macroeconomy through increased consumer expenditure and it's resulting multiplier effects. Lastly, the combined macroeconomic effect of the energy transition is expected to increase economic growth by 3 additional percent in comparison to baseline projections in which no such renewable energy developments occur.

On the other end of the spectrum, the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) initiated in 2011 by the South African Department of Energy, serves as a blueprint for pursuing the renewable energy agenda orchestrated by IRENA. The much celebrated REIPPPP document has been glorified as the world's fastest growing energy programme and one of the largest programmes in the current infrastructure development portfolio for the South African economy. In particular, the REIPPPP programme has been a dominant force in the global renewable energy markets in terms of ushering large-scale development of energy generation infrastructure as well as providing a conducive investment environment for energy infrastructure opportunities. However, contrary to the optimism on the role of renewable energy in achieving improved economic development in South Africa, very little empirical revelation has supported this cause. To put it more precise, a majority of previous econometric analysis examining the effects of renewable energy on economic growth in South Africa have found no significant effects amongst the time series (i.e. Al-Mulali et al. (2013), Tawari et al. (2015), Cho et al. (2015) and Bhattacharya et al. (2016)), whilst a few others either find a positive short-run (Sebri and Ben-Salha (2014)) or long-run (Apergis and Payne (2011) and Khobai and Le Roux (2018)) correlations between the variables.

One avenue of empirical research which remains unscathed for the South African economy or the entire sub-Saharan region as whole for that matter, relates to the issue of possible asymmetries existing in the renewable energy-growth relationship. As recently pointed out by Mbarek et al. (2018) the finding of a non-existent relationship between renewable energy and economic growth may due to researchers dependency on linear frameworks which are not be flexible enough to capture complex, asymmetric dynamics between the variables. Consequentially, one way of circumventing this issue would be through the use of nonlinear cointegration framework and up-to-date, very few studies have adopted this empirical strategy with the existing literature exclusively focusing on non-Sub-Saharan African economies (Apergis and Payne (2010, 2011), Alper and Oguz (2016) and Mbarek et al. (2018)). Our study contributes to this relatively fresh body of empirical knowledge, by becoming the first to examine possible asymmetries in the renewable energy-economic growth nexus for South Africa. In also differing from previous 'nonlinear studies', we rely on the recently introduced nonlinear autoregressive distributive lag (N-ARDL) model of Shin et al. (2014) which offers several advantages over other contending nonlinear cointegration frameworks such as performing better in smaller sample sizes and the model's flexibility in establishing significant asymmetric cointegration relations amongst a combination of I(0) or I(1) series.

The rest of the study is organized as follows. The following section provides a brief overview of renewable energy developments in South Africa. The third section reviews the associated literature review of the study. Section four presents the model and estimation techniques and the empirical results are reported in section five. The study is then concluded in the sixth section primarily in the form of policy implications.

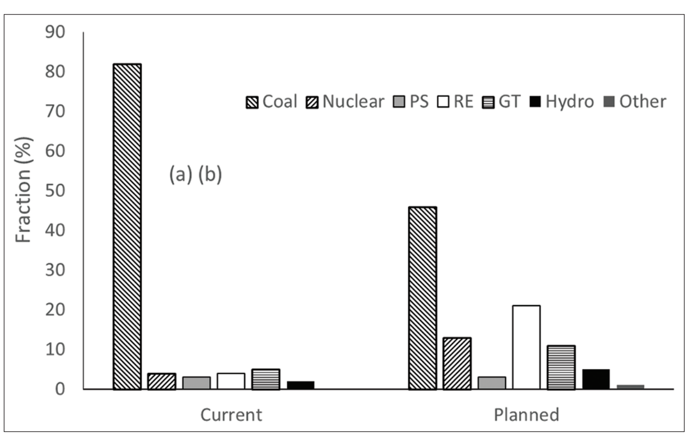
2. BRIEF OVERVIEW OF RENEWABLE ENERGY DEVELOPMENTS IN SOUTH AFRICA

South Africa is classified as a third world country with a total population of over 50 million people and, of the total population, 86% have access to electricity (Phiri and Nyoni, 2016). Eskom is the major supplier and distributor of energy through electricity production, supplying up to 95% of the total electricity consumed, the other 5% comes from independent power producers. Eskom has invested more than $22 billion since 2005 to increase its generation, transmission and distribution capacity by building state of the art power plants, expanding the transmission lines and at the same time decommissioning old inefficient power plants which has opened up opportunities for Renewable Energy Independent Power Producers (REIPP) (Eskom, 2016). However, the current plans of building three new coal power plants as means of increasing Eskom's capacity of 44,087-52,589 MW, are of great controversy, as electricity generation using coal fired power stations is the major green-house gas (GHG) producing activity in the South African energy industry. Although the nation is moving towards a renewable energy dominated energy matrix in reducing GHG emissions, it is clear that the major source of electricity in the foreseeable future will still be coal. In line with the global efforts to reduce fossil fuels consumption, the government of South Africa unveiled vital policies that are expected to lead to the successful introduction of renewable energy into the country's electricity generation matrix. Of special interest from these policies is the Renewable Energy White Paper of 2003 that stresses on formulating a strategy of translating the renewable energy goals and objectives into practicality with wind, solar and biomass being identified as sources with great potential of contributing more to the South African electricity grid by 2025 (Department of Energy, 2015).

