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THE DYNAMIC IMPACT OF ENERGY CONSUMPTION ON ECONOMIC GROWTH IN SUDAN: A VECTOR AUTOREGRESSION ANALYSIS

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ABSTRACT: *The purpose of this study is to analyze the dynamic effect of energy consumption and CO_2 emissions on economic growth in Sudan by utilizing annual time series data spanning the period 1971- 2015. After identifying the series order of stationarity by utilizing ADF and PP unit root tests, this study makes use of a ARDL and VAR model. The reason is that ARDL is preferable method since it incorporates both short and long run in its specification and can be used even when there is a mixed integration order. A VAR is the powerful in variance decomposition and the possibility of observing long run forecast in addition to the dynamic response to shocks.the findings indicate long run relationship among the variables of interest. Particularly, the results disclose that energy consumption and CO_2 emissions exert positive and significant effect on economic growth in the long run. The causality analysis of the gradual shift indicates a uni-directional relationship running from energy consumption to economic growth. The test results support energy-induced growth hypothesis, which reveals that energy use impact greatly on economic growth and energy saving and/or energy shocks negatively affect economic growth. This means that Sudan's economy is energy-driven and cannot embark or initiate conservative energy policies and strategies compromising economic growth. with the emergence of energy supply and global warming issues and their conceivable consequences on economic performance, investigating their interrelations is thus essential, which has been neglected baselessly in the literature especially in the case of Sudan.*

KEYWORDS: Sudan, VAR, ARDL, GDP, CO_2, and energy consumption

JEL Codes: Q53, Q56, Q57, R1

INTRODUCTION

Energy consumption is considered as a propelling force behind almost all the economic activities, particularly industrial sector. Therefore, high scale energy resource may upgrade the effect of technology and create tremendous economic expansion. High grade resources can work as facilitator of technology while low level resources can dampen the forcefulness of new technology Onakoya et., (2013). The effect of the causal relationship between energy use on economic growth has attracted the interests of energy economists and policy makers and has been an ongoing discussion topic for many decades, particularly since the petroleum crisis in 1970s and the unprecedented high levels of energy prices Elfaki et al., (2018).

Some authors have argued that energy consumption tracks with the economic performance and thus the size of energy use per capita could be used as an important indicator of modernization of the economy. Moreover, generally countries with higher energy use are more developed than otherwise Ojinnaka (1998).

Akinlo (2008) in his study concluded bi-directional relationship between energy consumption and economic growth when he examined the gradual shift and causal effect for Cameroon, Cote d'Ivoire, Gambia, Ghana, Senegal, Sudan, and Zimbabwe by employing an ARDL model. This argument could be supported by figure 1 which shows the co-movement between GDP per capita annual growth rate and the size of energy consumed in Sudan during period 1971 to 2015. The figure indicates almost similar pattern between the growth of economy and energy use.

The importance of energy can be clearly seen in other aspects of economic development. When the oil is exported it increases the foreign returns and exchange and transfer the technology in the process of energy exploration, production, and marketing. Furthermore, energy can create job opportunities in an industrial sector, this may increase wages and improve salaries, improvement in economic infrastructure and socio-economic activities which eventually will lead to promote the welfare. In the context of optimal development and efficient management of available energy resources, equitably allocation and efficient utilization can put the economy on the part of sustainable development. Starting from this viewpoint, adequate supply of energy thus becomes essential to the economic transformation. In doing so, understanding the dynamic effect of energy use on the economic growth trajectory is thus important.

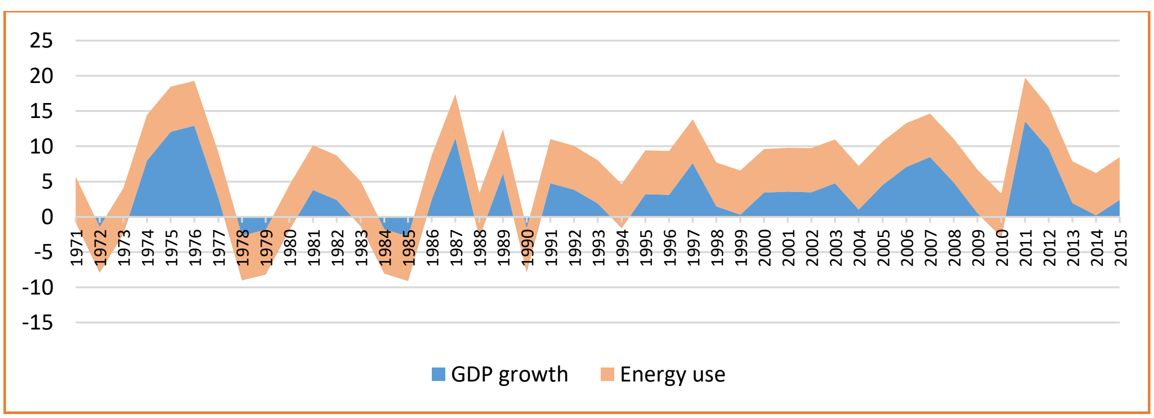

Figure 1. GDP per capita annual growth rate and energy consumption in Sudan**.** *World Bank. Accessed date 05.06.2021* *https://databank.worldbank.org/source/world-development-indicators#*

In Sudan, energy serves as the pillar of all economic sectors. Although the country is endowed with abundant renewable and nonrenewable energy resources but still suffering from endless energy supply crisis. Over ten years back, Sudan lost almost 80% of its oil returns due to the separation of South Sudan where most of the oil producing blocks were located or near to the border with South Sudan and the Republic of Sudan remains with the oil infrastructure including pipelines and refineries. This can be clearly seen from the dramatical dropdown in the pattern of energy use in figure 1. Presently, traditional biofuel and waste represent the basic energy source in Sudan. Since it considered the most of energy needs of the local population especially those who live in the rural areas with no access to electricity. The share or biofuel and waste in total energy source is around 67% followed by crude oil (29%), hydro (4%) and wind, geothermal and solar. Figure 2 presents the basic energy sources in Sudan.

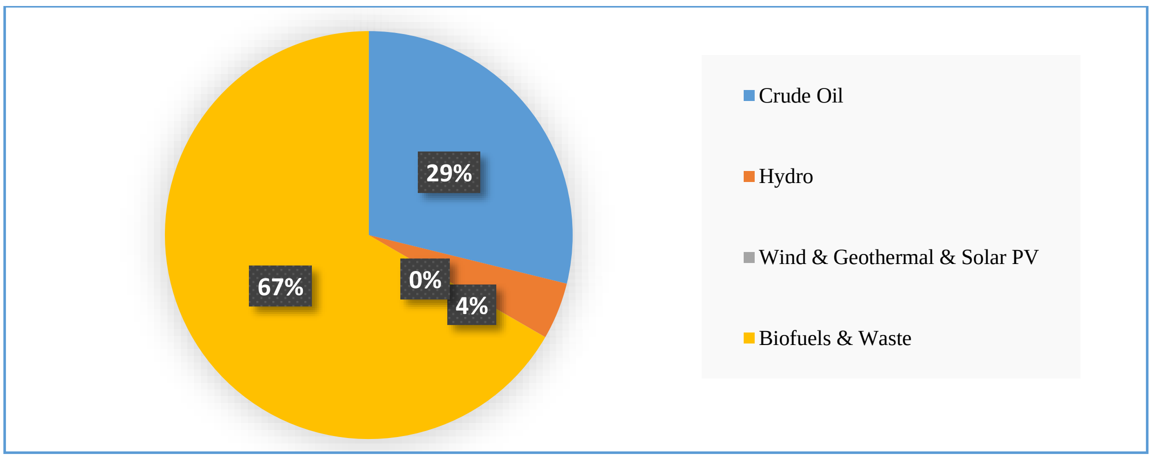

Figure 2. Total energy production in Sudan in 2017 (ktoe). *African union energy (AFREC). Accessed date 14.05.2021. https://auafrec.org/En/administration/bilan.php*

Sudan like most of the oil importing countries suffered a lot from sharp increase of oil prices in the last decade. Spending most of its hard currency earnings in importing oil but could not meet the increasing demand for energy. Even though the oil cost consumes more than 50% of the income earnings but oil represents only about 17% of total energy consumption previously (Omer, 1998). Currently energy is one of the key factors for the development of national economy in Sudan. An overview of the energy consumption situation in Sudan, figures 3 and 4 indicate that the household is the biggest sector consumes energy (50%) followed by transportation sector (30%), industry sector (10%), commercial and public sector (7%), and agriculture and forestry.

