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ANALYSIS OF THE NATURE AND DETERMINANTS OF ENERGY PRICE DYNAMICS IN SUB-SAHARAN AFRICA (SSA)

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Abstract: Energy is one of the most important resources needed for growth, and consumption is an indicator to measure the development of a country. Sub-Saharan Africa (SSA) is among the sub-regions in the world with the lowest energy use per capita and one of the reasons for this is the energy price dynamics that have affected energy policy that can engender sustainable economic growth. The main objective of the study is to assess the nature and determinants of energy price dynamics in SSA using 21 countries with a complete dataset between 1980 and 2017 on variables such as energy consumption, exchange rate, and inflation rate, while energy price index and federal fund rate are also included as exogenous variables. EGARCH is used to derive the nature of energy dynamics, while panel-ARDL is used to investigate the determinants of energy price dynamics. The results show that energy price dynamics are asymmetric in nature, while the federal fund rate and exchange rate remain the most important factors influencing energy price dynamics in the sub-region. The finding is contrary to the symmetric energy price obtained by some previous authors who used oil price to proxy energy price. This study used aggregated values of energy prices, which include renewable and non-renewable energy. The implication of the findings is that currency devaluation and rise in federal fund rate aggravate the dynamics in energy piece and this causes much more macroeconomic instabilities in SSA. It is recommended that SSA countries should be cautious to embrace currency devaluation policy, and should reduce dependency on the importation of renewable energy products.

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1. Introduction

The benefit of energy to the economic development of any country cannot be overemphasized. Apart from the fact that socio-economic activities depend on it, it also provides aid to production at a very significant level. These benefits all lead to improved welfare of the economic agents in society. Access to energy commodities, however, is influenced by many factors apart from availability in the economy. One such factor is the behavior of energy commodity price, which is the major variable that constitutes external shocks to the domestic economies in Sub-Saharan Africa (SSA) (International Energy Agency IEA, 2015). The dynamics of energy prices is an important factor affecting accessibility to energy commodities in SSA since access to energy is fundamental to human welfare and sustainable growth not only in the SSA region but also all over the world.

According to the IEA (2019), SSA is among the sub-regions in the world with abundant potential for energy generation, both renewable and non-renewable. Despite this, SSA is among the sub-regions in the world with the lowest energy use per capita, having an energy consumption per capita of an average of 9.8% of the GDP (Agency, 2017). Noteworthy is also the fact that the energy use per capita in Sub-Saharan Africa has been following a downward trend in recent times. For instance, for the whole SSA region, it fell from 798KWH in 2012 to 779KWH in 2013, and 763KWH in 2016. In Senegal, it fell from 305KWH to 293KWH and 279KWH within the same period; in South Africa, it fell from 2780KWH to 2731KWH and further to 2715KWH within the same period (World Bank, 2016).

However, the reason behind this fall in energy consumption has been mostly traced to the dynamics in energy prices, which have prevented many countries from planning for sustainable energy use (IEA, 2016). Energy commodity prices have unique characteristics of being externally fixed. The implication is that individual countries and regions of the world are either directly or indirectly subservient to the fluctuations and manipulations of energy commodity prices. Sub-Saharan African countries are no exemption in this regard, as they must all adjust their economic indicators according to the dictates of the international energy commodity price movements. Notable among the countries in SSA that have witnessed a fall in energy consumption are Nigeria, Angola, and Chad. For instance, in Nigeria, energy consumption fell by 2.1% in 2016 before gradually picking up in 2018, after the economic recession (Pueyo, Bawakyillenuo & Osiolo, 2016).

Access to energy commodities, however, is influenced by many factors apart from availability in the economy. One such factor is the behavior of energy commodity price, which is the major variable that constitutes external shocks to the domestic economies in SSA (IEA, 2015). The dynamics of energy prices are an important factor affecting accessibility to energy commodity in SSA since access to energy is fundamental to human welfare and sustainable growth not only in the SSA region but also all over the world. According to the IEA (2017), there have been fluctuations in global energy prices, and the overall effect of all these unstable energy prices is reflected in the inconsistent policy framework by many SSA countries in tackling the perennial energy consumption challenge bedeviling the sub-region; in addition, this has practically made it more difficult for the region to make positive progress towards the achievement of green growth. This, among other reasons, poses some important implications for the attainment of green growth in SSA.

More importantly, the nature of fluctuations in energy prices regarding energy commodities portends some implications on energy accessibility. For instance, there has been a debate in the literature on the asymmetric nature of energy commodity price dynamics as it affects sustainable productivity and income, among others. One of the salient debates in the literature is the controversies on the relative effects of changes in energy prices on output. Some schools of thought think that an increase in energy price has more effect on output than a decrease in energy prices (Omolade & Nglawa, 2019; Alquist, Kilian & Vigfusson, 2013). This debate still provides justification for examining the dynamic effect of energy prices.

Again, some factors are adjudged to be affecting energy pricing and these vary from region to region. It has been argued that a country with more capacity for the production of domestic energy manages fluctuations in energy prices better than a country without a good production capacity. However, this claim has been refuted by Bulmer-Thomas & Olomola (2013) and Sachs (2007), because most of the countries in SSA that have good energy productive capacity are mostly affected by energy price fluctuations, which is also evident in the theory of the resource curse (Lama & Medina, 2015). Therefore, an investigation of determinants of energy price dynamics might provide useful information on how there will be an improvement in energy use per capita in Sub-Saharan Africa (SSA).