The South African government's commitment to renewable energy rollout has been under scrutiny until a huge undertaking of obtaining approximately 18 GW of power from renewable sources was suggested (Walwyn and Brent, 2015). From 1996 three main policies were formulated, those being the White Paper on Energy Policy of 1998, White Paper on Renewable Energy of 2003 and the National Climate Change Response White Paper Policy of 2011, but with unsatisfactory implementation (Department of Energy, 2015). These policies were expected to be implemented following the guidelines of an Integrated Resource Plan (IRP) for electricity generation referred to as IRP 2010-2030. The objectives of the IRP 2010-2030 is to create a 20 year planning approach from 2010 to 2030 for the national utilities to meet the forecasted energy demand of 89.5 GW by the year 2030 (Department of Energy, 2013). The IRP 2010-2030 is supposed to be updated and improved after every 2 years. The updated versions during the course of the years have not been promulgated since 2010 making the original IRP to be used as a guideline plan for the rolling out of energy development. The latest update at the preparation of this manuscript came out in 2018 and it included a major reduction on the planned electricity from nuclear sources. The newly updated IRP has the following electricity generation contributions; 8100 MW from wind; 8100 MW from gas; 5670 MW from solar photovoltaic; 2500 MW from hydro and 1000 MW from coal (Department of Energy, 2018). The updated IRP suggests that the planned electricity generation from renewable sources will be 27%, a huge increase from the original allocation of 21%. The major reasons why the contribution of renewables has been increased in the IRP is the evident decrease of the cost of renewable sources and the extensive research that is currently being undertaken in the field of renewable energy. The original (i.e. 2010) and planned (i.e. 2030) electricity generation matrix are shown in Figure 1. The major sources of electricity being coal, nuclear, pumped storage (PS), renewable energy, gas turbine, hydro and others (Department of Energy, 2011). In general, it is clear that renewable energy sources are currently contributing less energy compared to non-renewable ones.

In the original plan, renewable energy technologies were expected to be contributing up to 21% of the total energy mix, thereby reducing the coal contribution to 46%. By the year 2015 more than 37 REIPPs, mostly using solar and wind as energy sources, have been connected to the national grid supplying a total of 1750 MW, 4% of the total energy (Department of Energy, 2015). Despite developing policies that seemed to usher South Africa into an era of renewable energy sources, the government has not yet shown commitment in terms of the physical development of renewable energy technologies. Greenpeace (2011) argues that since the adoption of the Renewable Energy White Paper of 2003, very little action has been undertaken by government on renewable energy compared to coal infrastructure. Furthermore, the government has left most of the development with regards to renewable energy to be in the hands of private investors.

Figure 1: South Africa's original plan on future electricity generation matrix



3. LITERATURE REVIEW

Empirical interest concerning the relationship between renewable energy and economic development gained prominence following the Oil embargo of the 1970's and ushered in a variety of renewable energy conversion techniques through technological development process (Sorensen, 1991). Although, initial empirical interest was particularly focused on the effect which energy consumption has on economic development (Kraft and Kraft (1978), Akarca and Long (1980), Yu and Hwang (1984), Yu and Choi (1985), Hwang and Gum (1991) and Yu and Jin (1992)), much more recent research has specifically focused on the relationship between renewable energy consumption and economic growth more prominently so for industrialized and European countries (Sardorsky (2009), Apergis and Payne (2010), Ocal and Aslan (2013), Lin and Moubarak (2014), Shahbaz et al. (2015), Inglesi-Lotz (2016), Rafindadi and Ozturk (2017), Kocak and Sarkgunesi (2017), Kahia et al. (2017)). For the specific case of South Africa the literature is not as exhaustive with the works of Apergis and Payne (2011), Al-Mulali et al. (2013), Sebri and Ben-Salha (2014), Tawari et al. (2015), Cho et al. (2015), Bhattacharya et al. (2016) as well Khobai and Le Roux (2018) serving as the studies available in the entire literature.

Apergis and Payne (2011) were among the first to include South Africa in a panel of 80 developing and developing countries in investigating the relationship between renewable energy and growth over the period 1990 and 2007. Relying on the FMOLS estimates, the authors are able to establish that in both industrialized and developing countries, renewable energy is a positive and significant contributor to economic growth. Using time series collected between 1980 and 2009, Al-Mulali et al. (2013) apply the FMOLS to investigate the renewable energy-growth nexus for 108 countries of which South Africa forms part of the panel sample. In differing from Apergis and Payne (2011), the study of Al-Mulali et al. (2013) establishes an insignificant relationship between renewable energy and economic growth for South African data.

On the other hand, Sebri and Ben-Salha (2014) investigate the impact of renewable energy, carbon emissions and trade openness on economic growth for the BRICS (Brazil, Russia, India and Chana) over the period 1971 and 2010. Using ARDL, FMOLS and DOLS estimates the authors particularly find no long-run correlation between renewable energy and economic growth for the South African economy using all estimators whilst the short-run estimates on the renewable energy variable obtained from the ARDL model are positive and statistically significant. Cho et al. (2015) investigate the renewable energy-growth relationship for a panel of 31 OECD and 49 non-OECD countries between 1990 and 2010. In particularly using the FMOLS and the VECM methodology and discover a positive and significant influence of renewable energy on economic growth for both OCED and non-OECD panels.