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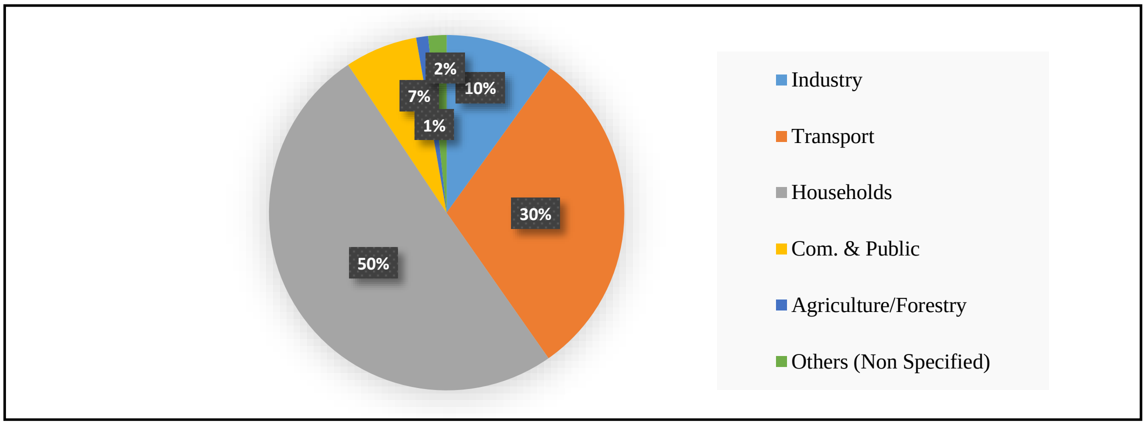

Figure 3. Total energy consumption in Sudan in 2017 (ktoe)**.** *African union energy (AFREC). Accessed date 14.05.2020. https://auafrec.org/En/administration/bilan.php*

Energy is an essential element in economic development since it promotes, and enhances economic growth, and the development. Post the energy crisis in seventieth last century, it has been realized that nonrenewable energy like fossil fuels, oil, and natural gas, are finite in extent, and should be regards as depleting resources, and since that time the efforts are directed to search for new sources of energy and this can be covered partially through renewable energy Elfaki et al., (2018).

Omer (2015) argued that Sudan's renewable energy strategy is well integrated in the National Energy Plan and "clearly spelled out" in the National Energy Policy, but more is yet to be done. The oil crises in the 1970s and the unprecedented high levels of energy prices, had a detrimental effect on growth, and necessitate for the implementation of energy conservation energy policies. Sudan like most of other countries had greatly affected by oil crises firstly in 1970s and secondly in 2011 when the separation of South Sudan has occurred. figure 1 above clearly illustrate these negative impacts.

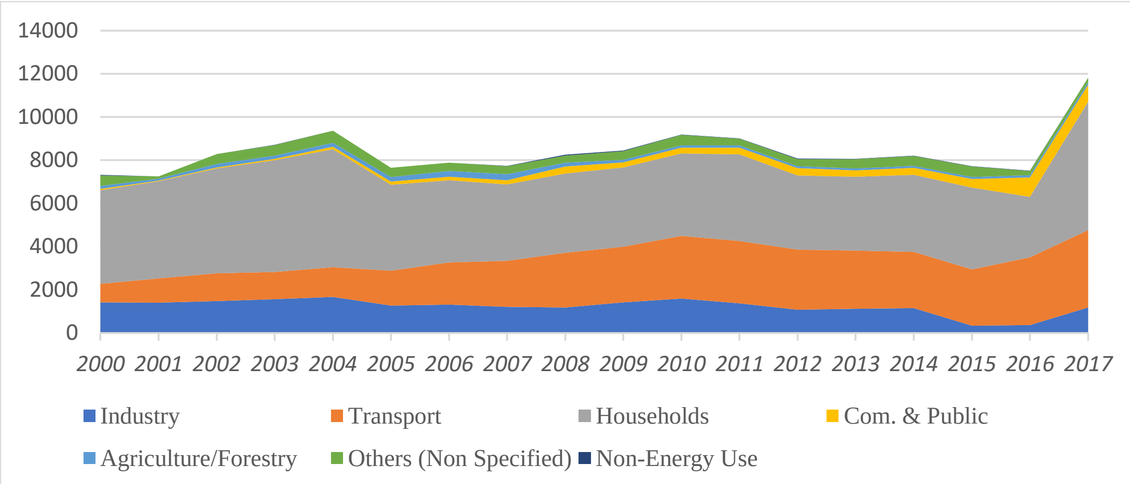

Figure 4. Total energy consumption in Sudan (2000-2017) (ktoe)**.** *African union energy (AFREC). Accessed date 14.05.2020. https://auafrec.org/En/administration/bilan.php*

Recently, Sudan has experienced a huge economic and political changes. the peaceful civil revolution that took place in 2018 has stepdown the political regime that prevailing since 1989 and the country is currently ruled up by a transitional government. The new transitional government has launched with IMF and World Bank a very hopeful and promising program for economic and institutional reform. On March 23 and 26, respectively, The Executive Boards of IMF and World Bank commended the authorities' sustained commitment to economic and institutional reforms under challenging circumstances and agreed that Sudan could be eligible for assistance under the Enhanced HIPC Initiative based on the preliminary assessment. This assessment is an important step towards forgiveness by all creditors of most of Sudan's total external debt, which was estimated at US$49.8 billion at the end of 2019 (IMF March 23, 2021).

The IMF Managing Director and Chair Kristalina Georgieva ascertained that the IMF and World Bank decision provides a clear acknowledgement of Sudan's sustained implementation of key economic and financial reforms under its staff-monitored program with the IMF. And she further mentioned that, helping Sudan achieve debt relief and unlock access to the needed resources to increase growth and reduce poverty is a key priority for the IMF and we look forward to continued cooperation with the authorities as we work toward the HIPC Decision Point.

So, it is clearly that Sudan is on the way of experiencing a tremendous economic and institutional reforms. In this context, it is needless to again reemphasizing the importance of implementing a suitable energy policy that promoting economic development. In doing so, understanding the dynamic effect of energy use on economic development trajectory can not be overlooked. Therefore, the main objective of this study is to investigate the dynamic impact of energy consumption on economic growth in Sudan. This study is expected to contribute greatly to literature related to energy consumption-growth studies generally and in Sudan specifically. It also expected to help the economic policy maker in Sudan to deriving a plausible energy policy.

The second objective of this study is to examine the causal effect between economic growth and environmental deterioration. The human beings are presently confronted by two major challenges; economic growth and preserving the environment (Uddin et al., 2017). When the economy starts moving along the development trajectory then at the earliest stage of the economic growth environment deteriorate due to air pollution, deforestation, and many other pollutants. With an increase in per capita income economy starts to develop and environmental deterioration declines (Shahbaz and Sinha, 2018). This association between economic growth and environmental degradation is hypothesized to be an inverted U-shaped relationship and is referred to in the literature as the Environmental Kuznets Curve (EKC). As environmental degradation has become more severe, the relationship between environmental degradation and economic growth becomes an increasingly important issue (Tutulmaz, 2015). Therefore, this study puts attention to the perceivable link between environmental deterioration and economic growth.

The rest of the paper is organized as follows: Section two reviews important literature on the subject. Section three presents the methodology. Section four shows the results and discussion while section five provides the conclusion.

LITERATURE REVIEW

The relationship between energy consumption and economic growth has been an ongoing debate among the researchers since long ago. Its importance comes out from the fact that the direction of the causality is helpful in designing energy policies that maintain energy security and sustainable economic growth. Moreover, it is also important politically because of the international economic relations (Yenişehirlioğlu, et al., (2016).

Over the last few decades, many studies have investigated the association between economic growth and energy consumption in the context of causality. However, the findings of empirical outcomes of the studies which investigated the relationship between these variables are mixed and inconclusive. In his survey of the recent progress in the literature of energy consumption–economic growth, Ozturk (2010) concluded that using different data sets, alternative econometric methodologies and different countries' characteristics are the main reasons of this conflicting results.

