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An Empirical Analysis of Short Run and Long Run Relationships between Energy Consumption, Technology Innovation and Economic Growth in Saudi Arabia

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ABSTRACT

This study investigates the short- and long-run relationships between energy consumption, technology innovation and economic growth in Saudi Arabia. The direction of causality between them was also determined using Granger causality. The data covers the period between 1980 and 2015, and autoregressive distributed lag (ARDL) was used for analysis as the series consist of the mixture of I(0) and I(1) order of integration. The results reveal that the variables are cointegrated which establish the existence of long run relationships between them. In the long-run, technology innovation has a negative effect on energy consumption while economic growth has a positive effect on energy consumption. Similar result was found in the short run. The results of the Granger causality show a unidirectional causality runs from technology innovation and economic growth to energy consumption. The results of this study support intensive investment in R&D and technology innovation by Saudi government and private companies as well as the implementation of energy efficiency and conservation policies to reduce energy demand, as this would not hamper the economic growth of Saudi Arabia. Government should fully explore the use of renewable energy sources and technologies such as solar and wind to bring about sustainable development in the country.

Keywords: Energy Consumption, Technology Innovation, Economic Growth, Saudi Arabia, Conservation Policies, Autoregressive Distributed Lag, Vision 2030
JEL Classifications: B13, C01, O32, Q43, Q54, Q58

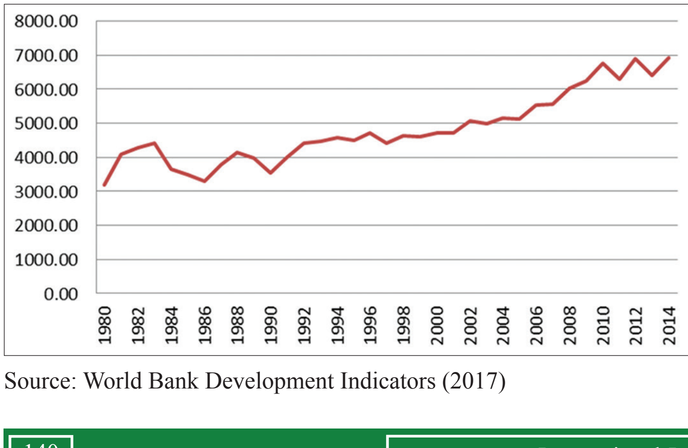
1. INTRODUCTION

Energy has been recognised as growth agent in every sector of economy across the world. It is an essential input in production and plays a vital role in the socio-economic and technological growth and development of a nation (Heinberg, 2003). Energy access is also important in all aspects of human development as it is a sine-qua-non to certain basic activities, such as heating, lighting, refrigeration and the running of household appliances, which would ordinarily not be possible without energy (Ogundari et al., 2017; Iwayemi, 2008). The level of energy consumption by the citizens of a country has been used as a yardstick for determining the country's energy poverty status as country with a low energy consumption per capita are relatively termed energy poor (Sambo, 2008; Akinwale et al., 2015). Many studies (Ozturk, 2010; Tang and Tan, 2013; Shahbaz et al., 2013; Khan et al., 2016; Ameyaw et al., 2017) have shown the positive relationship between energy consumption and economic growth. Despite the importance of energy consumption, the negative impact of its usage, specifically fossil fuel energy, in recent years cannot be undermined. Carbon emission from energy has contributed largely to the degradation of ozone layers, thus, there is a global effort towards ameliorating the level of greenhouse gas emissions so as to save the entire universe from the devastating consequences (Akinwale and Ogundari, 2017). Technological innovation becomes an integral method of generating a sustainable modern energy system as the energy path taken by most industrialised and emerging countries to become industrialised has been classified unsustainable in the current period (Sohag et al., 2015; Akinwale, 2017). This technological innovation cannot occur unconsciously within the country; rather it must be a coordinated action by the stakeholders (Olaopa et al., 2018; Akinwale and Surujlal, 2017). Policy interventions are required to drive technology innovation in a low-carbon energy system towards achieving a sustainable economic development (Ockwell and Mallett, 2013; Akinwale, 2017). Whether a country would implement energy conservation policy or not depend on the long run relationship between energy consumption, economic growth and technology innovation. If there is neither long-run nor causality from energy consumption to economic growth, then conservation policy could be easily implemented, otherwise restricting energy consumption could affect economic growth (Nasreen and Anwar, 2014).