In a separate study, Bhattacharya et al. (2016) investigate the renewable energy-growth nexus for the top 38 countries, inclusive of South Africa, between 1991 and 2012. The authors employ two approaches; the first is the panel FMOLS and DOLS, whereas the second estimates the individual DOLS estimates for each of the observed countries. For the entire panel, the authors find a positive and significant effect of renewable energy on economic growth for the entire panel whilst for individual country estimates, the long-run elasticity coefficient for the South African economy turns insignificant. More recently, Khobai and Le Roux (2018) use the ARDL and VECM models to investigate the relationship between renewable energy and economic growth in South Africa between the periods 1990 and 2014. The authors are able to establish that renewable energy is a contributing factor towards to economic growth in both the long-run and short-run, which is contrary to the findings of Apergis and Payne (2011), Al-Mulali et al. (2013), Sebri and Ben-Salha (2014), Tawari et al. (2015), Cho et al. (2015), Bhattacharya et al. (2016) but similar to the result found in the long-run for the panel study of Apergis and Payne (2011) and the short-run in the country-specific analysis of Sebri and Ben-Salha (2014).

In pooling together the above reviewed studies for the South African economy, it is interesting to note that all previous studies mutually employ linear cointegration models in reaching their final empirical conclusions. This is certainly of concern since the time periods covered in these previous studies extend over a host of structural breaks, most notably, the Asian financial crisis of 1999, the sub-prime crisis of 2007 as well as the Euro sovereign debt crisis of 2010. As critically argued and demonstrated in the recent works of Argesi and Payne (2011), Alper and Oguz (2016) and Mbarek et al. (2018), relying on linear frameworks in the presence of such structural breaks and asymmetries are likely to lead to problems of model mis-specification and consequentially misinformed policy implications. In following along this line of thinking, the empirical theme of this current paper, is that, perhaps incorporating nonlinearities in our empirical study would yield clearer results and hopefully direct the South African literature into a more decisive consensus.

4. EMPIRICAL MODEL

4.1. Baseline Econometric Model

Methodologically, Fang. (2011), Tugcu et al. (2012) and Inglesi-Lotz (2016), all rely a production function augmented with technical progress in order to theoretically and empirical quantify the impacts of renewable energy on economic welfare. The basic production function can be represented as follows:

$$Y = A\,(Kt)\alpha\,(Ht)\beta \qquad (1)$$

Where A is total factor productivity, Yt is the GDP growth rate, Kt is the physical capital, Ht is human capital, α and β are the elasticities of physical and human capital, respectively. Fang (2011) particularly highlights the problem of omission of the technical progress term in equation (1), and suggests the augmentation of the traditional production function with measures of renewable energy. In addition, we also add control variables from conventional growth theory such as government size, inflation and openness. We therefore present the following log-linear growth regression:

$$\begin{aligned} Ln(Yt) = Ln(A) + \alpha 1\, Ln(REt) + \alpha 2\, Ln(Kt) + \alpha 3\, Ln(Ht) \\ + \alpha 4\, Ln(Gt) + \alpha 5\, Ln(\pi t) + \alpha 6\, Ln(Xt) \end{aligned} \qquad (2)$$

Where REt is renewable energy, πt is the inflation rate and Xt is the international trade. And by taking the derivatives on both sides of equation (2) with respect to time, t, produces the following growth specification:

$$yt = \alpha 0 + \alpha 1\, ret + \alpha 2\, kt + \alpha 3\, ht + \alpha 4\, \pi t + \alpha 5\, gt + \alpha 6\, xt + et \qquad (3)$$

Where yt = Y_t /Yt, ret = RE_t/REt, kt = K_t/Kt, ht =H_t/Ht, gt = G_t/Gt, πt = π_t/πt, Xt = X_t/Xt, α1,…., α 5, are the elasticity measures of the independent variables to economic growth and et is a well behaved error term. Having specified our baseline regression specification reflected in equation (3), we proceed to outlay the econometric procedures used to carry out our empirical analysis.

4.2. Linear ARDL Model

In order to model our baseline cointegration relations between economic growth, renewable energy and other growth determinants, we specify a linear ARDL model as in the spirit of Pesaran et al. (2001). We choose the ARDL model over other contending cointegration models, such as the Engle and Granger (1987) or the vector error correction model (VECM) proposed by Johansen (1991) since the ARDL model (i) allows for modelling of time series variables whose integration properties are either I(0) or I(1) (ii) is suitable with small sample sizes and (iii) provides unbiased estimates of the long-run model even when some of the estimated regressors are endogenous. The conditional unrestricted equilibrium correction model (UECM) is specified as:

$$\Delta y_t = c_0 + \pi_{yy} y_{t-1} + \pi_{yx.x} x_{t-1} + \sum_{i=1}^{p-1} \psi'_i z_{t-i} + \delta' v_t + \xi_t \qquad (4)$$