In addition, the survey highlights that most empirical studies focus on either testing the role of energy (electricity) in stimulating economic growth or examining the direction of causality between these two variables. Apergis and Payne, (2009a), Squalli, (2007), Chen et al., (2007), Mozumder and Marathe, (2007) argued that the directions that the causal relationship between energy consumption and economic growth could be categorized into four hypotheses:

First, the neutrality hypothesis; it means that there is no causal relationship between energy consumption and economic growth. In other words, neither conservative nor expansive policies in relation to energy consumption have any effect on economic growth.

Second, conservation hypothesis; it means that there is a uni-directional causality running from economic growth to energy consumption. The validity of this hypothesis is confirmed if an increase in economic growth results in an increase in energy consumption. It is important because the validity of conservation hypothesis allows reducing energy consumption policies (Nazlioglu et al., 2014).

Third, growth hypothesis; if the direction of causality runs from energy consumption to economic growth the hypothesis is valid. It means that energy consumption plays a substantial role in economic growth directly and indirectly in the production process as a complement to labor and capital.

Fourth, feedback hypothesis; It implies that energy consumption and economic growth are jointly determined and affected at the same time. According to feedback hypothesis, negative energy shocks and/or energy conservation policies may be associated with a decrease in output growth (Hatemi & Irandoust 2005).

The theory of energy-growth nexus claims that the direction of the causality also depends on the development level of a country. Many researchers have argued that if the economy is industrialized and developed, direction of the causality will run from economic growth to energy consumption. On the other hand, if the economy is on the way to develop like emerging economies the direction of the causality will run from energy consumption to economic growth. Recently, a huge volume of studies has examined the relationship between energy consumption and economic growth. In this regard, some studies have relied on renewable energy sources such as biomass energy and some other studies have relied on nonrenewable energy sources such fossil fuels.

The studies that relied on renewables mainly biomass are as follows: Shahbaz et al., (2016) investigated the relationship between biomass energy consumption and economic growth by incorporating capital and trade openness in production function for the case of BRICS countries. The results showed that the feedback effect exists between biomass energy consumption and economic growth. Aydin, (2019) found different results when he investigated the effect of biomass energy consumption on economic growth in BRICS countries using a country-specific panel data analysis. He concluded that the growth hypothesis is valid in Brazil and India; however, the conservation hypothesis is valid in China and South Africa. The feedback hypothesis is supported in case of Russia. Ajmi and Inglesi-Lotz, (2020) found a feedback hypothesis when examining the short-run and long-run causality analyses between biomass energy consumption and economic growth nexus in OECD countries using panel cointegration analyses, dynamic OLS analyses, fully modified OLS analyses and panel VECM Granger causality tests.

Bildirici and Özaksoy (2016) also investigated the causal link between woody biomass energy consumption and economic growth in Sub-Saharan Africa using ARDL model. They found a uni-directional causality from woody biomass energy consumption to economic growth for Angola, Guinea-Bissau, and Niger, from economic growth to woody biomass energy consumption for Seychelles. The bidirectional relationship is confirmed for Benin, Mauritania, Nigeria and South Africa. Bhattacharya et al., (2016) relied on the Renewable Energy Country Attractiveness Index to investigate the effects of renewable energy consumption on the economic growth in major renewable energy consuming countries worldwide. They confirmed the evidence of long-run dynamics between economic growth and traditional and energy-related inputs. Ali et al., (2017) tested the dynamic implication of biomass energy consumption on economic growth in Sub-Saharan African countries using panel data analysis and concluded that there is a causal relationship between biomass energy consumption and economic growth. Their findings reveal that biomass energy consumption, capital stock and human capital are positively influence economic growth at 1 % level.

Destek (2017) examined the relationship between biomass energy consumption and economic growth in top ten biomass consumer countries. The obtained results indicate that the growth hypothesis is valid for Brazil, Germany, India, and Italy; the conservation hypothesis is proved in Sweden; the feedback hypothesis is supported in China and the United States, and the neutrality hypothesis is confirmed in Finland, Japan, and the United Kingdom. Bilgili and Ozturk, (2015) tested the long run dynamics of biomass energy consumption and GDP growth through homogeneous and heterogeneous variance structures for G7 countries. The findings of the study indicate that the growth hypothesis is valid, which means that biomass energy consumption have positive effect on economic growth in G7 countries. Aslan (2016) confirmed the growth hypothesis when he studied the causal relationship between the energy consumption and economic growth in U.S. using the ARDL model.

On the other hand, the studies that relied on nonrenewable energy sources such as fossil fuels are as follows: by employing a newly developed ARDL model, Odhiambo, (2009) investigated the intertemporal causal link between energy consumption and economic growth in Tanzania spanning the period 1971 to 2006 and concluded that there is a stable long-run relationship between energy consumption and economic growth. In addition, the results of the causality test, show that there is a unidirectional causal flow from total energy consumption to economic growth and a prima-facie causal flow from electricity consumption to economic growth. Omri (2013) examined the hypothesis in 14 MENA countries by using simultaneous-equations models with panel data. His test results indicated that there exists a bidirectional causal relationship between energy consumption and economic growth.

Apergis and Payne (2012) found a bidirectional causality between renewable and non-renewable energy consumption and economic growth in both the short- and long-run when examining the energy consumption-growth hypothesis in selected 80 countries within a multivariate panel framework over the period 1990–2007. By utilizing an ARDL model Fuinhas and Marques (2012) also found bidirectional causality between energy and growth in both the long-run and short-run, when they examined the nexus between primary energy consumption and economic growth in Portugal, Italy, Greece, Spain, and Turkey (PIGST).

Shahbaz et al., (2018) concluded that there is a positive association between economic growth and energy consumption in top ten energy-consuming countries (China, the USA, Russia, India, Japan, Canada, Germany, Brazil, France and South Korea) by employing the quantile-on-quantile (QQ) approach. Narayan and Doytch (2017) reached the feedback, growth and conservative hypotheses when testing the energy consumption-growth nexus in 89 countries divided into low level middle income: upper middle income and high-income panels. Baz et al., (2019) also concluded the same results by employ the Non-linear Autoregressive Distributed Lag (NARDL) model to test the causality between energy use and economic growth in Pakistan.

Yildirim and Aslan (2012) investigated energy consumption and economic growth nexus for 17 highly developed OECD countries. They concluded that while there exists uni-directional causality running from energy consumption to real GDP for Japan, bi-directional causality is found for Italy, New Zealand, Norway, and Spain. On the other hand, uni-directional causality from GDP to energy is found for Australia, Canada, and Ireland whereas no causal nexus is found for all other nine countries. And lastly Okoye et al., 92021) Analyzed the Energy Consumption and Economic Growth Nexus in Nigeria their results indicate that energy consumption and gross fixed capital formation significantly determine growth of economic activities in Nigeria.