Consequently, the main objective of this study is to investigate the nature and the determinants of energy price dynamics in SSA. The rest of the paper is divided into, a literature review, methodology, results and discussion, conclusion and recommendations.

2. Literature review

This section of the paper covers both the theoretical and the empirical literature that is relevant to the study.

2.1 Theoretical literature

One of the features of the neoclassical growth theory is the provision for the influence of energy on output growth (Corden & Neary, 1982). The equation is presented thus:

$$(Q_i \dots\dots, Q_m) = f\big(A,\ X_i \dots\dots,\ Xn, E_i \dots\dots,\ E_p\big) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots..(1)$$

It should be noted that Q_i in equation 1 represents various combinations of output levels, X_i is input combinations, while E_i is various combinations of energy types that are used in the output production process. These may include both the non-renewable and renewable forms of energy. The implication is that all these inputs including energies are important shift factors of output growth.

It is also obvious that the usage of the inputs in the production process depends on the approaches to production, which may be either capital intensive or labor intensive; all these affect the extent of usage of energy or natural resources in the production process. The main critique of this theory is that the scope is too narrow and the role of government in development is not emphasized. They believe institutions are very key to the development process, and this was not given prominence in the neoclassical growth theory (Omolade & Ngalawa, 2019).

2.2 Empirical literatures

Some studies have been conducted on the determinants of energy price, but the points of dichotomy are the proxies and the case study. Some studies used oil to proxy energy price, while some used electricity price. Again, the majority of these studies used developed countries, especially the OECD, as their case study. This section presents a brief review of those studies. For instance, Ubani (2013) examined the determinants of electrical energy consumption in Nigeria. Multiple regression analysis was adopted, and the results suggested that socioeconomic factors are the main determinants of electricity consumption in Nigeria, explaining about 90 percent of the variation in electricity consumption in the country. It was also discovered that the rate of urbanization in Nigeria mounted much pressure on electricity consumption in the country. In a more recent study, Neagu, Haiduc and Anghelina (2021) examined the relationship between renewable energy consumption and economic growth in 11 Central and Eastern European (CEE) countries from 1995 to 2015. Using a multivariate type of panel data analysis after the application of World Bank data on the relevant variables, findings revealed that renewable energy consumption and economic growth have long-run positive relationships in all the countries under review.

From another country, Li, Cursio, Sun and Zhu (2019) investigated the determinants of electricity prices in the energy market in China. The nonlinear form of the autoregressive distributed lag approach was adopted, and the result indicated that many macroeconomic variables affect electricity prices, and this suggests valuable contributions to energy policy in China.

Mulder, De Groot and Pfeiffer (2014) focused on the service sectors of the OECD countries and examined the determinants of energy intensity among them. More attention was given to climatic conditions that affect energy usage intensity in these countries, and the result of the survey suggested that climate change is very important to energy productivity in these countries.

Ruiz and Antonio (2012) analyzed the determinants of energy price volatility in Australia and discussed its effect on the economic activities in the country. Quantitative analysis was used to develop a measure of the uncertainty in energy prices and concluded that the usage of entropy and modified permutation entropy approaches are the best way to derive energy volatility, which represents a clear departure from what was obtainable in the energy market before.

In addition, Ghoshray (2011) investigated the persistence and volatility in energy markets in the BRICS. The paper designs a three-fold contribution to the underlying dynamic factors and causal effects of energy prices. Firstly, the paper undertakes a study of the underlying features to help note the time series path of non-renewable energy resources, which can have remarkable aftermath effects for economists and policymakers alike. The analysis is further stretched to ascertain the persistence of oil price shocks. Secondly, the study investigates the causal interaction between oil prices and the macroeconomy allowing for non-linear models recently recommended in the literature. Lastly, this study explicates the correlation between oil prices and agricultural commodities. From a policy point of view, these interrelationships of agricultural and oil prices need to be thoughtfully considered within the context of the recent energy crisis, which may of course continue in the future.

In the same vein, Regnier (2007) investigated the volatility of energy and oil prices generally since it is believed that since the 1973 oil crisis that energy and oil prices have become more volatile. Results from the quantitative analysis suggest that oil and refined petroleum prices are more volatile than any other energy commodity prices during the periods under review. More than 65% of volatility was traced to oil commodity prices, while about 35% was traced to other energy commodity prices.

Using more advanced techniques of analysis, Chan and Grant (2015) did a comparison of how some stochastic volatility models measure oil price volatility. These methods include GARCH, SV and AR1. It was found that all these methods showed different efficacy in measuring the volatility of oil prices. Notwithstanding, the result confirmed that SV models are the best in measuring all nine forms of oil prices examined in the study.

Wang, Zhang and Broadstock (2019) assessed the determinants of gas prices in the United States using the time-varying approach in the dynamic model analysis

(DMA). The data used was from 2001 and 2018, and the results of the analysis indicated that oil price is having a declining effect on gas pricing in the US. Factors that have a greater effect on gas pricing from the analysis are weather, demand and supply conditions. It was further discovered that the capital market is beginning to have a greater effect on gas pricing.

Shiferaw (2019) investigated the rate of dependency of agricultural products and commodity generally on natural energy prices. The Bayesian multivariate GARCH was used to analyze the data collected on the South African economy. The regime of the effect on the agricultural outputs was analyzed using the Markov switching approach. Results from the study show a strong relationship in the long run between agricultural outputs and energy price dynamics in South Africa.