Where Δ is a first difference operator, c0 is the intercept term, vt = (ret, kt, ht, gt, πt, xt), zt = (yt, vt), πyy and πyx. are the parameter vector of long-run elasticities, ψ'i. and δ' are the parameter vector of short-run-run elasticities, whereas ξt is a well-behaved disturbance term. To test for cointegration, Pesaran et al. (2001) define the constituent null hypothesis of no cointegration as

$$H0: \pi yy = 0,\ H0: \pi yx.x = 0 \qquad (5)$$

And this is tested against the alternative hypothesis of significant cointegration effects,

$$H0: \pi yy = 0,\ H0: \pi yx.x = 0 \qquad (6)$$

Pesaran et al. (2001) derive two sets of asymptotic critical values are provided for cases where all time series are I(1), purely I(0) or mutually cointegration. The bounds test for cointegration is evaluated via a conventional Wald or F-statistic. The decision rule for the tests is certain if the statistic falls outside the critical bounds values and inconclusive if the statistic falls within the critical bounds values. Only if the computed test statistic exceeds its upper bounds critical values are short-run and long-run ARDL effects deemed to exist with the transition between the two facilitated through an error correction mechanism.

4.3. Nonlinear ARDL Model

To derive the long-run asymmetric model regression used to investigate possible nonlinear cointegration relationship between renewable energy and economic growth, we follow in pursuit of Shin et al. (2014) and partition the renewable energy parameters into partial sum processes of positive and negative changes in ret which are specifically defined as:

$$re_{it}^{+} = \sum_{j=1}^{i} \Delta re_{it}^{+} = \sum_{j=1}^{i} \max(\Delta re) \quad (7)$$

$$re_{it}^{-} = \sum_{j=1}^{i} \Delta re_{it}^{-} = \sum_{j=1}^{i} \min(\Delta re) \quad (8)$$

Shin et al. (2014) demonstrate that the model regression (4) can be transformed into the following nonlinear error correction representation:

$$\Delta y_t =_0 + \sum_{i=1}^{n1} \psi y_{t-1} + \sum_{i=1}^{n2} \lambda_{1i} re_{t-i}^{+} + \sum_{i=1}^{n3} \lambda_{2i} re_{t-i}^{-} + \sum_{i=1}^{n4} \lambda_{3i} k_{t-i}$$
$$+ \sum_{i=1}^{n5} \lambda_{4i} h_{t-i} + \sum_{i=1}^{n5} \lambda_{5i} g_{t-1} + \sum_{i=1}^{n6} \lambda_{6i} \pi_{t-1} + \sum_{i=1}^{n7} \lambda_{7i} x_{t-1} + \rho y_{t-i} + \delta_1 re_{t-i}^{+}$$
$$+ \delta_2 re_{t-i}^{-} + \delta_3 k_{t-i} + \delta_4 h_{t-i} + \delta_5 g_{t-i} + \delta_6 \pi_{t-i} + \delta_7 x_{t-i} + \xi_t \quad (9)$$

The traverse between short-run disequilibrium and the new long-run steady state of the system can be estimated through the following cumulative dynamic multipliers:

$$M_h^{+} = \sum_{j=0}^{n} \frac{\partial y_{t+j}}{\partial re_i^{+}}, M_h^{-} = \sum_{j=0}^{n} \frac{\partial y_{t+j}}{\partial re_i^{-}}, h = 0,1,2\ldots. \quad (10)$$

Where M_h^{+} and $M_h^{+} \rightarrow \beta+$ and β−, respectively as h→∞. Note that the long-run coefficients are computed as β+ = −(δ1/ρ) and β− = − (δ2/ρ), respectively, with the nonlinear error correction term is computed as $\xi t-1 =$ GDPt $- \beta +' X_h^{+} - \beta -' X_h^{-}$. Moreover, Shin et al. (2014) suggest the testing of three hypotheses in order to validate asymmetric cointegration effects within the specified N-ARDL model. The first is an extension of the non-standard bounds-based F-test of Pesaran et al. (2001) which is used to test for overall asymmetric cointegration relations i.e.

$$\text{H01: } \rho = \lambda 1 = \lambda 2 = 0 \quad (11)$$

The second hypothesis tests for long-run asymmetric effects in which the null hypothesis of no long-run asymmetric effects is tested as:

$$\text{H02: } \rho = \beta+ = \beta- \quad (12)$$

Whereas the empirical final hypothesis which is formulated concerns short-run asymmetric effects whereby the null hypothesis of no short-run asymmetric effects is tested as:

$$\text{H03: } \delta 1 = \delta 2 \quad (13)$$

Note that the latter two null hypotheses of 'no long-run' and 'no short-run' asymmetric effects can be evaluated by relying on standard Wald tests.