RESEARCH METHODOLOGY

MODEL SPECIFICATION AND DATA

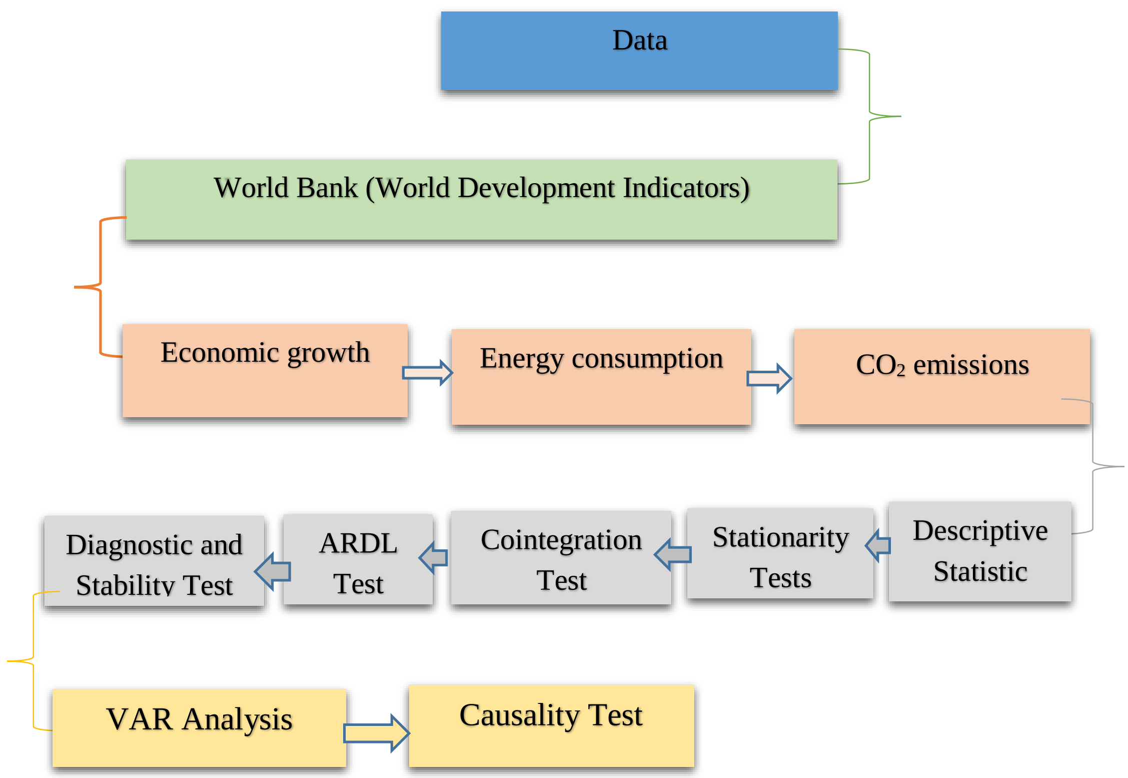

Figure 5. Analysis flowchart

To investigate the relationship between energy consumption and economic growth in Sudan this study uses GDP per capita annual growth rate and energy use (kg of oil equivalent per capita) as a proxy for economic growth and environmental quality, respectively. To have a better understanding to the effect of energy consumption on environmental quality, carbon dioxide (CO_2) emissions (metric tons per capita) is added to the model to represent the environmental pollution. All the data about the GDP, energy consumption and carbon emissions are obtained from the World Bank (world development indicators) see figure (5). All variables are transformed to the natural logarithmic form in an empirical analysis. Following the empirical work and testing procedures of Singh and Vashishtha (2020), khoshnevis and Shakouri (2018) and Anning et al., (2017), our models can be specified as follows:

$$lnGDP_t = \alpha_0 + \alpha_1 lnENC_t + e_t \qquad (1)$$

$$lnGDP_t = \varphi_0 + \varphi_1 lnENC_t + \varphi_2 lnCO2_t + e_t \qquad (2)$$

Where ENC is the energy consumption measured in kg of oil equivalent per capita, GDP is economic growth measured in per capita income growth rate and CO_2 is carbon dioxide measured in metric tons per capita, α_1 *and* φ_1 are the long-run elasticity and e_t is the error term. The bivariate specification might not capture all the factors that may affect economic growth therefore additional variable (CO_2) can be added to the models in that manner.

1.1.Method of estimation

Most time series data are non-stationary in nature which result in misleading outcomes of regression analysis. To test for the stationarity properties of the variables this study uses the augmented Dickey–Fuller (1979) (ADF), Phillips and Perron (1988) (PP) tests. The null hypothesis of the ADF and PP tests indicate a unit root. To examine the relationship between energy consumption and economic growth in Sudan this study utilizes the Autoregressive Distributed Lag (ARDL) model for the many advantages that distinguish it among other methods. First, this model does not required that all variable be integrated of order zero or I(0). Second, both short-run and long-run models are estimated simultaneously. Third, autocorrelation problem is removed. In addition, the ARDL method tends to perform better in a small sample size compared to other multivariate analysis (Adebayo et al., 2021). To test the existence of cointegration relationships among the variables in model (1) and (2) the unrestricted error correction term (ECT) proposed by Pesaran et al. (2001) can be specified as follows:

$$\Delta lnGDP_t = \delta_0 + \delta_1 lnGDP_{t-1} + \delta_2 lnENC_{\ t-1} + \sum_{i=1}^{q} \delta_3\, \Delta lnGDP_{t-i} + \sum_{i=0}^{p} \delta_4\, \Delta lnENC_{t-i} + \Theta ECT_{t-i} + \mu_t \qquad (3)$$

$$\Delta lnGDP_t = \lambda_0 + \lambda_1 lnGDP_{t-1} + \lambda_2 lnENC_{t-1} + \lambda_3 lnCO2_{t-1} + \sum_{i=1}^{q} \lambda_4\, \Delta lnGDP_{t-i} + \sum_{i=0}^{p} \lambda_5\, \Delta lnENC_{t-i} + \sum_{i=0}^{m} \lambda_6\, \Delta lnCO2_{t-i} + \Theta ECT_{t-i} + \nu_t \qquad (4)$$

Where equations (3) and (4) are ARDL (q, p, and m) models and the lag lengths are chosen according to Schwarz information criterion (SIC). The bound test for cointegration is conducted based on the joint null hypothesis of no cointegration $H_0\colon \gamma_1 = \gamma_2 = \gamma_3 = \gamma_4 =$

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0 against the alternative of cointegration $H_1: \gamma_1 \neq \gamma_2 \neq \gamma_3 \neq \gamma_4 \neq 0$. The Wald F-statistic is employed to examine the existence of cointegration relationship among the selected variables. The F-statistic is compared with the lower and upper bounds critical values. If the F-statistic is greater than the upper critical bound, then the null hypothesis of no cointegration is rejected and thus cointegration does exist. If the F-statistic, however, is less than the lower critical bound the null hypothesis cannot be rejected and, therefore, cointegration does not exist. If the cointegration relationship exists, then the error correction model (ECM) can be estimated. The ECM shows the short-run dynamics and the speed of adjustment to disequilibrium.

To analyze the dynamic interactions between the energy consumption shocks, economic growth and carbon emissions this study employs Vector Autoregression (VAR) approach. In addition to that, the VAR model will be utilized for variance decompositions. In this regard, following the testing procedures of Singh and Vashishtha (2020), khoshnevis and Shakouri (2018) and Anning et al., (2017), our VAR models can be specified as follows:

$$LnGDP_t = \alpha_0 + \sum_{i=1}^{m} \alpha_1 LnGDP_{t-i} + \sum_{i=0}^{n} \alpha_2 LnENC_{t-i} + \sum_{i=0}^{p} \alpha_3 LnCO2_{t-i} + \mu_{1t} \qquad (5)$$

$$LnENC_t = \beta_0 + \sum_{i=1}^{m} \beta_1 LnGDP_{t-i} + \sum_{i=0}^{n} \beta_2 LnENC_{t-i} + \sum_{i=0}^{p} \beta_3 LnCO2_{t-i} + \mu_{2t} \qquad (6)$$

$$LnCO2_t = \gamma_0 + \sum_{i=1}^{m} \gamma_1 LnGDP_{t-i} + \sum_{i=0}^{n} \gamma_2 LnENC_{t-i} + \sum_{i=0}^{p} \gamma_3 LnCO2_{t-i} + \mu_{3t} \qquad (7)$$

Where GDP, ENC and CO2 emissions are all endogenous variables and they represent economic growth, energy consumption and carbon dioxide emissions. The VAR model is powerful method in variance decomposition and the possibility of observing long run forecast in addition to the dynamic response to shocks of the variables in the vector system. Therefore, this study makes use of a vector autoregression model to accomplish the study objectives.

RESULTS AND DİSCUSSİON

In this segment of the study we present the discussion of the results in the following manner: initially we set off with analysis by the investigation into the summary descriptive statistic properties. The descriptive statistic reports the measure of central tendencies and dispersion. Table 1 indicates that energy consumption has the highest average, followed by economic growth and carbon dioxide emissions (CO_2). All series show negative Skewness except carbon emissions. Furthermore, only carbon emissions mirror normal distribution reported by Kurtosis which is less than 3. Table 2 outlines the possible existence of stationarity of the variables. The Augmented Dickey-Fuller

(ADF) and Phillips-Perron (PP) unit root tests were used to test the stationarity. The findings of unit root test in table 2 and figure 8 (a. b c) in the appendix show that the all variables are tested at level as well as first-difference.

The Augmented Dickey-Fuller and Phillips-Perron tests results are almost similar since none of the variables is integrated of the second order or I(2). The unit root test results show the mix order of integration. Although the Autoregressive Distributed Lag model or bound test to cointegration is preferable due to many advantages, but it has low power since it does not take into consideration the possibility of structural break or regime shifts in the cointegrating vector (Gregory and Hansen, 1996; Hatemi-j, 2008). Table 3 illustrate the results of unit root test with one structural break. The results indicate that all the variables are non-stationary at I(1). From the analysis of various unit root tests, the variables are found to be compatible with Autoregressive Distributed Lag model.