The Saudi energy sector is growing rapidly so as to keep pace with the increase in electricity demand in the country. The yearly consumption rose at a rate of 7–9%, which is largely due to the fully subsidised energy price and increased in population. The electricity consumption per capita stood at 9,444.22 kWh while total energy consumption per capita stood at 6,937.23 kg as at year 2014 (World Bank Development Indicators (2017). World Data on Energy usage). Figure 1 shows the energy consumption per capita between 1980 and 2014, and it could be seen that the energy consumption has considerably increased over time. The total installed electricity generation capacity in Saudi Arabia is approximately 45,000 MW with total reliance on oil and natural gas plants (Alrashed and Asif, 2014). While oil accounted for an approximate of 57%, natural gas accounted for the rest. Residential sector accounted for approximately half of the total electricity consumption, whereas industrial sector accounted for nearly 18% of the electricity consumption in the country (Alrashed and Asif, 2015). Most of the residential houses are not adequately insulated in a way that would reduce energy consumption, and the consumers are less concerned with energy wastage because of its accessibility and low cost.

There are recent arguments in literature on the link between energy consumption, technology innovation and economic growth within and across countries. While some studies (Romer, 1990; Sohag et al., 2015; Pradhan et al., 2017) opine that technology innovation is a catalyst to economic growth and crucial for improving energy efficiency by reducing energy use as it provides opportunities for the economy to switch from depletable sources to renewable energy to meet energy demands; others (Inekwe, 2015; Tuna et al., 2015) reveal that it is either economic growth that leads to technology innovation or there exists no significant relationship

Figure 1: Energy consumption per capita (Kg of oil equivalent) in Saudi Arabia



Source: World Bank Development Indicators (2017)

between them, and that technology innovation has not been able to reduce the energy consumption (Khan et al., 2016) but rather increase the level of energy consumption. Though, technological innovation reduces energy consumption slightly but it might not reduce a great share of the energy used (Sohag et al., 2015). For example, if the price of energy drops as a result of energy efficiency, the reduced price might encourage economic agents to use more energy (Greening et al., 2000). There are also diverse opinions of the impact of economic growth (income) on energy consumption and which one granger causes the other (Yoo, 2006; Payne, 2010; Akinwale et al., 2013; Khan et al., 2016). Based on the lack of consensus in literature and the unavailability of studies that combine the three variables in a single model in the Saudi Arabia's economy, this study therefore investigates the short- and long-run as well as the causal direction between energy consumption, technology innovation and economic growth. Examining this relationship in the Saudi Arabia's economy is timely as the government is currently engaging in various activities to achieve her "transformation agenda 2020" and "Vision 2030."

2. LITERATURE REVIEW

This section reviews relevant literature on technology innovation, energy consumption and economic growth though the studies which combine the three variables are limited. Jin and Zhang (2014) examine China's potential transition from its energy-intensive status quo to an innovation-oriented growth prospect using endogenous growth model which incorporate technological innovation and its interaction with fossil energy use and the environment. They reveal that a small amount of capital installation will incentivize investment in physical capital rather than R&D-related innovation, and this leads to accumulation of energy-consuming capital resulting into an intensive use of fossil energy otherwise known as energy-intensive growth pattern. However, when the mechanism of R&D related innovation was introduced into the economy, the economic system embarked on R&D for innovation until the dynamic benefit of R&D is equalized with that of capital investment. Thus, the economy evolves along an innovation-oriented balanced growth path where consumption, physical capital and technology all grow, whereas fossil energy consumptions drop and environmental quality improves. Pradhan et al. (2017) investigate the Granger causal relationships between innovation, economic growth, ICT infrastructure and some other macroeconomic variables using panel data from 32 high income OECD countries from 1970 to 2016. They found that all of these variables are cointegrated with innovation implying long run relationship among them. There is bidirectional causality between innovation, economic growth and ICT infrastructures in the long run as well as various short run.

