



Path to sustainable energy consumption: The possibility of substituting renewable energy for non-renewable energy

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ABSTRACT

Globally, energy consumption profile is largely dominated by fossil fuels with non-renewable energy sources accounting for as high as 84% of the total energy mix in 2019. Non-renewable energy resources emit high carbon and are subject to resource depletion which create concerns over environmental safety and resource sustainability. To correct these scenarios, there is need to rejig energy mix of individual countries by reducing the share of non-renewable energy and increase that of renewables. Nigeria is one of the countries which has a significant proportion of its energy consumption accounted for by non-renewable energy sources. This study therefore aims to examine the interfuel substitution possibility between renewable and non-renewable energy in Nigeria for the period 1987–2016. Owing to the existence of contemporaneous cross-error correlation in the system of equations which violates a key assumption of the Ordinary Least Squares (OLS) estimation technique, the seemingly unrelated regression (SUR) procedure was employed to estimate the parameters. The results show substantial evidence of substitution possibilities between renewable and non-renewable energy. To maximally actualise the potential of renewable energy in the country, the study recommends that the government should, especially at this developmental stage, design and develop an integrated renewable energy planning and investment that will promote investment in research, market development and regulation of renewable energy resources.

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1. Introduction

The pivotal role of energy resources on economic growth across the globe has been empirically proven by several energy economists (see Refs. [1–4]). However, as the latest trend in the world's aspirations for prosperity is sustainable development, economic growth is now seen as a necessary condition for prosperity while the sufficient condition is sustainable development. Thus, energy is now being assessed not merely on its ability to drive economic growth but also on the sustainability of such growth. Sustainable development acknowledges that growth must ensure inclusiveness, environmental stability, and fights poverty in a way that guarantees wellness for the present need of the society without forfeiting the need of tomorrow's generations. It requires the efficiency of resources use in the growth process in a manner that guarantees prosperity for both the present and long-term wellness of people and the environment.

Energy resources are broadly categorized into renewable and non-renewable.¹ Globally, non-renewable energy dominates the energy consumption profile. In 2019, about 583.90 EJ of energy was consumed worldwide with only 66.64 (or 11.41%) exajoules accounted for by renewable energy sources including hydropower while the combined non-renewable energy sources of oil, coal and natural gas accounted for 492.34 (or 84.32%) exajoules (British Petroleum (BP), 2020). As non-renewable energy are mostly fossil fuels with high carbon emission, their dominance in the energy consumption profile has serious consequences for sustainable development not only with respect to resource sustainability but also in terms of environmental sustainability.

The energy information administration (EIA) [5] has, since 2009, been warning about the environment, social and economic unsustainability of the current trends in the supply of energy. To

¹ Renewable energy refers to energy resources that are naturally replenished on a human timescale (e.g. solar, wind, hydro) while non-renewable energy resources are those that cannot be replenished on a human timescale. Non-renewable energy are mostly fossil fuels such as petroleum, coal, and natural gas.

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ensure economic development and sustainability, it is thus imperative to reduce the dominance of non-renewable energy sources while simultaneously increasing the contribution of renewable energy sources in the energy consumption profile of economies across the globe. The possibility of such substitution can be examined within the inter-fuel substitution framework as demonstrated in the pioneering work of Berndt and Wood [6].

This study therefore aims to contribute to the extant literature by empirically obtaining the estimates of substitution elasticities between the competing energy pairs of renewables and non-renewables and contributes to the extant literature in a number of ways. First, it provides inferences for the handlers of energy policies on the importance of trading off high carbon-emitting fossil fuels for renewables. Secondly, it also guides in the ability of policy makers to evaluate the comparative effects of different energy policy options such as between carbon taxation and renewable subsidy regimes. Third, computed estimates from the analysis are relevant for the development of computable general equilibrium models that are mainly suited for the energy sector which are generally different from the other types of computable general equilibrium models [7].

Nigeria has been chosen due to several reasons. First, with an estimated population in excess of 190 million (2017 estimates) and a Gross Domestic Product (GDP) of 375.745 billion (at current US\$) in 2017, Nigeria is reputed as not only the most populous country in Africa but also one of the largest economies in the continent [8]. Secondly, the country's energy sector is one of the most critical sectors that drive its economy. Apart from creating employment, the energy sector, especially the crude oil subsector, is the largest source of foreign exchange for the country thus serving as the mainstay of the country's economy. Nigeria is endowed with ample of energy resources both renewable and non-renewable. For instance, the country is regarded as the second oil rich country in Africa (behind only Libya) and 10th in the world with total proved reserves of 5.1 billion tonnes at the end of 2018. The country is also ranked 10th in the world in gas with a proved reserve of 5.3 trillion cubic meters by the end of 2018 [9].