	LNGDP	LNENC	LNCO2
Mean	1.150629	6.249294	-1.248425
Median	1.236091	6.237082	-1.353528
Maximum	2.607390	6.494755	-0.674557
Minimum	-1.459677	5.977889	-2.008962
Std. Dev.	0.929139	0.126442	0.362682
Skewness	-0.699423	-0.253483	0.062134
Kurtosis	3.503856	3.170496	1.819648
Jarque-Bera	4.144954	0.536405	2.641263
Probability	0.125874	0.764753	0.266967
Sum	51.77829	281.2182	-56.17914
Sum Sq. Dev.	37.98514	0.703456	5.787677
Observations	45	45	45

Table 1. Descriptive statistic test.

Variables	**ADF**		**PP**	
	C	C&T	C	C&T
$LnENC_{it}$	-1.002168 (0.7444)	-2.811969 (0.2009)	-0.678818 (0.8415)	-2.722611 (0.2330)
$LnGDP_{it}$	-3.757428* (0.0069)	-3.626618* (0.0407)	-4.872646* (0.0002)	-5.019888* (0.0010)
$LnCO_{2it}$	-1.131661 (0.6947)	-1.740084 (0.7158)	-1.263730 (0.6380)	-1.524646 (0.8058)
$DLnENC_{it}$	-8.372003* (0.0000)	-8.279040* (0.0000)	-8.854254* (0.0000)	-8.756224* (0.0000)
$DLnGDP_{it}$	-8.706700* (0.0000)	-8.849246* (0.0000)	-15.81112* (0.0000)	-15.64214* (0.0000)
$DLnCO_{2it}$	-8.237642* (0.0000)	-9.154592* (0.0000)	-8.078920* (0.0000)	-9.145919* (0.0000)
*Note: * denotes significant at%5. C refers to intercept, C&T refers to intercept and trend. Values in ( ) are p-values.*				

Table 2. Unit root test

Variables	**ADF**			
	C	**Break date**	**C&T**	**Break date**
$LnENC_{it}$	-3.705433 (0.2803)	2011	-4.580780 (0.1075)	2011
$LnGDP_{it}$	-4.170306 (0.1061)	1999	-4.665040 (0.0848)	2014
$LnCO_{2it}$	-3.398079 (0.4425)	2001	-3.476447 (0.7064)	2000
$DLnENC_{it}$	-10.13805* (0.01)	2012	-8.807661* (0.01)	2012
$DLnGDP_{it}$	-10.13283* (0.01)	1989	-10.04596* (0.01)	1989
$DLnCO_{2it}$	-11.13457* (0.01)	1993	-10.99527* (0.01)	1993
*Note: * denotes significant at%5. C refers to intercept, C&T refers to intercept and trend. Values in ( ) are p-values*				

Table 3. ADF unit root test with structural break.

After identifying the series order of stationarity and stationarity with structural break, this study proceeds to explore the long-run relationship among the study parameters. Granger (1981) and, Engle and Granger (1987) were the first to introduce the idea of cointegration, providing tests and estimation procedure to evaluate the existence of long-run relationship between set of variables within a dynamic specification framework. Cointegration is an econometric concept that mimics the existence of a long-run equilibrium among underlying economic time series that converges over time. Though, cointegration establishes a stronger statistical and economic foundation for empirical error correction model, which brings together short and long-run information in modeling variables. Therefore, testing for cointegration is a necessary step to confirm if a model empirically shows meaningful long run relationships. If it failed to establish the cointegration among underlying variables, it becomes imperative to continue to work with variables in differences instead. However, the long run information will be missing (Nkoro and Uko, 2016).

Table (4) presents the cointegration test results among the variables. The value of the F-statistic (14.74348) is greater than the upper critical value (4.14). It is possible to conclude that the cointegration test shows the existence of long-run relationships among the variables in interest. This indicates that the independent variables converge to the dependent variables. After the bound test confirms the existence of cointegration among the underlying variables we proceed to estimate the ARDL model. Table 5 portrays the findings of ARDL model. The outcomes of the ARDL model are as follows:

a. The research discloses that energy consumption exerts positive and significant effect on economic growth in long-run. Thus, energy consumption promotes economic growth as can be clearly observed that a 1% increase in energy consumption increases economic growth by a magnitude of 2.938%. This result gives support to the energy-induced growth hypothesis. This result agrees with Odhiambo (2009), Hondroyiannis et al., (2002), Belke et al., (2011), Wolde-Rufael, (2009), Lee and Chang (2008). But this outcome also contradicts many other studies (see for instance, Ozturk and Acaravci, (2010), Aqeel and Butt (2001), Apergis and Payne (2010)). This results clearly implies that the Sudan economy is energy-driven and cannot embark on or initiate conservative energy policies and strategies, compromising economic growth. In other words, this result should be explained as be sufficiently robust enough to support the inference that energy consumption plays a minor role in the economic growth of Sudan.

b. The ARDL findings also reveal that there is positive interaction between economic growth and CO_2 emissions in both short-run and long-run. This infers that a 0.47 % upsurge in economic growth is due to a 1% increase in CO_2 emissions. This result may indicate that the environmental pollution is inducing economic growth in Sudan. This means that environmental deterioration generates economic growth. This may be due to the lack of stringent environmental and protection policies. Based on the Environmental Kuznets Curve hypothesis (EKC) this outcome may indicate that the economic development in Sudan is still at a scale-effect stage where both environmental deterioration and economic growth are growing and moving together at the same time. The EKC hypothesis postulates that when the economy starts moving along the growth trajectory then at the earliest stage of the economic growth environment deteriorate due to air pollution, deforestation, and many other pollutants. With an increase in per capita income economy starts to develop and environmental deterioration declines. This outcome agrees with many studies (see for example, Alnour et al., 2021; Al-Mulali et al., 2015; Lacheheb et al., 2015; Sirag et al., 2018). But this finding also contradicts many other studies (see for instance, Işık et al., (2019), Katircioğlu (2014). Ozatac et al., (2017). Pata, U. K., & Aydin, M. (2020).

c. The speed of adjustment is seen to facilitate long-run convergence among the parameters with a significant and negative error correction term (ECT) coefficient, the result of ECT is 0.9 which presents the evidence of cointegration among the parameters, and this signifies the capability of the model to witness 9% speed of adjustment to verify the tendency to equilibrium in the long-term on economic growth because of energy consumption and carbon emissions.

Test Statistic	**Value**	**k**
F-statistic	14.74348	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

Figure 4. Bounds to cointegration test.

Short-run Coefficients				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(LNENC)	-7.571853	2.746540	-2.756869	0.0088
D(LNCO2)	0.427634	0.342566	1.248326	0.2194
ECT	-0.904068	0.136376	-6.629210	0.0000
Cointeq = LNGDP - (2.9380*LNENC + 0.4730*LNCO2 -16.7544)				

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Long-run Coefficients				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
LNENC	2.938026	1.110890	2.644750	0.0117
LNCO2	0.473010	0.369470	1.280240	0.2080
C	-16.754354	6.929290	-2.417904	0.0204

Figure 5. ARDL test results

Our Autoregressive Distributed Lag model is further evaluated by diagnostic test. Table 6 presents the findings of the Breusch-Godfrey Serial Correlation LM Test. İt indicates that the model does not suffering from serial correlation since the null hypothesis of no serial correlation can not be rejected due to probability value which is greater than 5% level of significance. Furthermore, table 7 outlines the Breusch-Pagan-Godfrey test of heteroskedasticity. The results show that no evidence of heteroskedasticity is detected since the null hypothesis of no heteroskedasticity can not be rejected, because the p-value is 0.1011. In addition, our model is also further tested by the Histogram Normality test. Figure 6 indicates that the model follows the normality since the probability value of the Jarque-Bera test is 0.183. In addition, the stability of our model is assessed using the cumulative sum (CUSUM) and cumulative sum of squares (CUSUMSQ) tests as suggested by Pesaran. Figure 9 and 10 in appendix present the findings of CUSUM and CUSUMSQ for our model. The models have passed the stability tests indicating the stability of the estimated parameters.