5. DATA AND EMPIRICAL ANALYSIS

5.1. Data Description and Unit Root Tests

Our empirical models are estimated with data retrieved from the World Bank online database and to ensure the series are consistent with the variables specified in our theoretical and empirical growth regressions, we collect the following 9 time series; GDP growth (yt), renewable energy consumption as percentage of total final energy consumption (re), combustible renewables and waste as a percentage of total energy (re_comb), renewable electricity output as a percentage of total electricity output (re_elec), gross fixed capital formation as a percentage of GDP (kt), secondary schooling enrolment (ht), general government final consumption expenditure as a percentage of GDP (gt), CPI inflation (π) and trade as a percentage of GDP (xt). Note that we employ three measures of renewable energy (re, re_comb, re_elec) to enforce robustness of our empirical analysis and since these measures of renewable energy are only available from 1991 to 2016, we limit the scope of our entire study to this period. To get a better picture of the time series, Table 1 presents the descriptive statistics of the time series in Panel A and their correlation matrix in Panel B. We are quick to note that from the correlation matrix, only the renewable energy consumption as percentage of total final energy consumption (re) has a positive correlation with economic growth whereas the other two measures of renewable energy (i.e. combustible renewables and waste as a percentage of total energy (re_comb) and renewable electricity output as a percentage of total electricity output (re_elec)) produce unconventional negative correlations with growth. Nevertheless, these preliminaries are still to be validated via formal cointegration analysis.

Even though pre-testing for stationarity is not so much a priority for the ARDL and nonlinear ARDL models, we consider unit root testing of the time series as a relevant exercise, just to ensure that none of the variables are integrated of an order I(2) or higher. Table 2 presents the ADF and DF-GLS unit root tests as performed on the levels (Panel A) and first differences (Panel B) of our observed time series variables. Note that all tests have been performed with an intercept as well as with both an intercept and trend. The unit root tests produce rather mixed results for the series when performed in their levels, with the order of integration not only differing amongst the variables but also differing amongst the same variable performed with different tests. However, the results appear more transparent in their first differences with all series managing to reject the unit root hypothesis, with the sole exception of the ADF tests performed on the schooling variable.

Table 1: Descriptive statistics and correlation matrix

	y	re	re_comb	re_elec	k	h	g	π	x
Panel A: Descriptive statistics									
	2.62	17.25	10.97	0.73	18.46	87.71	19.20	6.87	54.66
	2.99	17.11	10.99	0.67	18.99	89.55	18.98	5.78	55.11
	5.60	19.12	12.18	1.29	23.51	102.75	20.80	15.33	72.87
	−1.54	15.57	9.65	0.08	15.15	65.01	17.81	1.39	38.05
	2.03	0.99	0.60	0.32	23.36	9.43	0.84	3.48	8.74
	−0.51	0.14	−0.16	0.21	0.25	−0.85	0.33	1.11	−0.12
	2.54	1.91	2.69	2.24	2.14	3.66	1.99	3.71	2.64
	1.04	1.32	0.21	0.79	0.83	2.79	1.19	4.54	0.15
	0.59	0.52	0.90	0.67	0.66	0.25	0.55	0.10	0.93
Panel B: Correlation matrix									
y	1								
re	0.04	1							
re_comb	−0.06	0.81	1						
re_elec	−0.12	−0.17	0.18	1					
k	−0.33	−0.81	−0.75	−0.01	1				
h	0.42	−0.42	−0.60	0.07	0.21	1			
g	−0.23	−0.15	−0.29	0.14	0.14	0.41	1		
π	−0.59	0.01	0.19	0.13	0.39	−0.69	−0.26	1	
x	0.42	−0.45	−0.59	0.12	0.43	0.81	0.12	−0.29	1

Table 2: Unit root test results

variables	ADF		DF-GLS	
	Intercept	Intercept and trend	Intercept	Intercept and trend
Panel A: Levels				
y	−2.78*	−2.63	−2.46**	−2.67
re	−2.81*	−3.86**	−2.73***	−4.06***
re_com	−1.80	−3.08	−1.76*	−2.74
re_elec	−2.81*	−3.86**	−2.73***	−4.06***
k	−2.34	−3.03	−2.19**	−2.69
h	−1.16	−2.97	0.10	−2.46
g	−1.47	−2.38	−1.44	−2.53
π	−3.52**	−3.49*	−1.85*	−2.51
x	−1.65	−2.86	−1.40	−3.02
Panel B: First differences				
y	−5.51***	−5.34***	−5.56***	−5.14***
re	−4.38***	−4.42***	−4.07***	−5.11***
re_com	−4.91***	−4.77***	−4.81***	−4.99***
re_elec	−4.38***	−4.42**	−4.07***	−5.11***
k	−3.45**	−3.29*	−2.98***	−3.33**
h	−2.66	−2.54	−3.74***	−4.37***
g	−4.95***	−4.97***	−5.05***	−5.17***
π	−4.66***	−5.48***	−2.06**	−5.53***
x	−5.80***	−5.37***	−5.35***	−5.86***

"***", "**", "*" represent 1%, 5% and 10%, respectively

However, given the relative stronger power offered by the DF-GLS test especially in sample samples we conclude that none of our employed series is integrated of an order higher than I(2). We are hence permitted to proceed with our modelling and estimation of our ARDL and NARDL regressions with less fear of spurious regression estimates.