Kim (2011) examines the contributions of R&D stock to economic growth using the R&D-based Cobb-Douglas production function during the years 1976–2009 in South Korea and finds that R&D activities create the most efficient methods to raise competitiveness in the corresponding economy, which ensures stable and continuous economic growth. Cameron (1996) reviews the empirical evidence on the link between innovation and economic growth, whereby factors such as R&D spending, patenting, and innovation counts are used as measures of innovation. The study concludes that innovation makes a significant impact on economic growth and that there are significant spillovers between countries, firms and industries, and to a lesser extent from government-funded research. The study of Goel and Ram (1994) reveals a positive impact of research and development (R&D) outlays on economic growth. Kirchhoff et al. (2007) reveal that university R&D encourages the formation of new firms which creates employment and positively impacts on gross domestic product (GDP). Hasan and Tucci (2010) investigate the relationship between innovation and the economy and find that there is an increase in economic growth for countries that increase their level of patenting. Akinwale et al. (2012) investigate the impact of R&D and innovation, labour and capital on economic growth in Nigeria using least square method between 1977 and 2007. The results reveal that gross expenditure on R&D has negative and significant impact on economic growth, and they infer that the level of R&D spending and innovation support of government is still relatively low. Moreso, it is not enough to increase spending on R&D and innovation when there are weak institutions, high corruption practices, low interaction between the academia and the industry, uncoordinated industrial clusters, among others. They therefore suggest strong "political will" of government to create an enabling environment for innovation. Tuna et al. (2015) examine the relationship between R&D expenditures and economic growth in Turkey and their result reveals no long run relationship and no causality between them. Inekwe (2015) also reveals in his study that the effect of R&D spending on growth is insignificant in lower income economies while it is positive for upper middle-income economies.

Tang and Tan (2013) explore the nexus of electricity consumption, economic growth, energy prices and technology innovation in Malaysia, and they found that electricity consumption and its determinants are cointegrated. The empirical results also reveal that income positively affects electricity consumption, while energy prices and technology innovation negatively affect it in the long run. The Granger causality results further shows that technology innovation Granger-cause economic growth and electricity consumption; and that electricity consumption and economic growth Granger-cause each other both in the short and in the long run. Sohag et al. (2015) investigate the effects of technological innovation on energy use in Malaysia by extending the Marshallian demand framework using an autoregressive distributed lag (ARDL) bounds testing approach for the sample period 1985–2012. The results confirm both short- and long-run theoretical predictions that technology innovation reduces energy use while GDP per capital increases energy use. This suggests that technological innovation is an important factor in reducing energy use and improving energy efficiency in Malaysia without impairing economic growth. Moreover, Wong et al. (2013) establish that OECD countries are able to enjoy greater energy efficiency gains due to their sizeable technological innovation compared to other developing countries. Khan et al. (2016) also investigate the impact of technological innovations, economic growth, energy price on energy use at aggregate and disaggregate levels for the economy of Pakistan using an extended Marshallian demand function for the period 1971–2013, and the variables are cointegrated which indicates long run relationship among the variables. The results fail to confirm the negative relationship between technology innovation and aggregate energy use, and in fact technology innovation seems to be the main driver of energy demand in Pakistan, except for petroleum products and electricity, highlighting the existence of rebound effect. The result also reveal that elasticity of energy demand with respect to real GDP per capita and energy price are insignificant implying income and price variations do not affect energy consumption in the long-run in Pakistan.

Since price is also a factor influencing demand from the Marshallian demand function, the impact of energy price on energy consumption is also observed. The empirical results are mixed in various studies. Studies such as Zhou and Teng (2013) in China, Altinay (2007) in Turkey, Khan et al. (2016) in Pakistan, find no significant price elasticity of energy demand indicating inelastic energy demand. However, studies such as Tang and Tan (2013) in Malaysia; Fei and Rasaiah (2014) in Ecuador, South Africa and Canada find significant impact of price elasticity of energy price signalling that energy demand would reduce as price increases and *vice versa*.