F-statistic	2.919791	Prob. F(2,40)	0.0655
Obs*R-squared	5.732626	Prob. Chi-Square(2)	0.0569

Table 6. Breusch-Godfrey Serial Correlation LM Test:

F-statistic	2.421757	Prob. F(2,42)	0.1011
Obs*R-squared	4.652898	Prob. Chi-Square(2)	0.0976
Scaled explained SS	5.056627	Prob. Chi-Square(2)	0.0798

Table 7. Heteroskedasticity Test: Breusch-Pagan-Godfrey

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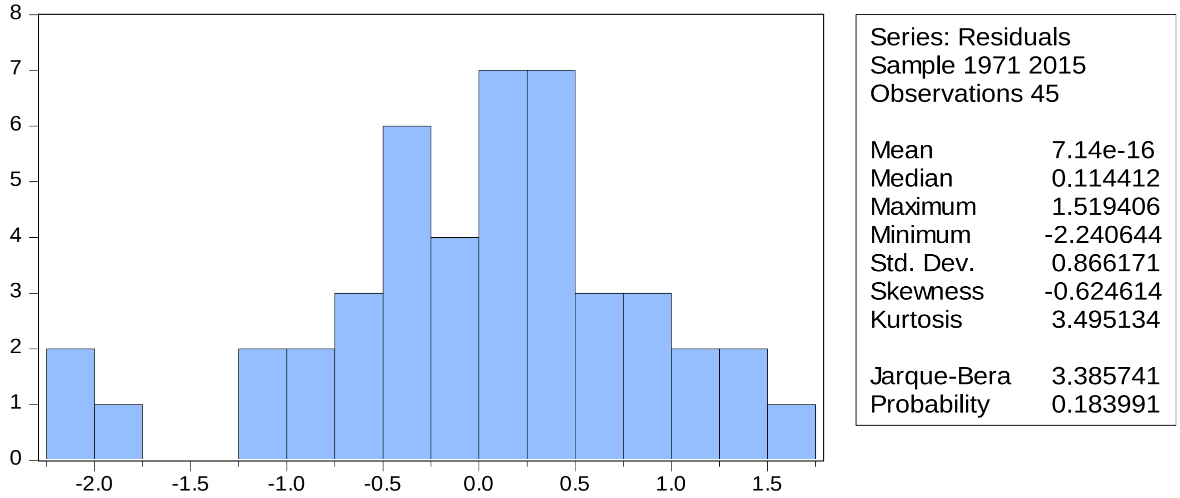

Figure 6. Histogram normality test: model

In this part of the study, we assess the relative contribution of the variables to the fluctuation in economic growth, energy consumption and CO_2 emissions. This is done by analyzing the forecast variance of the economic growth, energy consumption and carbon emissions over different horizons. Tables 8, 9 and 10 outlined the VAR model outcomes which indicate the percentage contribution of innovations in each of the variables.

Period	S.E.	LNGDP	LNENC	LNCO2
1	0.763374	100.0000	0.000000	0.000000
2	0.870253	78.72692	14.29346	6.979622
3	0.946770	79.56386	14.35273	6.083418
4	0.969273	80.39944	13.74710	5.853459
5	0.973162	80.55396	13.63827	5.807770
6	0.982316	80.07095	13.96411	5.964942
7	0.987008	79.43502	14.47301	6.091973
8	0.990692	79.44914	14.48425	6.066610
9	0.991010	79.44244	14.49135	6.066209
10	0.991542	79.39065	14.52848	6.080870

Table 8. Variance Decomposition of LNGDP.

Variance decomposition to economic growth indicates that shocks to economic growth are important source of variation in economic growth accounting for 100% and 79.39% in first

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period and after 10 periods respectively, while the shocks of energy consumption is the second important source of variation in economic growth accounting for 14.528% after 10 periods. Lastly, carbon dioxide emissions explain around 6.080% of the variation in economic growth after 10 periods.

Period	S.E.	LNGDP	LNENC	LNCO2
1	0.041452	6.418109	93.58189	0.000000
2	0.050386	12.01289	82.25345	5.733663
3	0.056656	11.52662	79.62105	8.852330
4	0.062427	9.593818	77.80004	12.60614
5	0.068407	8.294253	76.04001	15.66574
6	0.074575	7.671216	72.86777	19.46101
7	0.080743	7.069816	69.13279	23.79740
8	0.087096	6.306590	65.51442	28.17899
9	0.093868	5.583418	62.09462	32.32196
10	0.101173	4.979462	58.72205	36.29848

Table 9. Variance Decomposition of LNENC.

Variance decomposition to energy consumption reveals that the shocks of energy consumption are basic source of variation in energy consumption accounting for 93.58% and 58.72% initially and after 10 periods correspondingly, while the shocks of economic growth are the second important source of variation from the first period up to third period accounting for 6.418% and 11.52% in first and third period, respectively. The results also reveal that the shocks of carbon emissions are the second important source of variation in energy consumption from period 4 up to period 10 accounting for 12.606% and 36.298% in period 4 and 10, respectively.

Period	S.E.	LNGDP	LNENC	LNCO2
1	0.151431	3.343692	22.15940	74.49691
2	0.179787	2.578500	23.64580	73.77570
3	0.209280	4.076751	20.54983	75.37342
4	0.228573	4.389948	18.03836	77.57169
5	0.245998	4.020098	15.71996	80.25994
6	0.262865	3.583059	13.77577	82.64118
7	0.279766	3.238031	12.20662	84.55535
8	0.296932	2.934189	11.10610	85.95971
9	0.314956	2.623270	10.46489	86.91184
10	0.334353	2.328051	10.19328	87.47867
Cholesky Ordering: LNGDP LNENC LNCO2				

Table 10. Variance Decomposition of LNCO2.

Variance decomposition to carbon emissions (CO_2) shows that shocks of carbon emissions are important source of variation in carbon emissions accounting for 74.49% and 87.47% in period 1 and 10, respectively. Also, the variance analysis shows that shocks of energy consumption are the second important source of variation in carbon emissions in all periods. And lastly, the shocks of economic growth can only explain 2.32% of variation in carbon emissions.

Impulse response functions expose the dynamic response of each endogenous variable in the VAR system to a shock in other variables. This dynamic process enables us to see the impact of a unit shock on one variable on present and future values of itself and the other variables. Hence all variables in the system are affected through one standard deviation shock occurred in innovations of any variable in the VAR system. Figure 11 in appendix presents impulse response analysis. The first raw of the figure shows the response of GDP to its own shock and the shocks in energy consumption and CO_2 emissions. With the impulse of GDP, GDP declines sharply till second period, then increases steadily till the sixth period, then keep its relatively higher level for the following quarters. With the shock of energy use, the GDP increases steadily till the second quarter, then sharply declines till the fourth quarter, then keep its relatively low level in the rest quarters. Regarding the impulse of CO_2 emissions, economic growth increases up to second quarter, then declines till the third quarter and no clear response can be observed after the third quarter. The send line of the figure presents the response of energy use to the shocks in GDP and CO_2, it clearly that energy consumption does not respond to the shocks in energy use and GDP after the fourth quarter but is seems to have long run negative impact to the shock in CO_2 emissions. The last raw exhibits the response of CO_2 emissions to its own shock and the shocks in GDP and energy use. No clear response to shock in GDP after the second period, but it responds negatively to shocks in energy use. With the impulse to CO_2 emissions, CO_2 decrease sharply till the second quarter then keeps its relatively low level for the following quarters.

Table 12 and figure 7 report the causality analysis of the gradual shift. The causality test results reveal the following: (i) growth hypothesis between economic growth and energy consumption, since we can reject the null hypothesis of no causal relationship running from energy consumption to economic growth. This hypothesis reveals that energy use has great impact on economic growth and energy saving and/or energy shocks negatively affect economic growth. This result is in line with finding of Odhiambo, (2009) for Tanzania but contradicts the conclusion of Yildirim and Aslan (2012) for 17 highly developed OECD countries. (ii) the neutrality hypothesis between economic growth and carbon emissions since we cannot reject the null hypothesis of no causality relationship between economic growth and carbon emissions. (iii) uni-directional relationship running from carbon emissions to energy consumption since we can reject the null hypothesis of no causal relationship running from carbon emissions to energy consumption.