Mosquera-López and Nursimulu (2019) investigated the drivers of electricity energy and this was done using structural breaks and threshold regressions. The nonlinearities of the model were taken into cognizance. The spot market price of electricity was used and the result shows that renewable energy sources remain the most important determinants of electricity spot prices. In addition, both long- and short-run relationships were confirmed between electricity price and the drivers.

Wu, Ma and Tang (2019) investigated the determinants of reducing negative energy in the form of C02 emission costs. The price of the energy relationship with C02 costs is crucial to the study. A study of 286 cities in a panel estimation of the Chinese economy was analyzed. The application of panel regression showed that there is a strong relationship between energy price and marginal abetment cost of C02 MAC.

Zarnikau, Tsai and Woo (2020) examined the dynamic nature of energy prices and ancillary services using real-time market data in the US economy. The regression analysis uses the hourly data of electricity prices and the result indicated that demand-side management and reduction of inter-regional transmission congestion are very evident in the findings.

From the literature review, the majority of studies focused on energy price rather than its movement. In addition, few studied the movement of oil price to proxy energy price. This might not capture the totality of energy prices, since there are some non-oil energy commodities, and therefore this study used the composite price index of all energy commodities and focused on Sub-Saharan Africa (SSA), which is one of the regions with severe challenges regarding energy consumption.

3. Methodology and data

This section explains the research method embraced to achieve the objectives of the study. It also discusses the theoretical framework on which the model specification relies.

3.1 Theoretical framework

From the theoretical literature discussed in the previous chapter, the neoclassical growth theory of Corden and Neary (1982) is selected as a precursor for the model specification used to achieve this objective. The neoclassical perspective of the production function explains the linkages between energy and growth. A general form of the production function describes the relationship between energy and economic activity (Corden & Neary, 1982). The function is presented as follows:

$$(Q_i \ldots\ldots, Q_m) = f\left(A,\ X_i \ldots\ldots, Xn, E_i \ldots\ldots, E_p\right) \ldots\ldots (2)$$

Where Q_i is various outputs, X_i is various inputs such as capital, and labor, among others; A is the constant, which is also known as total factor productivity. E_i is energy inputs used in the production process, which can be energy from both renewable and non-renewable sources. From equation 1, a production function expressing output as a function of other inputs and energy is formulated as follows:

$$Q_{i,t} = f(X_{it},\ E_{it}) \ldots\ldots (3)$$

Where $Q_{i,t}$ is the output growth rate of country *i* at period *t*, $X_{i,t}$ represents other variables that are necessary for the production process in country *i* at period *t*, $E_{i,t}$ represents energy inputs used in the production process in country *i* at period *t*.
Using the Cobb-Douglass production function, as it is used in Omolade and Ngalawa (2014), due to its flexibility in linearising, equation 3 can be presented as follows:

$$Q_{i,t} = A_{it}X_{it}^{\beta}E_{it}^{\alpha} \ldots\ldots (4)$$

All variables are as defined before, except A_{it}, which is the constant aimed to capture technological progress in production.
Making $E_{i,t}$ the subject of the formula:

$$E_{i,t} = Q_{it}^{-\alpha}\left(A_{it}X_{it}^{\beta}\right) \ldots\ldots (5)$$

The linear form of the equation can be expressed by taking the log as follows:

$$log\ E_{i,t} = -\alpha logQ_{i,t} + log\left(A_{i,t}X_{i,t}^{\beta}\right) \ldots\ldots (6)$$

By expansion of equation 6, we have:

$$log\ E_{i,t} = -\alpha logQ_{i,t} + logA_{i,t} + \beta logX_{i,t} + \mu_t \ldots\ldots (7)$$

The implication of equation 7 is that energy input, which will be proxied by the energy input price, can be expressed as a function of output, technological progress and other shift factors. However, for the purpose of our objective, energy price volatility is used to proxy $E_{i,t}$, which is the energy price dynamics. Energy use per capita is used to proxy $Q_{i,t}$ and, according to Avila, Carvallo, Shaw and Kammen (2017), this represents energy consumption in each of the countries covered in the study. $X_{i,t}$ is other shift factors that can affect energy pricing, such as exchange rate and inflation rate, and an exogenous variable, called federal fund rate, has also been adjudged to have an influence on energy pricing dynamics in SSA. According to Omolade and Ngalawa (2014), the federal fund rate is the discount rate of the US Reserve Bank. Every dollar borrowed from the US is discounted at this rate, and therefore it is a powerful instrument that affects international transactions that are usually denominated in dollars. The importance of this variable is because energy price is conventionally traded in the dollar.