There are also numerous studies with differing results on the relationship between energy consumption and economic growth. While some studies (Shahbaz et al., 2013; Acaravci et al., 2015; Akinwale and Muzindutsi, in press) suggest unidirectional causality from energy consumption to economic growth, other studies (Yoo, 2006; Lean and Smyth, 2010; Akinwale et al., 2013; Ameyaw et al., 2017) reveal the reverse case. Meanwhile, there are some studies (Tang and Tan, 2013; Nasreen and Anwar, 2014; Mezghani and Haddad, 2017) that also show bidirectional causality between them, whereas few studies (Apegris and Payne, 2009; Ozturk and Acaravci, 2013) show no causality. Thus, there is no consensus on the energy-growth nexus in the literature.

Some of the differing results at many instances are due to the omission of important variables, methodological differences and peculiarities of the economy (Ozturk, 2010; Payne, 2010; Akinwale and Grobler, in press). This study therefore extends beyond bivariate model by examining energy consumption, technology innovation, energy price and economic growth in Saudi Arabia.

3. METHODOLOGY

3.1. Data and Sample Period

Annual time series data covering the period 1980–2015 on energy consumption per capita (in kg), GDP per capita (Constant at 2010 US$), technological innovation (total patent application in the country i.e. both residents and non-residents) and consumer price index were collected from the 2017 update of World Bank's World Development Indicator as published through the online database of World Bank. The variables used in the models are: EC for energy consumption per capita, GDP for real GDP per capita, TIN for technological innovation and P as consumer price index. Since data on energy price is not readily available and most energy prices of various products are distorted due to large subsidy, this warrants the use of consumer price index as energy price in many studies (Lean and Smyth, 2010; Tang and Tan, 2013; Khan et al., 2016) so the study also adopts CPI as proxy for energy price. The choice of the starting period was constrained by the availability of data on technological innovation.

3.2. Method and Model Specification

This study followed what was used by Tang and Tan (2013) among other studies which is basically on the theory of Marshallian demand function. Energy demand can be derived from this Marshallian demand function, and can be written as a function of income and price as follows:

$$EC_t=f(Y_t,P_t) \quad (1)$$

Where EC_t is energy consumption, Y_t is income or economic growth and P_t is the energy prices. For the purpose of this research, equation (1) is then extended by incorporating technology innovation as an additional variable that influence energy demand/consumption. Further to this, Y_t would be replaced by GDP_t and TIN_t would be used for technological innovation. Thus, the new empirical model for energy consumption in Saudi Arabia is written as follows:

$$EC_t=f(GDP_t, P_t, TIN_t) \quad (2)$$

After natural logarithm of equation 2 is taking, then the new model is:

$$EC_t=\beta_0+\beta_1 lnGDP_t+\beta_2 lnP_t+\beta_3 lnTIN_t+\mathcal{E}_t \quad (3)$$

From equation 3 above, ln denotes the natural logarithm, $lnEC_t$ is per capita energy consumption, $lnGDP_t$ is per capita real income, lnP_t is the price, and $lnTIN_t$ is technology innovation. The error term $\mathcal{E}_t$ is assumed to be spherically distributed and white noise (Tang and Tan, 2013). The expected signs for the coefficients of real income, energy price and technology innovation are $\beta_1>0$, $\beta_2<0$, and $\beta_3<0$ respectively. Few studies such as Khan et al. (2016) also believe that β_3 can be >0 as the elasticity of energy demand with respect to technology innovation may be positive or negative depending on the nature of technology innovation, and its relative effect on production and consumption.