5.2. Analysis from Linear Regression Estimates

Using our four measures of renewable energy, we model three ARDL model specifications (i.e. f(y|re, k, h, g, π, x), f(y|re_comb, k, h, g, π, x), f(y|re_elec, k, h, g, π, x)), and as a first step in our modelling process we place a maximum lag restriction of p+4, q=4, and then sequentially trim down on the lags until we identify the model regression which produces the minimum information criterion value. Both the AIC and SC criterion predict optimal lags of p=1, q=0 for all model specifications. To ensure cointegration effects exist within our selected ARDL(1,0,0,0,0,0,0) specifications, we perform bounds test on the chosen model with the results of this empirical exercise being reported in Table 3 below. The computed F-statistics of 4.32, 5.08 and 4.38 all exceed the corresponding 99% critical bound value of 3.99 hence supplying strong evidence of cointegration effects with our ARDL specifications.

We present our baseline linear estimates in Table 4, and in supplementing our ARDL specifications we provide long-run estimates from OLS and dynamic OLS estimators yielding a total of 12 long-run and 4 short-run regressions. The results from the long-run estimates reported in Panel A of Table 4 are mixed, being similar in coefficient sign across the different estimators but differing in coefficient significance. The most consistent finding amongst the regression is that of an insignificant long-run coefficient on all 4 renewable energy coefficients across all 12 estimated regressions. In context of the South African literature, our findings concur with those previous found in Al-Mulali et al. (2013), Tawari et al. (2015), Cho et al. (2015) and Bhattacharya et al. (2016) yet differs from that found in Sebri and Ben-Salha (2014), Apergis and Payne (2011) and Khobai and Le Roux (2018).

The findings reported for the short-run coefficients in Panel B of Table 4 are no else different, with the renewable energy coefficient being statistically insignificant across all four estimated ARDL regressions. The remaining short-run regression coefficients are particularly significant for the government size (Δg) and exports (Δx), variables being negative for the former and positive for the later which are more or less consistent with the previous results recently found in Sunde (2017) and Phiri (2018). Similarly, insignificant coefficients on the human capital development and domestic investment variables have been previously found in the works of Biza et al. (2015) and Malangeni and Phiri (2018) and who respectively explain that high level of government spending and accumulated debt most likely crowd out domestic investment whilst the low quality of human capital is responsible for it's non-contribution to sustainable growth.

Table 3: ARDL bounds test for cointegration

Panel A: Test statistics		
Model function	**Selected specification**	**F-statistic**
f(y|re, k, h, g, π, x)	ARDL(1,0,0,0,0,0,0)	4.32***
f(y|re_com, k, h, g, π, x)	ARDL(1,0,0,0,0,0,0)	5.08***
f(y|re_ele, k, h, g, π, x)	ARDL(1,0,0,0,0,0,0)	4.38***
Panel B: Critical bounds value		
Significance (%)	**I(0) bound**	**I(1) bound**
10	1.99	2.94
5	2.55	3.28
1	2.88	3.99

"***", "**", "*" represent 1%, 5% and 10%, respectively

5.3. Analysis from Nonlinear Regression Estimates

Having modelled our baseline ARDL specifications, we proceed to investigate for possible nonlinear effects between renewable energy and economic growth in South Africa. To this end, we modify our previous ARDL model regressions by portioning the renewable energy variables into their positive and negative elements which then produces a nonlinear ARDL growth specification. As before, we begin our modelling process by testing for nonlinear cointegration effects and to recall, there are three tests which are used to this end namely, the F-statistic for general asymmetric cointegration as well as the two Wald test statistics for long-run and short-run asymmetries. These test statistics are reported in Panel A of Table 5 alongside the optimal lag length selection whilst Panel B reports their associated 1%, 5% and 10% critical values. The reported F-statistics of 5.63, 5.65 and 5.40

Table 4: Linear regression estimates for renewable energy-growth regressions

	f(y/re, k, h, g, π, x)			f(y/re_com, k, h, g, π, x)			f(y/re_ele, k, h, g, π, x)		
	OLS	FMOLS	ARDL	OLS	FMOLS	ARDL	OLS	FMOLS	ARDL
Panel A: Long-run									
Re	−0.45	0.01 (0.98)	−0.38 (0.61)						
re_comb				−1.06 (0.25)	−0.21 (0.85)	−2.09 (0.14)			
re_elec							−0.45 (0.51)	0.01 (0.98)	−0.38 (0.61)
K	−0.26 (0.22)	0.01 (0.99)	−0.24 (0.29)	−0.49 (0.14)	−0.01 (0.98)	−0.89 (0.11)	−0.26 (0.22)	0.01 (0.99)	−0.24 (0.29)
h	−0.10 (0.43)	−0.21 (0.06)*	−0.14 (0.46)	−0.12 (0.33)	−0.24 (0.09)*	−0.02 (0.88)	−0.10 (0.43)	−0.21 (0.06)*	−0.14 (0.46)
g	−0.62 (0.36)	−0.92 (0.02)**	−0.55 (0.51)	−0.65 (0.34)	−0.92 (0.01)**	−0.77 (0.33)	−0.62 (0.36)	−0.92 (0.01)**	−0.55 (0.51)
π	−0.36 (0.09)*	−0.57 (0.00)***	−0.41 (0.19)	−0.29 (0.11)	−0.60 (0.03)**	−0.10 (0.69)	−0.36 (0.09)*	−0.57 (0.00)***	−0.41 (0.19)
x	0.18 (0.09)*	0.23 (0.00)***	0.19 (0.10)	0.18 (0.09)*	0.24 (0.00)***	0.15 (0.18)	0.18 (0.09)*	0.23 (0.00)***	0.19 (0.10)
Panel B: Short-run									
Δre			−0.45 (0.49)						
Δre_com						−2.05 (0.06)*			
Δre_elec									−0.45 (0.47)
Δk			0.08 (0.84)			−073 (0.02)**			0.08 (0.84)
Δh			−0.06 (0.70)			0.02 (0.89)			−0.06 (0.70)
Δg			−1.36 (0.05)*			−1.65 (0.02)**			−1.36 (0.05)*
Δπ			−0.28 (0.13)			0.02 (0.91)			−0.28 (0.13)
Δx			0.19 (0.09)*			0.17 (0.09)*			0.19 (0.09)*
ect(−1)			−1.21 (0.02)**			−1.08 (0.00)***			−1.21 (0.02)**