3.2 Model specification

Following the theoretical build-up, the model explaining the relationship between energy price dynamics and its determinants is based on the empirical study of Xiarchos and Burnett (2017), where the relationship between economic growth and energy price was assessed. However, Xiarchos and Burnett (2017) were much more concerned with the growing relationship with energy price, yet some macroeconomic variables such as exchange rate and inflation rate were included in the study. This study modified Xiarchos and Burnett's (2017) model by replacing economic growth with energy consumption, which has been supported as more relevant to energy price than economic growth (Avila, Carvalo & Kammen, 2017). Consequently, combining the theoretical and the empirical perspective, the model that explains the relationship between energy price dynamics and its determinants is specified as follows:

$$EPVOL_t = \gamma + \alpha logQENERGY_{i.t} + \beta_1 logEXR_{i,t} + \beta_2 logFFR_{i,t} + \beta_3 logINF_{i,t} + \mu_t \qquad (8)$$

It should be noted that EPVOL represents the energy price dynamics, which will be derived from the EGARCH model that is explained below. This variable is key to the objective of this study as it will explore the nature of energy price dynamics and later come up with the conditional variance equation residual that will be used to proxy energy price dynamics (See Demachi, 2012; Omolade et al., 2019). Therefore, the implication of this is that equation 7 cannot be estimated without first generating

the EPVOL via the EGARCH process. QENERGY is the energy consumption, EXR is the exchange rate, INF is the inflation rate and FFR is the federal fund rate.
Firstly, energy price dynamics are developed via the exponential generalized autoregressive conditional heteroskedasticity (EGARCH [1,1]). The energy price dynamics are measured by estimating the following EGARCH model:

$$engyp_t = \varphi + engyp_{t-1} + \mu_t \qquad (9)$$

The AR[1] approach is followed. The following EGARCH model is estimated:

$$ln\sigma^2 = \omega + ln\sigma_{t-1}^2 + \alpha \left|\frac{\mu_{t-1}}{\sigma_{t-1}}\right| + \gamma \left|\frac{\mu_{t-1}}{\sigma_{t-1}}\right| \qquad (10)$$

In equation 10 above, μ_t is residual, and σ denotes the conditional variance obtained from equation (9). Here, if < 0, it indicates the asymmetric character of energy price dynamics. This means that a negative price shock has a larger influence on volatility than a positive price shock does. In the panel analysis, this estimate of the conditional variance is used for energy price dynamics.

3.3 Data sources and description of variables

Table 1 shows the sources of data used for the analyses as well as their descriptions.

Table 1 Data sources and variables descriptions

Variables	Description	Measurement
EPVOL	Energy price volatility	It is measured by the conditional variance of the EGARCH model estimated in equation 10
QENERGY	Energy consumption	The measurement is by total energy use per capita in each of the countries.
EXR	Exchange rate	It is estimated as an annual average using monthly averages. (The domestic currency units in relation to the US dollar.)
INF	Inflation rate	The main measurement uses CPI, which is the consumer price index. The annual change in the percentage of prices of a basket of commodities is used. The Laspeyres formula is generally used. Laspeyres index= $\frac{\sum(P_{i,t} x Q_{i,0})}{\sum(P_{i,0} x Q_{i,0})} X\ 100$ Where: $\mathbf{P_{i,0}}$ is the price of the individual item at the base period, and $\mathbf{P_{i,t}}$ is the price of the individual item at the observation period. $\mathbf{Q_{i,0}}$ is the quantity of the individual item at the base period.

FFR	Federal Fund Rate	This is the rate of interest at which the US banks borrow and lend money among them, particularly from the Federal Reserve Bank of the US. It usually changes about 8 times annually, based on the dictates of economic activities.

Source: Authors' computation, 2021

Table 2 Descriptive statistics of the variables

	EPVOL	EXR	FFR	INF	QENERGY
Mean	0.913569	11039774	4.873985	85.46674	684.6166
Median	-1.035585	74.61000	6.000000	6.800000	456.3600
Maximum	26.34855	6.72E+09	10.00917	23773.10	3129.080
Minimum	-44.81623	0.000000	0.070000	-72.72900	0.000000
Std. dev.	15.38984	2.72E+08	3.473672	1005.920	600.9786
Observations	609	609	609	609	609

Source: Author's computation, 2021

The mean energy consumption is 684.6166. This value is closer to the minimum than the maximum limit. The implication of this is that energy consumption in SSA during the period under review is, on average, very low. It should be noted that the consumption of energy is proxy by energy use per capita in the SSA. Therefore, it implies that energy usage across SSA is low during this period. However, while other variables in the model have mean values that are closer to the minimum than the maximum, only energy price dynamics show a mean value of 0.913569, which is closer to the maximum than the minimum. The implication of this is that energy price dynamics are relatively high during the period under review in the SSA. The federal fund rate, inflation rate and exchange rate all show values that are relatively closer to their minimum values. Again, considering the standard deviation values for the variable, it is clear that variables such as inflation rate, federal fund rate and energy consumption have low variance figures, which show that their data is less widely dispersed. For exchange rate and energy volatility, their data appears to be more widely dispersed, because their standard deviations are high.

3.4 Estimating techniques: Panel auto-regressive distribution lags model (panel ARDL)

The panel ARDL is adopted to assess the determinants of energy price dynamics. This is because it gives room for flexibility in terms of criteria and requirements regarding the panel unit root test, as it accommodates both I(1), which is an integration of order one, and I(0), integration of order zero or stationarity at a level. Again, it will assist in studying both the long- and short-run impacts of the determinants on energy price dynamics. With this, it will be possible to ascertain which of the variables has a sustained or long-run effect on energy price dynamics and which of them has a transitory effect. The technique is carried out in three stages, namely the pre-estimation tests, model estimation and post-estimation tests. This estimating technique is carried out in three stages. The first stage is the pre-estimation test, which includes the panel unit root test and panel model lag length selection

3.4.1 Panel unit root test

The necessary condition to be fulfilled before the application of panel ARDL is that the variables must be stationary either at level or after the first difference. In econometrics literature, there are various approaches to panel unit root tests; notwithstanding, it has been advised that more than one approach should be used to ensure consistency in the result. In this analysis, ADF and IPS, which are the most widely used in the literature due to their consistency, are applied. The second step is lag length selection.