Before the data could be used to determine the existence of long run and causality direction of the variables, it is necessary to determine the order of integration of each variable. This is done with the use of unit root testing. Granger and Newbold (1974) stated that using non-stationary data in causality tests can yield spurious causality results. Hence, unit root tests are used to investigate if trending data should be first differenced or be differenced at higher order to render the data stationary. This study use augmented dickey fuller (ADF) and Phillips-Perron (PP) tests to check the stationarity of the data. A preliminary analysis of trend, stability and variability of the variables was also conducted using diagnostics statistics.

To investigate the existence of a long run equilibrium relationship between energy consumption and its determinants, an ARDL model is used to test the presence of cointegration among the variables. ARDL was chosen for this study because of the advantages it has over other tests of long run. This includes its ability to combine a mixture of variables that are stationary at level, I(0) and those that are stationary at first difference, I(1) (Tang and Tan, 2013; Akinwale and Muzindutsi, in press). Thus, ARDL can be used irrespective of whether the explanatory variables are purely I(0), purely I(1), or mutually cointegrated, but it cannot be used when variables are stationary at the second difference, I(2) (Pesaran and Shin, 1998). It is also found that the ARDL bounds testing approach is more efficient when the samples is small (Pesaran and Shin, 1998). The ARDL model is therefore expressed thus:

$$\begin{aligned}\Delta LEC_t &= \alpha_0 + \sum\nolimits_{j=0}^{n}\gamma_j\Delta LEC_{t-j} + \sum\nolimits_{j=0}^{n}\beta_j\Delta LGDP_{t-j} \\ &+ \sum\nolimits_{j=0}^{n}, {}_j\Delta P_{t-j} + \sum\nolimits_{j=0}^{n}\delta_j\Delta LTIN_{t-j} + \varphi_1 LEC_{t-1} \\ &+ \varphi_2 LGDP_{t-1} + \varphi_3 LP_{t-1} + \varphi_4 z_{t-1} + \varepsilon_t\end{aligned} \quad (4)$$

Where: ΔLEC_t is the change in the natural log value of energy consumption at time t; $\Delta LGDP_t$ represents the change in the natural log value of GDP at time t; ΔP_t is the change in the natural log value of price at time t and $\Delta LTIN_t$ is the change in the natural log value of trade openness. α_0 is the intercept, n is number of lags and ε_t is the error term. Coefficients β_j, γ_j, Θ_j and δ_j represent the short-run dynamics of the model; while φ_1, φ_2, φ_3, and φ_4, are used to test for the long-run relationship known as bound cointegration test. Based on Equation 4, the following hypothesis was therefore set to test for co-integration:

Null hypothesis (H_0) for no co-integration: $\varphi_1=\varphi_2=\varphi_3=\varphi_4=0$

Alternative hypothesis (H_1) for co-integration $\varphi_1\neq0$, $\varphi_2\neq0$, $\varphi_3\neq0$, $\varphi_4\neq0$

If the null hypothesis of no cointegration is rejected the alternative of cointegration or inconclusiveness is considered on the basis of comparison between F-statistic (calculated) and critical values provided by Pesaran et al. (2001). If the estimated F-value is greater than the upper critical value then there is a cointegrating relationships between the variables but if the estimated F-value lies between the lower and upper critical values the result remained inconclusive unless additional information is provided. However, if the estimated F-value is lesser than the lower critical value, the H_0 cannot be rejected and this suggests that there is no cointegration between the variables.

As the existence of cointegration is established between the variables, then error correction model is estimated to obtain the short run and long run parameters. While short run causal effects is indicated by the F-statistic on the explanatory variables, the long run causal relationship is denoted by the t-statistic on the coefficient of the lagged error-correction term (ECT) (Narayan and Smyth, 2006; Belloumi, 2014; Akinwale and Grobler, in press). This is expressed in Equation 5 as follows:

$$\begin{aligned}\Delta EC_t &= \alpha_0 + \sum\nolimits_{j=0}^{n}\gamma_j\Delta EC_{t-j} + \sum\nolimits_{j=0}^{n}\beta_j\Delta LGDP_{t-j} \\ &+ \sum\nolimits_{j=0}^{n}\theta_j\Delta P_{t-j} + \sum\nolimits_{j=0}^{n}\delta_j\Delta LTIN_{t-j} + \lambda ECT_{t-1} + \varepsilon_t\end{aligned} \quad (5)$$

Where ECT_{t-1} is the error correction term and λ is the coefficient of ECT which measures the speed of adjustment to the equilibrium.