"***", "**". "*" denote 1%, 5% and 10% critical levels, respectively reported in Panel A suggest the presence of overall asymmetric cointegration effects for the three regressions, f(y|re+, re−, k, h, g, π, x), f(y|re_comb+, re_comb−, k, h, g, π, x) and f(y|re_elec+, re_elec−, k, h, g, π, x), respectively. On the other hand, the Wald statistics for long-run asymmetries (0.18 for f(y|re+, re−, k, h, g, π, x), 0.07 for f(y|re_comb+, re_comb−, k, h, g, π, x) and 0.01 for f(y|re_elec+, re_elec−, k, h, g, π, x)) as well as those for short-run asymmetries (1.25 for f(y|re+, re−, k, h, g, π, x), 0.56 for f(y|re_comb+, re_comb−, k, h, g, π, x) and 0.43 for f(y|re_elec+, re_elec−, k, h, g, π, x)) are all insignificant as their values are below the lower 10% critical bound level of 1.92.

The insignificant short-run coefficients on both positive and negative partitions of the renewable energy variable displayed in Panel A of Table 6 further reinforces the insignificant asymmetric short-run Wald statistics previously observed. The remaining short-run coefficient coefficients are more or less the same as that found for the linear ARDL estimates. Similarly, the long-run coefficient estimates reported in Panel B of Table 7 are identical to those of the linear ARDL estimates including the insignificant coefficient estimates observed on both positive and negative partitions of the renewable energy variable. In collectively tying together our results, we conclude on insignificant effects of renewable energy on economic growth over the long-run as well as a linear short-run correlation between the series.

5.4. Diagnostic Tests and Stability Analysis

Owing to the extensiveness of our empirical estimates, we present the residual diagnostics tests and stability analysis in two tables. The first table, Table 5, collectively reports the results obtained for all 12 estimated linear equations whereas Table 8 reports the findings from the 4 estimated nonlinear regressions. Panels A of both Tables 5 and 8, reports the residual test statistics for normality, serial correlation, heteroscedasticity and functional form, whereas Panel B of both Tables present a summary of the CUSUM and squares of CUSUM (CUMSUMSQ) stability tests. As can be observed, all produced tests statistics reported in Tables 5 and 8 are encouraging in the sense of finding well-behaved disturbance

Table 5: Diagnostic tests and stability analysis for linear regressions

	f(y/re, k, h, g, π, x)			f(y/re_comb, k, h, g, π, x)			f(y/re_elec, k, h, g, π, x)		
	OLS	FMOLS	ARDL	OLS	FMOLS	ARDL	OLS	FMOLS	ARDL
Panel A: Residual diagnostics									
normality	0.09 (0.95)	3.12 (0.21)	0.35 (0.84)	0.28 (0.87)	2.24 (0.33)	0.29 (0.87)	0.09 (0.95)	3.12 (0.21)	0.35 (0.84)
SC	0.55 (0.59)		0.89 (0.44)	0.42 (0.67)		0.49 (0.63)	0.55 (0.59)		0.89 (0.44)
het	0.37 (0.89)		0.79 (0.61)	0.31 (0.92)		0.59 (0.75)	0.37 (0.89)		0.79 (0.61)
FF	0.39 (0.70)		0.29 (0.78)	0.04 (0.97)		0.01 (0.99)	0.39 (0.70)		0.29 (0.78)
Panel B: Stability analysis									
CUSUM	Stable		Stable	Stable		Stable	Stable		Stable
CUSUMSQ	Stable		Stable	Stable		Stable	Stable		Stable