3.4.2 Panel model lag selection criteria

As part of the requirements for the panel ARDL estimation, there is the need to first confirm the model selection criteria for the panel model to be estimated. There are three most widely used model selection criteria approaches for panel data, namely Akaike information criterion (AIC), the Bayes factor and/or the Bayesian information criterion (BIC) (which to some extent approximates the Bayes factor) and Hannan-Quinn information criterion. However, the most suitable one among the three for panel data is the AIC, because it measures the goodness of fit of the estimated statistical model, among others. Consequently, this study makes use of the Akaike information criteria (AIC) as the yardstick for the selection of a particular model for panel estimation (Deaton, 1985).

3.4.3 Panel cointegration test

The next step is to estimate the panel cointegration. There are three notable types of panel cointegration tests, namely the KAO, Pedroni and the Johansen panel cointegration tests. This study will apply KAO and Pedroni, as the two do not require stringent conditions that the variables must be I (1) variables.

3.4.4 Panel ARDL/PMG estimation

Next is the estimation of the panel ARDL regression. It has been argued that the long-run relationships exist only within the context of cointegration among integrated variables (Johansen, 1995; Philipps & Hansen, 1990). However, panel ARDL is another panel data technique that makes it possible to estimate both the long- and short-run relationships among variables via the pooled mean group PMG or mean group MG approaches. This study uses the PMG approach to analyze the panel ARDL, since it imposes fewer restrictions in terms of N and T sizes when compared to MG. It is believed that the PMG approach still performs better in a relatively small sample than the MG (Pesaran, Shin & Smith, 1999).

4. Results and discussions

This section presents and discusses the empirical results. Comparisons with previous empirical findings are also made in order to draw some inferences.

The estimated EGARCH or conditional variance equation for energy price is presented as follows:

$$ln\sigma^2 = \underset{(1.263175)}{7.909107^{***}} + \underset{(0.458343)}{0.648485}\, ln\sigma_{t-1}^2 + \underset{(0.214030)}{0.317362} \left|\frac{\mu_{t-1}}{\sigma_{t-1}}\right| - \underset{(0.184937)}{0.657641^{***}} \left|\frac{\mu_{t-1}}{\sigma_{t-1}}\right| \quad (11)$$

*, **, ***: significance at 10%, 5% and 1% respectively

4.1 Identification of asymmetric or symmetric effect

To interpret the results in equation 11, the identification of symmetric or asymmetric effect is focused on. It should be noted that equation 11 is the estimated EGARCH model for energy price. The results show that energy prices have an asymmetric effect during the period under review. This is because the coefficient (-0.657641) is less than zero, which is negative, but the t-statistic is statistically significant. This indicates that negative news in the energy market will have a more pronounced effect on volatility than positive news will. Consequently, the residual of the conditional variance equations that is $ln\sigma^2$ in equation 11 will be used to proxy energy price dynamics in subsequent equations.

4.2 Panel unit root test

Table 3 contains the results of the panel unit root tests. Two methods of panel unit root tests are applied in the study, namely the ADF panel unit root test and the Im Pesaran and Shin IPS panel unit root test.

Table 3 Panel unit root test for the determinants of energy price dynamics

		With Intercept		With Trend and Intercept		
Variable	**Test**	**Statistic**	**P-value**	**Statistic**	**P-value**	**Order of integration**
LEPVOL	ADF	271.189*	0.000	199.681*	0.000	I(0)
	IPS	-14.224*	0.000	11.5519*	0.000	I(0)
LEXR	ADF	233.262*	0.000	197.839*	0.000	I(1)
	IPS	-11.2694*	0.000	10.4293*	0.00	I(1)
LFFR	ADF	149.117*	0.000	264.860*	0.00	I(0)
	IPS	-8.49107**	0.026	14.8209**	0.00	I(0)

LINF	ADF	160.332**	0.019	141.440**	0.00	I(0)
	IPS	-8.39500*	0.000	7.91936*	0.00	I(0)
LQENERGY	ADF	235.250*	0.000	211.506*	0.000	I(1)
	IPS	-12.3789*	0.000	11.9188*	0.000	I(1)

NB: */**/*** denotes significance at 1%, 5% and 10%, respectively
Source: Authors' computation, 2020

The results of the panel unit root tests show that the variables are mixtures of I(1) and I(0). This means that they are stationary at both levels and after the first difference. For instance, energy price volatility, federal fund rate and inflation rate are all stationary at levels, because the test statistic at levels has a more absolute value compared to the critical values at all levels of significance. If the null hypothesis is rejected, it means that we fail to reject the alternative hypothesis of stationarity, thereby indicating that there is no unit root, that is, the series is stationary. However, this situation only holds after the first difference for energy consumption and exchange rate, and consequently, they are I(1) variables, while others are I(0) variables.

4.3 Model selection criteria for determinants of energy price dynamics

The lag length selection criteria for the panel ARDL are first examined. This enables us to determine the optimal lag length for the ARDL model to be estimated. The results of the model lag length selection criteria are presented in Table 4.