4. RESULTS ANALYSIS

4.1. Analysis of Unit Root Tests

The existence of unit root at second difference I(2) signifies non stationary of the variable which could lead to spurious results. In order to ascertain the absence of unit root in the variables used in the model, unit root test was conducted using the standard ADF and PP unit root tests. The results of the unit root tests are presented in Table 1. The results show that GDP and energy consumption are stationary at first difference, technology innovation is stationary at level and first difference whereas price is stationary at second difference. Consequently, price was removed from the model so as to avoid spurious result. After the removal of consumer price index, then the model consist of the mixture of I(0) and I(1) series, suggesting that ARDL is the appropriate model to test for cointegration.

4.2. Bounds Tests and Long Run Analysis

Akaike information criteria selected lag 2 as the optimal lag for the model, and the results of bounds cointegration tests are presented in Table 2. These results show that the estimated F-value (7.2) is greater than the upper critical value (6.36) at 1% level of significance. This implies that the null hypothesis which states that there is no cointegration is rejected; hence, there is a long run relationship between energy consumption, technology innovation and economic growth in Saudi Arabia as shown in Table 2.

The direction and the significance of the long run relationship between the variables are shown by Equation 6. The results show that while technology innovation has a negative long run effect on energy consumption, GDP growth has a positive long run effects on energy consumption.

$$LEC = -21.7780 - 0.0052\ LTIN + 3.0945\ LGDP \quad (6)$$

The result also indicates that technology innovation does not have significant impact on energy consumption whereas GDP growth has a statistically significant impact on energy consumption at 10% level of significance. The negative effect of technology innovation implies that 1% improvement in technology would reduce energy consumption by 0.0052. This means that technology innovation would lead to a reduction of energy consumption in Saudi Arabia though this is not statistically significant. This might be due to the present low level of innovation and technology at the residential sector as well as the industry such as poor insulation of the houses and factories. The positive effect of GDP on energy consumption specifies that 1% increase in GDP growth would lead to 3.09% increase in energy consumption. This means that Saudi Arabia residents tend to consume more energy as the economy grows, and the impact is statistically significant. These results are in line with the results obtained in the studies of Sohag et al. (2015) and Ameyaw et al. (2017) among others. These results suggest that Saudi Arabia can benefit immensely in the long run by strengthening her technology innovation as well as engage in conservation policies as these would reduce the energy consumption in the long run without affecting economic growth.

4.3. Analysis of Short Run Relationship and Error Correction Modelling

The result of the error correction model and short run relationship is presented in Table 3. The ECT_{t-1} coefficient is negative as required and it is statistically significant at 1% significant level. This ECT_{t-1} coefficient (−0.1275) also implies that a short run deviation from the long run disequilibrium is corrected by 12.75% towards a long run equilibrium path each year. This sign and significance of ECT signify that there is at least a long run causality running from technology innovation and economic growth to energy consumption. This further establishes the existence of long run relationship between the variables.

Table 3 also shows that in the short run, GDP has a positive impact on energy consumption whereas technology innovation has a negative impact on energy consumption. Moreso, GDP is statistically significant at 10% while technology innovation is not statistically significant. This is similar to the results obtained in the long run, and this is clearly depicting that increase in economic growth would increase energy consumption while the development of new technology innovation or improvement on the existing ones would decrease energy consumption.