Table 6: N-ARDL regression estimates

	f(y|re, k, h, g, π, x)		f(y|re_comb, k, h, g, π, x)		f(y|re_ele, k, h, g, π, x)	
	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value
Panel A: Short-run						
Δre(+)	−1.19	0.24				
Δre(−)	0.02	0.98				
Δre_comb(+)			−1.27	0.42		
Δre_comb(−)			−0.93	0.50		
Δre_elec(+)					−1.19	0.24
Δre_elec(−)					0.02	0.98
Δk	0.02	0.51	−0.16	0.75	0.35	0.51
Δh	−0.05	0.81	−0.10	0.58	−0.05	0.81
Δg	−1.18	0.09*	−1.76	0.02**	−1.19	0.09*
Δπ	−0.43	0.05*	−0.11	0.66	−0.43	0.05*
Δx	0.24	0.04*	0.15	0.13	0.24	0.04*
ect(−1)	−1.34	0.02**	−1.39	0.00***	−1.34	0.02**
Panel B: Long-run						
re(+)	−0.77	0.56				
re(−)	0.06	0.96				
re_comb(+)			−1.95	0.19		
re_comb(−)			−2.22	0.20		
re_elec(+)					−0.77	0.56
re_elec(−)					0.06	0.96
K	−0.15	0.49	−0.93	0.12	−0.15	0.49
H	−0.10	0.71	−0.03	0.83	−0.09	0.71
G	−0.33	0.72	−0.89	0.45	−0.33	0.72
Π	−0.48	0.10	−0.07	0.81	−0.48	0.10
x	0.24	0.05*	0.13	0.37	0.24	0.05*

"***", "**", "*" represent 1%, 5% and 10%, respectively. P-values reported in parentheses ()

Table 7: NARDL tests for nonlinear cointegration

Panel A: Test statistics				
Model function	**Selected specification**	**F-statistic**	**LR**	**SR**
f(y|re+, re−, k, h, g, π, x)	ARDL(1,1,0,0,0,0,0,0)	5.63***	0.18	1.25
f(y|re_comb+, re_comb−, k, h, g, π, x)	ARDL(1,1,0,0,0,0,0,0)	5.65***	0.07	0.56
f(y|re_elec+, re_elec−, k, h, g, π, x)	ARDL(1,1,0,0,0,0,0,0)	5.40***	0.01	0.43
Panel B: Critical value bounds				
Significance (%)	**I(0) bound**		**I(1) bound**	
10	1.92		2.89	
5	2.17		3.21	
1	2.73		3.90	

"***", "**", "*" represent 1%, 5% and 10%, respectively

Table 8: Diagnostic tests and stability analysis for nonlinear regressions

	f(y/re, k, h, g, π, x)		f(y/re_com, k, h, g, π, x)		f(y/re_ele, k, h, g, π, x)	
	Coefficient	**P-value**	**Coefficient**	**P-value**	**Coefficient**	**P-value**
Panel A: Residual diagnostics						
norm	0.34	0.84	0.44	0.80	0.34	0.84
SC	1.03	0.40	0.39	0.69	1.03	0.40
Het	0.63	0.74	0.54	0.80	0.63	0.74
FF	0.32	0.76	0.01	0.99	0.32	0.76
Panel C: Stability analysis						
CUSUM	Stable		Stable		Stable	
CUSUMSQ	Stable		Stable		Stable	

terms, correct function form as well as regression stability within a 5% critical level. Altogether these findings from Tables 5 and 8, persuade us to accept our findings from our empirical regressions of an insignificant influence of renewable energy on economic growth in South Africa over both the short-run and the long-run.

6. CONCLUSSION

Inspired by advancements in the recent empirical literature, our current study sought to investigate the possibility of a nonlinear cointegration relationship between renewable energy and economic growth for the South African economy. An in-depth review of the previous literature reveals that former South African studies concerned with the renewable energy-growth relationship, have all assumed a linear relationship between the time series and this has resulted in a variety of conflicting empirical evidences. In re-examining the empirics, we apply both linear and nonlinear ARDL econometric models to estimate dynamic growth regressions augmented with renewable energy as a technological input using time series data collected between 1991 and 2017. To ensure robustness of our analysis we employ three measures of renewable energy namely, (i) renewable energy consumption as percentage of total final energy consumption, (ii) combustible renewables and waste as a percentage of total energy and (iii) renewable electricity output as a percentage of total electricity output. Despite our empirical findings advocating for significant cointegration effects, the influence of renewable energy on economic growth is not statistically different from zero regardless of the measure of renewable energy employed or whether a linear or nonlinear econometric model is estimated.

So, what is there to learn from our current study. Firstly, our findings resemble a bulk majority of previous South African studies which have found no influence of renewable energy on economic growth (Al-Mulali et al. (2013), Tawari et al. (2015), Cho et al. (2015) and Bhattacharya et al. (2016)). Considering that these former studies relied on linear frameworks whereas our study makes use of nonlinear models, the common finding of no relationship between renewable energy and growth pushes the literature closer to a mutual consensus. Secondly, the insignificance of renewable energy towards economic growth indicates that South Africa may not yet be ready to make a full transition into an economy dominated by renewable energy sources. On the forefront of concerns facing renewable energy dependency are the anticipated job losses expected to occur in the mining sector which could further distort an already fragile labour market. Another concern which may serve as a hindrance to growth opportunities for renewable energy is that the market structure for energy in South Africa is monopolized by the government parastatal, ESKOM, and hence renewable energy cannot feasibly compete with traditional, fossil fuel dominated of energy production in terms of both productivity and employment creation. However, with escalating global environmental pressures, it is in the best interest of the South African government to pursue renewable energy strategies by particularly focusing on legislative issues prohibiting the uptake of renewable energy sources and the limited access of independent power producers to the national energy grid.

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