Table 4 Model lag length selection criteria for determinants of energy price dynamics

Model	LogL	AIC*	BIC	HQ	Specification
1	-3028.517035	8.151012	8.931492	8.451286	ARDL(1, 1, 1, 1, 1)
3	-3025.841269	8.198300	9.104858	8.547080	ARDL(2, 1, 1, 1, 1)
2	-2992.686491	8.221126	9.379839	8.666918	ARDL(1, 2, 2, 2, 2)
4	-2986.416852	8.259140	9.543931	8.753437	ARDL(2, 2, 2, 2, 2)

Source: Authors' computations, 2020

The results from the model selection criteria indicate that using the AIC criteria the first model appears to be the most appropriate to be estimated; therefore, ARDL(1, 1, 1, 1, 1) with the least AIC value is used for the panel ARDL model.

4.4 Panel ARDL for the determinants of energy price dynamics in Sub-Saharan Africa (SSA)

Considering the results of the panel unit root test, it is obvious that the linear panel data approach of fixed and random effect cannot be applied, because the variables are not integrated of the same order, and therefore the use of panel ARDL. In terms of the unit root test, panel ARDL accepted combinations of I(1) and I(0) variables. Notwithstanding, since the estimation will include both the long-run and short-run relationship, the need exist to investigate the existence of cointegration first.

4.5 Panel cointegration test for the determinants of energy price dynamics in Sub-Saharan Africa (SSA)

This approach is necessary to investigate the existence of long-run relationships among the variables to be included in the panel ARDL model. This is because the results will be divided into long- and short-run relationships; consequently, the verification of panel cointegration will enable us to identify which of the two equations estimated is to be given priority. The Pedroni panel cointegration test approach is adopted ahead of Johansen panel cointegration due to the results of the panel unit root test. The result is presented in Table 5.

Table 5a Pedroni panel cointegration test: No deterministic trend

Null hypothesis: No cointegration				
Trend assumption: No deterministic trend				
Newey-West automatic bandwidth selection and Bartlett kernel				
Alternative hypothesis: Common AR coefs. (within-dimension)				
			Weighted	
	Statistic	Prob.	Statistic	Prob.
Panel v-statistic	6.747754	0.0000	3.944449	0.0000
Panel rho-statistic	-10.04361	0.0000	-9.551539	0.0000
Panel PP-statistic	-19.16040	0.0000	-18.43957	0.0000
Panel ADF-statistic	-9.300049	0.0000	-9.078776	0.0000
Alternative hypothesis: individual AR coefs. (between-dimension)				
	Statistic	Prob.		
Group rho-statistic	-9.225322	0.0000		
Group PP-statistic	-23.13194	0.0000		
Group ADF-statistic	-10.16927	0.0000		

Source: Author's Computations, 2020

Table 5b Pedroni panel cointegration test: With deterministic trend and intercept

Null hypothesis: No cointegration				
Trend assumption: Deterministic intercept and trend				
Newey-West automatic bandwidth selection and Bartlett kernel				
Alternative hypothesis: Common AR coefs. (within-dimension)				
			Weighted	
	Statistic	Prob.	Statistic	Prob.
Panel v-statistic	4.601994	0.0000	1.833425	0.0334
Panel rho-statistic	-7.030968	0.0000	-6.716842	0.0000
Panel PP-statistic	-22.75225	0.0000	-22.12952	0.0000
Panel ADF-statistic	-9.881201	0.0000	-9.767778	0.0000
Alternative hypothesis: individual AR coefs. (between-dimension)				
	Statistic	Prob.		
Group rho-statistic	-5.613843	0.0000		
Group PP-statistic	-30.06414	0.0000		
Group ADF-statistic	-10.06430	0.0000		

Source: Authors' computations, 2020

The results of the panel cointegration test as it appeared on both tables show that the null hypothesis of no cointegration is overwhelmingly rejected both in panel and group statistics. These results speak volumes of the existence of cointegration among the variables. The result implies that energy price dynamics and their determinants have a significant long-run relationship. Consequently, all the variables included as determinants of energy price dynamics can jointly influence it in the long run. The next effort is to estimate both the long- and short-run relationships among the variables. To estimate the long- and short-run relationships using the panel ARDL approach, the model lag length selection criteria must be established. This is the first step in this stage.

4.6 Panel ARDL estimates for determinants of energy price dynamics

The estimation of the panel ARDL using the pooled mean group (PMG) approach is divided into two, namely the long-run and short-run estimates. It should be noted that the rationale for selecting PMG has been discussed under the methodology. The results from the analysis are presented in Table 6a.

Table 6a Long-run results for PMG of determinants of energy price dynamics

Selected Model: ARDL(1, 1, 1, 1, 1)				
Variable	Coefficient	Std. error	t-statistic	Prob.*
	Long-run equation			
QENERGY	-0.002882	0.003012	-0.956857	0.3390
EXR	-4.85E-10	3.50E-09	-0.138656	0.8898
INF	-0.000459	0.000796	-0.576709	0.5643
FFR	0.078942	0.001711	0.706664	0.0300

Table 6b Short-run results for PMG of determinants of energy price dynamics

	Short-run equation			
COINTEQ01	-1.024997	0.018131	-56.53422	0.0000
D(QENERGY)	-0.007772	0.063570	-0.122253	0.9027
D(EXR)	2.699039	1.357549	1.988170	0.0472
D(INF)	0.460836	0.139527	3.302843	0.0010
D(FFR)	2.569037	0.081973	31.33997	0.0000
C	3.572720	0.607658	5.879488	0.0000
Mean dependent var	0.309324	S.D. dependent var		20.61753
S.E. of regression	13.06024	Akaike info criterion		7.927488
Sum squared resid	117352.1	Schwarz criterion		8.675522
Log-likelihood	-3112.342	Hannan-Quinn criter.		8.214546

Source: Author's Computations, 2020

The results as shown in Table 6b are an indication that the determinants of energy price dynamics have a relationship with it in both the long- and short-run periods. However, it appears that their effects are more transitory than permanent.