4.4. Analysis of Granger Causality Tests

Table 4 presents the results of the pairwise Granger causality tests conducted to further examine the short run relationship between the variables. The results show that there is unidirectional causality from technology innovation and GDP to energy consumption, as well as from GDP to technology innovation. These results are also consistent with findings of Lean and Smyth (2010), Tang and Tan (2013), Akinwale et al. (2013) and Sohag et al. (2015) among others. This result indicates that technology innovation is very important to the reduction of energy demand by households and firms in Saudi Arabia. Innovation regarding household appliances, bulbs, heating and cooling system among others would reduce the household energy consumption which accounted for more than 50% of the energy used in KSA. Also, technology innovation which would make most of the industrial machine and equipment energy efficient should also be given priority by the government and the private sector. This technology innovation is expected to bring about a drastic reduction in energy consumption, which would lead to reduction in carbon emission. The unidirectional causality of GDP to energy consumption signifies that an increase in economic growth would encourage energy consumption at a faster rate. Thus, government is encouraged to implement conservation and energy efficient policies without any fear of harming economic growth. This conservation policy will also engender the reduction in energy demand which would lead to the reduction of the quantity of carbon emitted into the environment.

Table 1: Results of unit root tests

Variable	ADF		PP		Order of integration
	Levels	First Difference	Levels	First difference	
LEC	−0.9039	−3.6376**	−0.2410	−9.0089***	I (1)
LTIN	−5.4710***	−6.7490***	−5.1048***	−6.7490***	I (0)
LGDP	−2.2293	−4.3570***	−2.4377	−4.6755***	I (1)
LP	0.3355	−2.0885	1.3647	−1.9726	I (2)

***,**,*indicate 1%, 5% and 10% level of significance, respectively, ADF: Augmented dickey fuller, PP: Phillips-Perron

Renewable energy sources and technologies should be fully harnessed by the government since there is abundance of sun and wind in Saudi Arabia. The result of unidirectional causality from GDP to technology innovation implies that the growth in the economy will lead to the advent of more technology innovation, though a feedback effect was expected for this. However, the present low level of technology innovation, when compared with some emerging and developed economies might warrant this.

4.5. Analysis of Diagnostic Tests

The adequacy of the model has been validated through various diagnostic tests, including Breusch-Godfrey Serial Correlation LM test, Jarque-Berra test, Heteroskedasticity test, CUSUM of squares and CUSUM tests. Table 5 shows that the null hypotheses for no presence of autocorrelation and heteroscedasticity cannot be rejected. Also, the residuals are found to be normally distributed. Furthermore the CUSUM of Squares in Figure 2 also shows that the relationship between the variables is stable over the period, though Figure 3 shows that CUSUM shortly goes out of the bound in 2009 but falls back within the bound in a very short time. This could be as a result of the aftermath of global financial crisis in 2008, which Saudi Arabia was able to absorb within a short time due to the nature of their financial system. Summarily, the diagnostic tests confirm the validity of the specified model.

5. CONCLUSION

This study examines the relationship between energy consumption, technology innovation and economic growth in Saudi Arabia. This study becomes important considering the current efforts of the Saudi government in transforming the economy towards the achievement of Vision 2030, and also the limited studies relating to these three variables in Saudi Arabia. The results of ADF and PP tests show that the series consist of both I(0) and I(1) making ARDL bound testing approach the most suitable method of analysis for this model. ARDL bound test shows that energy consumption, technology innovation and economic growth are cointegrated, hence establishes the existence of long run relationships between them. The ECT also corroborates the long run relationship between the variables, as it has the required negative sign and significant at 1% level of significance. The results of both long run and short run relationships are similar as they both reveal that while technology innovation has a negative relationship with energy consumption; economic growth has a positive relationship with energy consumption. Furthermore, the results of pairwise Granger causality show that there is unidirectional causality running from technology innovation and GDP to energy consumption, as well as unidirectional causality running from GDP to technology innovation.