Null Hypothesis:	Obs	F-Statistic	Prob.
LNENC does not Granger Cause LNGDP	44	6.46616	0.0149
LNGDP does not Granger Cause LNENC		0.21271	0.6471
LNCO2 does not Granger Cause LNGDP	44	3.03958	0.0888
LNGDP does not Granger Cause LNCO2		0.01489	0.9035
LNCO2 does not Granger Cause LNENC	44	3.88446	0.0555
LNENC does not Granger Cause LNCO2		3.36385	0.0739

Table 11. Pairwise Granger Causality Tests

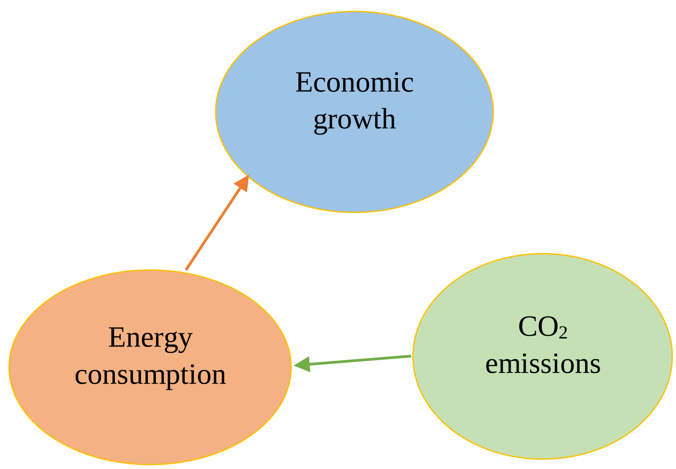

Figure 7. Interaction between energy consumption, GDP, and CO_2 emissions in Sudan.

CONCLUSION AND POLICY IMPLICATIONS

This study contributes to the existing research by investigating the effect of energy consumption on economic growth taking into consideration the impact of carbon dioxide emissions in Sudan utilizing annual time series data spanning between 1971 and 2015 due to data availability. The Autoregressive Distributed Lag model and Granger gradual shift causality, and VAR model were employed to achieve the stated objectives. The findings reveal that there is significant interaction among the variables of interest. Particularly, the result of the bound test indicates that all indicators have long run interrelations. Moreover, the ARDL results show energy consumption has a positive significant effect on economic growth in the long run but in the short run energy use impact negatively on economic growth. The CO_2 emissions also impact positively on economic performance in the short run and long run but insignificant effect. This means that, Sudan economy is energy-driven, and energy consumption promotes the economic performance in Sudan. The impetus behind this is attributable to the reality that Sudan's economy used to basically depending on petroleum sector before the separation of South Sudan where most of the oil area is located. After the separation of South Sudan, Sudan lost more than 80% of its oil resources causing huge negative consequences on the performance of economy.

Furthermore, we employed Granger causality test to detect the direction of the causality among the variables. The causality test indicates a uni-directional relationship running from energy consumption to economic growth. The outcome confirms the growth hypothesis. In addition, and to analyze the relative contribution of the variables to the fluctuation in economic growth, energy consumption and CO_2 emissions and the dynamic response to shocks this study utilized a vector autoregression (VAR) model. The dynamic tracing enables us to observe the effect of a unit shock in one variable on current and future values on itself and another variable(s) Bilgili (2003).

Based on the abovementioned outcomes, it is essential to explore policies that maintain sustainable development plan focus more on environmental aspects. The aim should be to ensure the best practice to minimizing the trade-off between economic growth and environmental quality. Additionally, since the outcomes support growth hypothesis, it means that energy has a great impact on economic growth as subsidiary factor of production and the economy cannot embark or initiate conservative energy policies and strategies compromising economic growth. Therefore, it also vital to explore policies that exclude conservative or saving energy policies.

This study has relied on aggregated data of energy use, which is very clear limitation, this study recommends that future research should investigate the dynamic impact of energy consumption on economic growth through disaggregated data. Since disaggregated data may show clearly and individually the contribution of each source on economic performance it might have a good policy implication.

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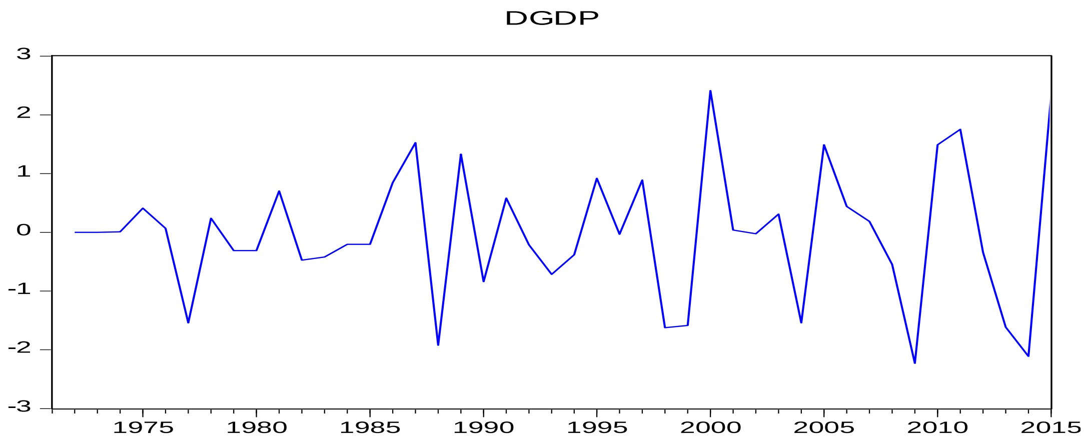
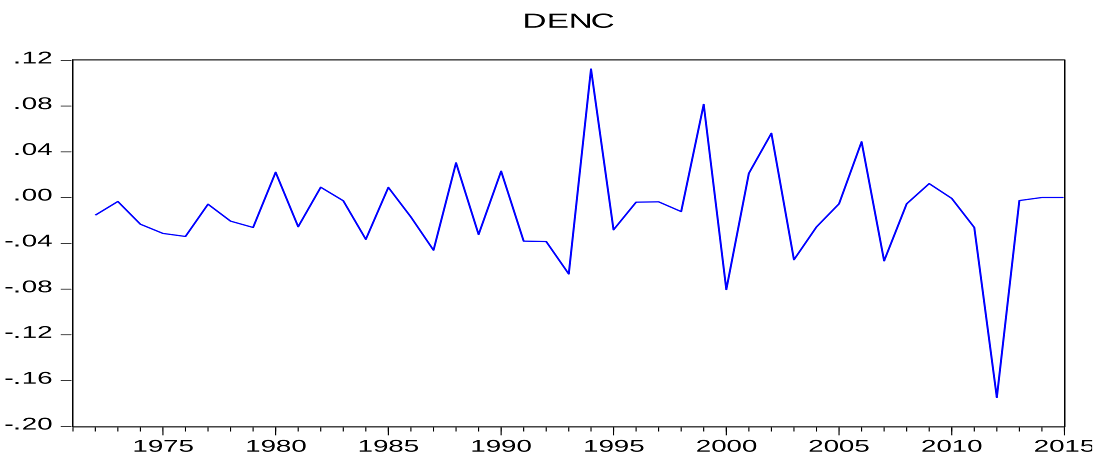
APPENDIX

(a)



(b)



(c)