Starting with the short-run results, the average estimates of the coefficients are used because the preliminary statistics have shown that data on the variables largely has low variance, and therefore the data is less widely dispersed, exhibiting uniform distribution across the cross-sectional unit. Again, the energy price dynamics, which are the dependent variable, are the same for all the cross-sectional units. The short-run estimated panel equation results show that all the variables used as determinants have significant impacts on energy price dynamics, except for energy consumption. The coefficients of the exchange rate are 2.699039 and it is significant at 5%. This is an indication that, in SSA, the exchange rate is an important factor that drives energy prices. The implication is that currency devaluation in SSA aggravates volatilities in the energy price, while the appreciation of currency will reduce energy price dynamics.

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Inflation rate is another variable with a significant impact on energy price dynamics in the short-run period. Results show that the coefficient is 0.460836, and it is also significant at 5%. This indicates that inflation rate is another important factor affecting energy price dynamics in SSA. The positive and direct relationship between inflation rate and energy price dynamics implies that the dynamics in energy prices in SSA are more during a rise in inflation than a fall in inflation. In the same vein, just like what we noticed under the exchange rate relationship with energy price dynamics, the result of the relationship between inflation and energy price dynamics also shows that it is more pronounced in the short run than in the long run.

Still, in the short-run result, the federal fund rate has a coefficient of 2.569037 and it is also statistically significant. The implication is that the federal fund rate also has a significant short-run effect on energy price dynamics.

Energy consumption, which is used as one of the determinants, failed to have a significant impact on energy price dynamics in the short run. The consumption is proxied with energy use per capita. This result shows that energy consumption in SSA is not enough to exert significant impacts on the dynamics of energy prices in SSA during the periods under investigation.

For the long-run coefficients, the federal fund rate is the only true exogenous variable included in the model, which is not controlled by the SSA countries. The federal fund rate is the only variable with a significant long-run impact on energy price dynamics. The long-run coefficient is 0.078942, and it is significant at 5%. This implies that the federal fund rate is the only determinant used in the estimated panel model for the energy price dynamics in SSA with sustained effect. Again, it should be noted that the coefficients, both in the long- and short-run periods, are positive and significant; therefore, a rise in the federal fund rate aggravates energy price dynamics in SSA and vice versa. The general implications of the results are that out of all determinants, the federal fund rate has the most pronounced effect on energy price dynamics in SSA because apart from having a significant transitory effect on energy price dynamics, the effect is also permanent.

Notwithstanding, their joint effects, in the long run, are significant, as shown in the panel cointegration test conducted earlier. Therefore, combinations of the exchange rate, inflation rate, energy consumption and federal fund rate are important factors driving energy price dynamics in the long run.

The cointegration coefficient that is the error correction term value is -1.024997, and the value is significant at 5%, which is an indication that the adjustment process is in the right direction and the feedback is also impressive. Whenever there is disequilibrium in the economy, the speed of adjustment is about 102%, which shows a very high speed of recovery after disequilibrium. In all the estimated ARDL panel models, the dynamic relationship between energy price dynamics and its determinants is significant.

Results from the analysis have indicated that energy price dynamics are asymmetric, and this shows that bad news in the energy market, such as price increases, is capable of causing more volatilities than good news such as a fall in energy prices. Furthermore, the result implies that whenever there is a rise in the prices of energy commodities in the market, it causes immediate and much more sporadic effects on other related items such as electricity per kilowatt price in the market than when there is a fall in energy price. It should be noted that the aggregated energy price is used in this study, and this includes all forms of energy, either oil or nonoil forms of energy, and therefore the effects of its movement have been shown to be asymmetric in nature. This result underscores the importance of energy price movement in the selected SSA countries. It indicates that the general macroeconomic climate becomes more volatile whenever there is an upward movement in energy prices in the selected SSA countries.

However, this result is in sharp contrast to the findings of some authors, such as Demachi (2012) and Omolade (2014), among others, who found the symmetric effect of energy price. Investigation into these studies shows that they made use of crude oil prices alone to proxy energy prices, which resulted in the symmetric effect they obtained in their results. As earlier stated, this study used aggregated energy price, which includes prices of energy from different sources and not oil alone. The usage of aggregated energy prices is believed to be all-encompassing as it includes the composite prices of all forms of energy, and therefore it gives a better representation of energy commodities than oil (World Bank, 2018). This has been shown to have an asymmetric effect against the symmetric effect obtained when the only oil price is used. The reason behind this result might not be unconnected to the fact that crude oil prices are more homogenous and therefore the price movement effect might be symmetric (Tapatta, 2008). In contrast, the energy price is more diversified as it comprises different forms of energy prices that are aggregated and decomposed to be one. The results have shown that a rise in energy price might have serious implications on the SSA economy as it is capable of triggering prices of other related commodities in the economy.