The empirical results from this study provide some managerial implications for the policy makers. The long run causality running from technology innovation to energy consumption and the

Figure 2: CUSUM of squares at 5% level of significance

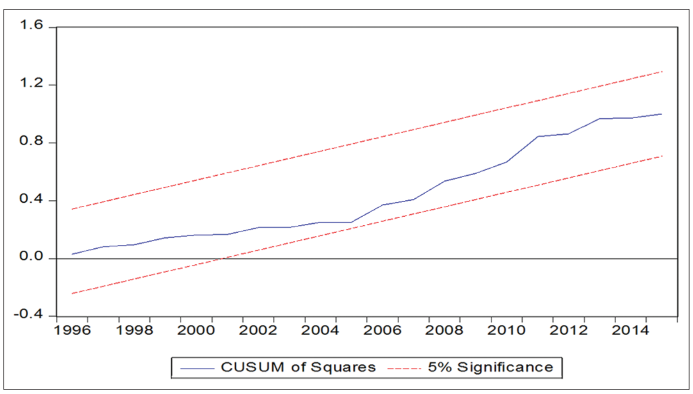


Figure 3: CUSUM at 5% level of significance

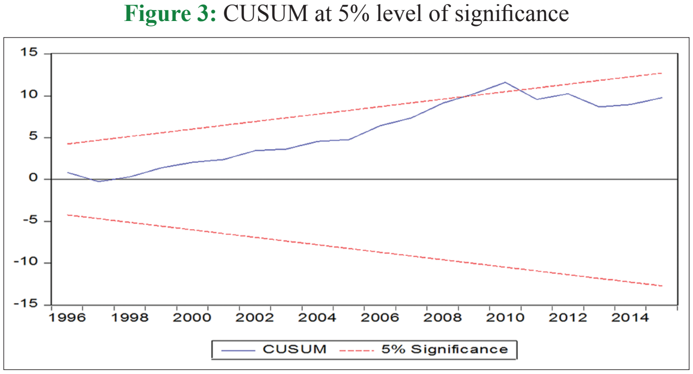


Table 2: ARDL bounds test

Test statistic	Value	K
F-statistic	7.2003	2
Critical value bounds		
Significance	**I0 bound**	**I1 bound**
10%	3.17	4.14
5%	3.79	4.85
2.5%	4.41	5.52
1%	5.15	6.36

ARDL; Autoregressive distributed lag

Table 3: Short run analysis and error correction model

Variable	Coefficient	Std. error	t-statistic	Prob.
D (TIN)	−0.065287	0.038680	−1.687866	0.1062
D (GDP)	0.394634	0.203782	1.936547	0.0664
$ECTt^{-1}$	−0.127526	0.030028	−4.246845	0.0002

Table 4: Pairwise granger causality results

Null hypothesis	F-statistic
D (LGDP) does not Granger Cause D (LEC)	3.68942**
D (LEC) does not Granger Cause D (LGDP)	2.57285
D (LTIN) does not Granger Cause D (LEC)	2.95330*
D (LEC) does not Granger Cause D (LTIN)	2.39085
D (LTIN) does not Granger Cause D (LGDP)	1.62801
D (LGDP) does not Granger Cause D (LTIN)	3.66198**

***,**,* indicate 1%, 5% and 10% level of significance, respectively

Table 5: Diagnostic test results

Item	Applied test	P value	Decision
Serial correlation	LM test	0.1643	No serial correlation
Normality	JacqueBera	0.8415	Variables are normally distributed
Heteroscedasticity	Breusch Pagan Godfrey	0.2073	No heteroscedasticity

negative relationship between them implies that development of new technology innovation and the improvement on the existing ones would reduce the level of energy demand in Saudi Arabia which would further lead to reduction in carbon emission. Furthermore, the long run causality running from GDP to energy consumption and the positive relationship between them indicates that the expansion in economic activity in Saudi Arabia would exacerbate the extent of energy demand by the households and firms; thus, the adoption of energy conservation policies by the government would not impair economic growth in realising Vision 2030.

The policy makers are therefore required to make policy that would continue to encourage government investment in R&D that would generate technology innovation and at the same time create an enabling environment for the private sectors to invest in R&D which would generate technology innovation so as to reduce the extent of energy consumption. This study also suggests that government can successfully implement energy efficient and conservation policies as these will not hamper economic growth of the Saudi economy but rather improve the quality of the environment. Alternative energy through renewable energy sources and technologies such as solar and wind should be fully explored by the government to create sustainable economic development.

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