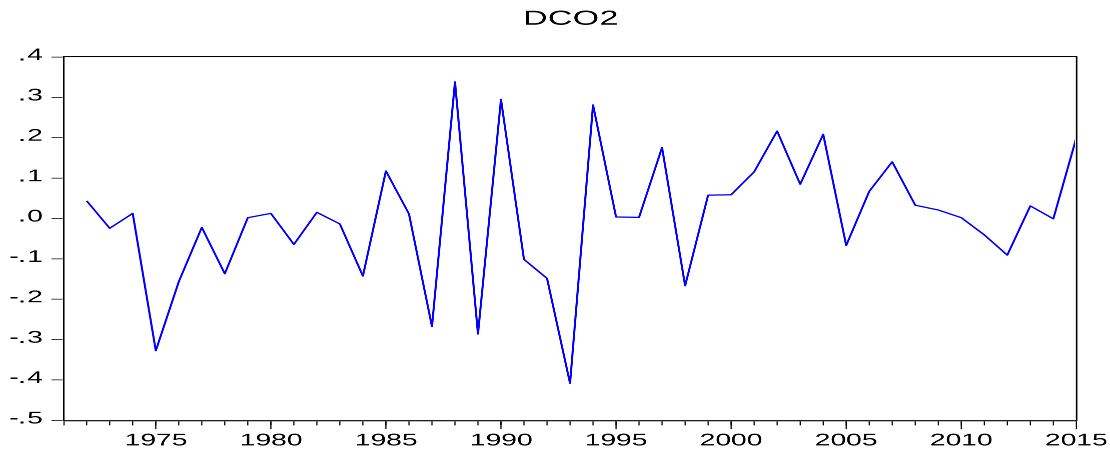


Figure 8. Stationarity test

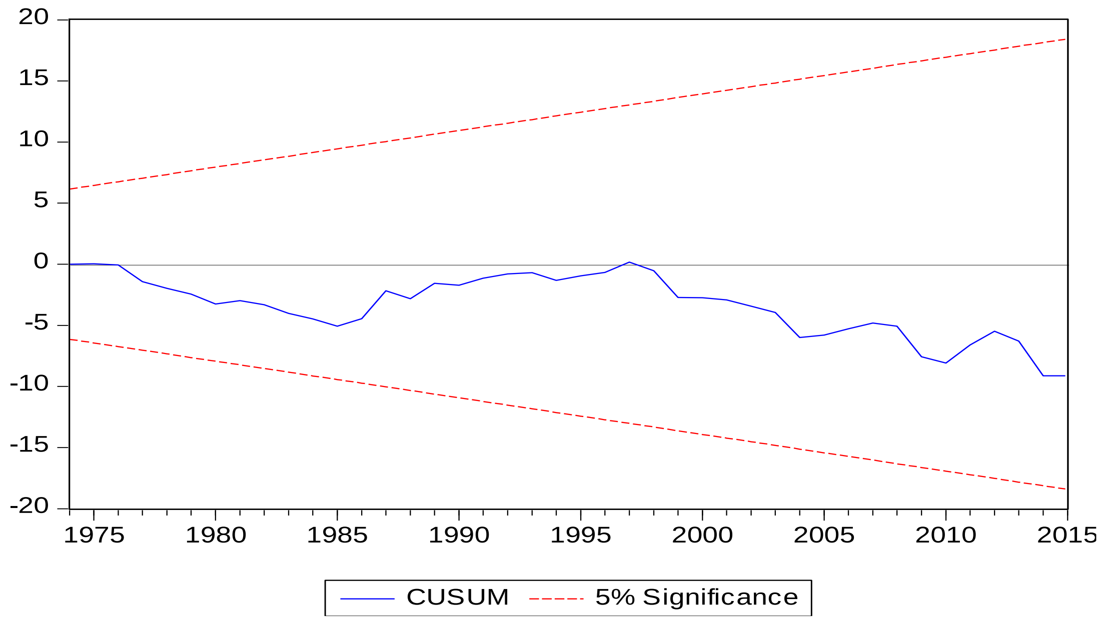


Figure 9. CUSUM stability test

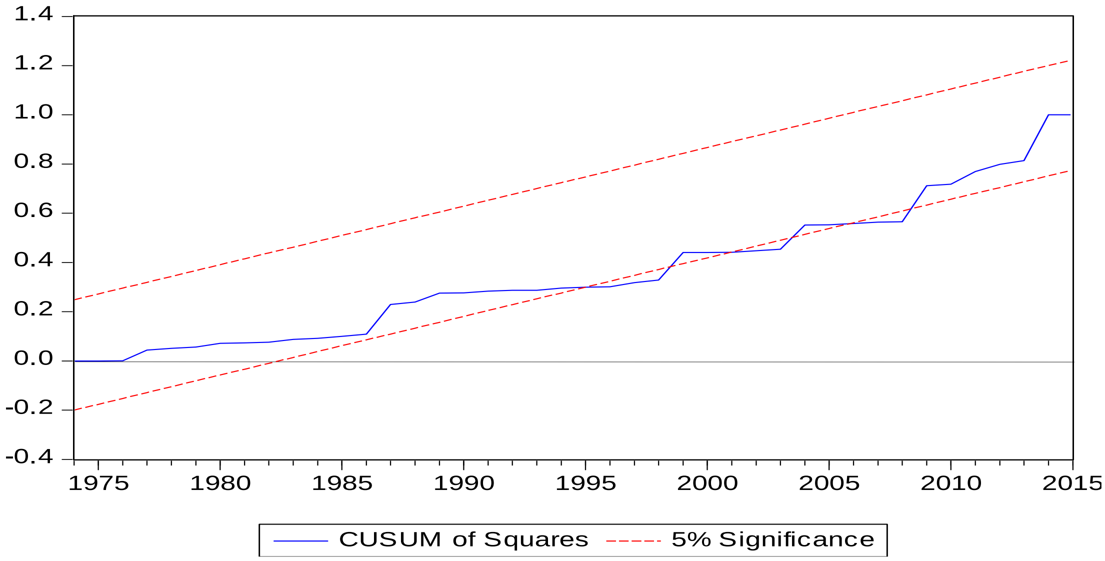


Figure 10. CUSUMSQ stability test.

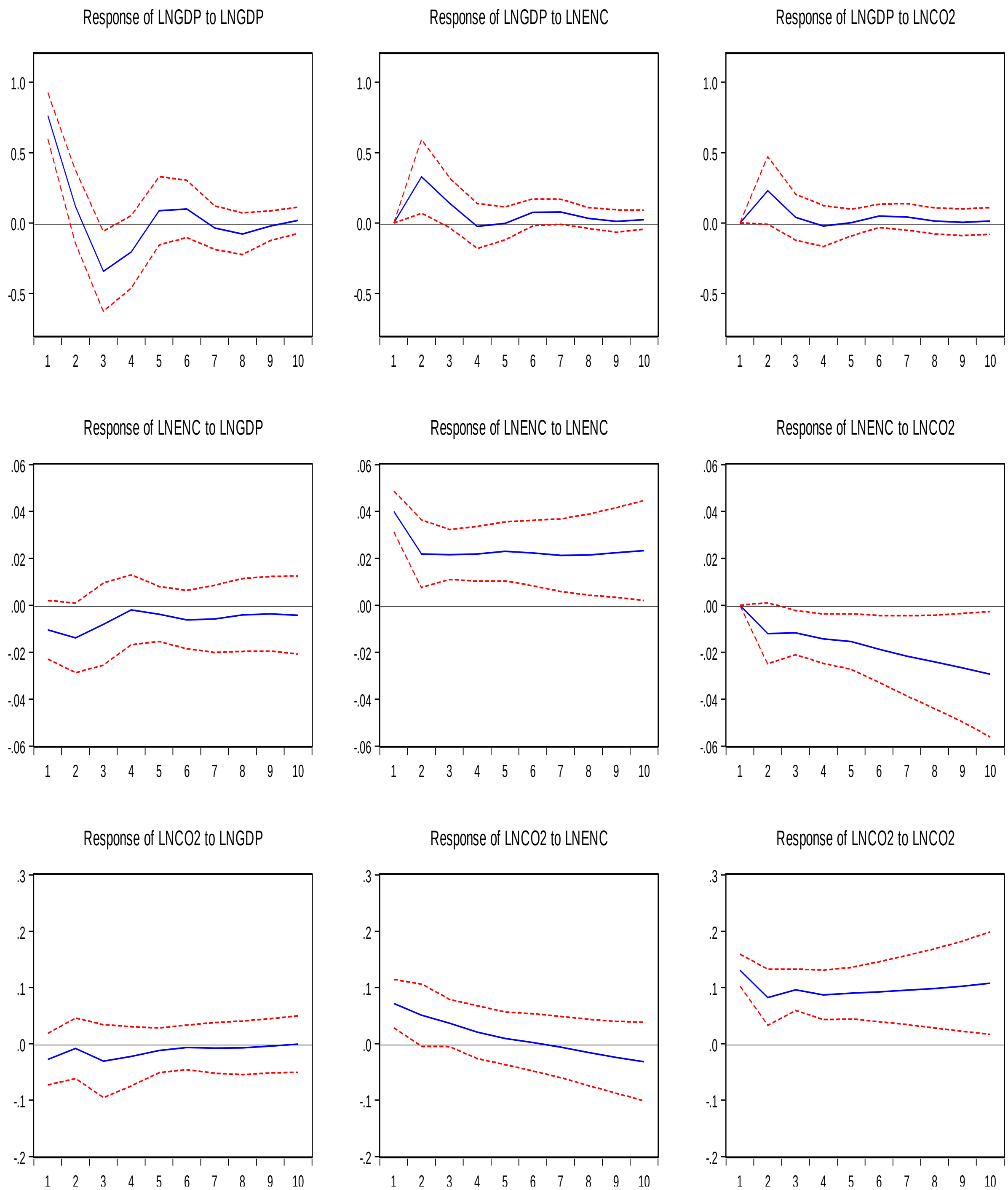


Figure 11. Impulse response