The exchange rate and federal fund rate are variables with the most dominant effects on energy price dynamics. This further confirms the exogenous nature of energy price dynamics because the federal fund rate is an exogenous variable to the SSA, while most of the sampled countries in the SSA practice a floating exchange rate system, which is subservient to foreign exchange market trends.

The relationship between energy price dynamics and exchange rate has shown that exchange rate depreciation in SSA is capable of aggravating energy price volatility. In the same vein, the effect is more pronounced. The relationship between energy price dynamics and exchange rate as obtained in this study is an indication that the results support the asymmetric effects of energy price, which was discovered under the first objective of the study. Currency depreciation is capable of causing upward movement in energy prices since most of the countries are energy commodity importing countries. The rise in the energy price is capable of aggravating volatilities in the SSA economy, which is a reflection of the asymmetric effect of energy price dynamics. In the same vein, results from this study have shown that exchange rate is a major driver of energy price dynamics. Despite the fact that studies such as Jibril (2016), Ogundipe, Ojeaga and Ogundipe (2014), among others, used only oil price to proxy energy price, yet their result on the relationship between exchange rate and oil price volatility remains the same with what is obtained in this study. This result has shown that fluctuations in energy prices in SSA might be empirical due to the exchange rates of member countries in the sub-region.

The result from this study has shown that energy consumption fails to have a significant influence on energy price dynamics. This implies that the energy use per capita, which is used to proxy energy consumption, is not substantial enough to cause any significant change in the energy price dynamics in SSA. It should be noted that in the descriptive statistic of the variables it was clear that energy consumption is the only variable that is closer to the minimum limit than the maximum limit, which implies that energy consumption in SSA is very low and falls below average. The reason behind this might not be unconnected to the fact that most SSA countries are less industrialized, and therefore consume less energy than industrialized countries; again, energy generation per capita in the region is among the lowest across the globe (World Bank, 2019). Consequently, its docile effect on energy price dynamics might be as a result of this. Several studies have shown that energy consumption and energy use per capita in SSA ranked among the lowest across various sub-regions in the world (Mohammed, Mustafa, & Bashir, 2013; Nyiwul, 2017).

The last variable used as a determinant of energy price dynamics is the federal fund rate. It is a true exogenous variable in the model as it is not determined by the SSA. Results from the analysis have shown that the federal fund rate is the most important variable driving energy price in SSA. The effect on energy price dynamics is significant at 1%, making it the most important factor affecting energy price dynamics. This implies that it has a sustained effect on energy price dynamics in SSA. This finding further underscores the vulnerability of the energy market in SSA to external shock. The positive and significant relationship that is obtained between the two clearly shows that a rise in the federal fund rate is capable of aggravating energy price dynamics in SSA. The rise in the federal fund rate leads to a rise in the price of energy commodities and therefore causes much more volatilities. The scenario further justifies the asymmetric effect of energy price, which was earlier confirmed in the study. According to Naoyuki and Farhad (2014), the US monetary policy is an important factor that drives the energy market across the globe, because usually energy commodity prices are denominated in US dollars and traded in the same way. Findings from this study have shown that the situation is not different in SSA, as the federal fund rate has been shown to be an important factor that drives energy prices in the sub-region.

5. Conclusions and policy recommendations

The study has confirmed that energy prices are truly volatile in Sub-Saharan Africa (SSA), and the upward movement of energy prices causes more dynamics in the macroeconomic performances of SSA. In other words, it is concluded from the study that the nature of the energy price dynamics is asymmetric, and it has some implications for the achievement of green growth in SSA.

Energy price has been shown in the study to be a true exogenous variable to SSA. This is because the analysis of the determinants has shown that exogenous factors play a more significant role in determining its movements. The federal fund rate, which is the interest rate in the USA, is the major factor that determines the dynamics in the energy prices. The exchange rate was also shown as a major factor that affects energy price movement. In most SSA, a flexible exchange rate is practiced, which makes it exogenous to a certain extent. Therefore, it is concluded that energy price dynamics are mostly determined by exogenous factors to the SSA.

In the same vein, and as part of the conclusions from this study, energy consumption is not an important factor that determines energy price dynamics in SSA. This further underscores the nature of energy price dynamics as exogenous. It is evident from all the analyses done in the study that levels of consumption of energy commodities in SSA failed to have any significant impact on energy price dynamics. This conclusion is not in isolation, as previous preliminary investigations have shown that energy use per capita in SSA is very low on average. This might be the reason why it has no significant impact on the determination of energy price dynamics.

The study has also shown that exchange rate depreciation in SSA is capable of aggravating energy price dynamics. It was discovered that the more the currencies of the SSA countries are devalued, the more the dynamism in energy prices will be. This conforms to the initial conclusion on the asymmetric nature of energy price dynamics, devaluation of currency causes energy commodities to be more expensive because they are denominated in foreign currency, often the US dollar.

In the same vein, and still, on factors affecting energy price dynamics, the study concludes that a rise in the federal fund rate has resulted in the upward movement in energy prices is significant. The implication is that an increase in the monetary policy rate in the US will lead to a rise in the energy price dynamics in SSA.

It is recommended that SSA should be very careful about the implementation of currency devaluation policies in their various countries, as it has been shown that it exposes the economy to more energy price shocks. In addition, SSA should reduce its dependence on the importation, which causes the economy to be more subservient to foreign monetary policy, especially the US. This study has shown that the federal fund rate has serious implications for energy price dynamics in Sub-Saharan Africa (SSA).

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