Thirdly, despite the importance of the energy sector to the country's economy, energy consumption profile of Nigeria is largely dominated by fossil fuels. Fig. 1 summarizes the energy consumption profile of the country between 1980 and 2016. The main

energy consumption types in the country are oil, natural gas and renewables such as hydropower and solar energy while the contribution of coal is very minimal. According to the data obtained from the BP's Statistical Review of World Energy, between 1980 and 2016, total energy consumption in Nigeria was 32.310 (quad Btu) with about 30.397 (quad Btu) or 94% of these accounted for by the combined fossil fuels of coal, natural gas and petroleum products while only about 1.914 (quad Btu) or 5.9% was accounted for by renewable energy.

This scenario is considered dangerous not only from the perspective of resource sustainability but also from that of environmental safety. Resource wise, fossil fuels are non-renewable and as such subject to possible extinction. Though Nigeria is endowed with huge deposit of natural gas resources, the total proved reserves was 5.3 trillion cubic metres by the end of year 2018 and was projected to last for only 108.6 years provided the current production and consumption rates are maintained. The same concern is also entertained in the case of crude oil as the total proved reserves of 5.1 billion tonnes as at the end of year 2018 was estimated to last for only five decades if the current production and consumption rates are maintained [9].

Fourthly, Nigeria's ecological deficit, a measure of the difference between a country's ecological footprint and its biocapacity, increased from 30.08 million global hectares in 1980 to 704.82 million global hectares in 2016 representing an increase of about 149% within that period [10]. This is in addition to the other negative consequences of energy related activities such as oil spills, mud drilling, gas flaring, canalization of oilfields and seismic explosives detonation on the ecological resources of the country especially in the Niger Delta region where large deposits of these resources are found [11].

The vulnerability of Nigeria's economy to shocks in global price of crude oil, the non-renewable nature of fossil fuels, and their negative environmental consequences portend that the country's current energy profile which is largely skewed in favour of fossil fuels is patently unsustainable and unless drastic measures are taken to reverse the situation, the country could face both economic and environmental catastrophes. Though Nigeria needs its energy sector to continue to power its growing economy and provide electricity for its teeming population, the sector needs to be decarbonised by rejigging its energy mix in a way that will not only

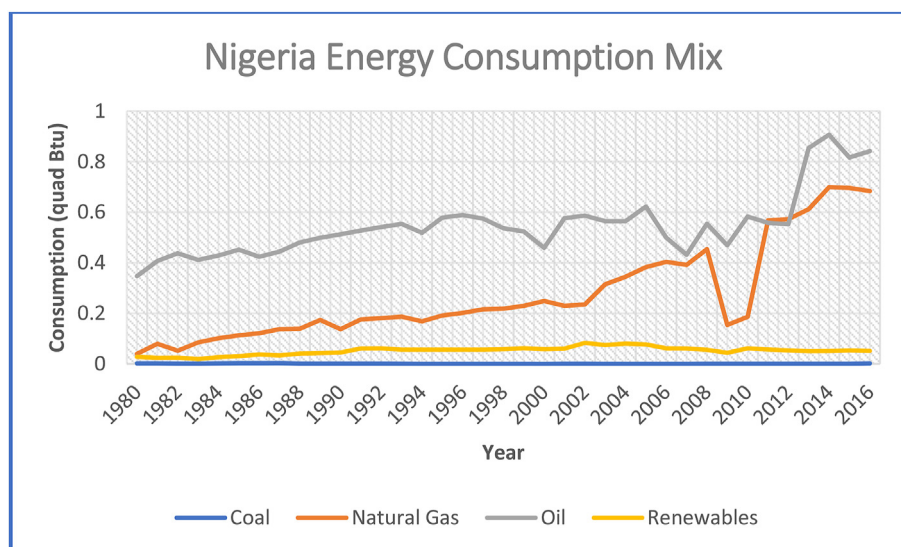


Fig. 1. Nigeria energy consumption Mix:1980–2016. Source: BP's statistical review of world energy.

promotes economic stability but also engenders environmental safety. This means that the country has to move away from carbon intense non-renewable energy sources to low-carbon and sometimes carbon-neutral renewables. Renewable energy has significant potentials in Nigeria and could bridge the huge energy gaps in the country, especially in remote areas [11]. However, Nigeria's ability to improve the proportion of renewable energy consumption in its total energy consumption profile depends largely on the degree of substitution possibility between renewable and non-renewable energy.

The remainder of the article is organized with the discussion on related literature in section 2 and methodology and data in section 3. Section 4 discusses the result while section 5 concludes with policy implications, study limitations and suggestion for future research.

2. Literature review

Energy economics, as a specialized area of study in economics, is one of the areas that have generated several research questions and hypotheses including the question on the true nature of the nexus between energy consumption and economic growth, the dynamic relationship between energy and environment, and the nature of the substitutability relationships between the various energy sources. These research questions and hypotheses have elicited various responses from experts on the subject. For instance, authors such as Sabishchenko et al. [12]; Saluga et al. [13]; Hussain et al. [14] and Haseeb et al. [15] have examined various aspect of the subject including management of the energy sector, management of decision making process in the cost of equity of coal-fired power generation projects, investigation of an adaptive neuro-fuzzy inference system to predict the relationship among energy intensity, globalization, and financial development and the natural resources curse-economic growth hypotheses respectively.

Contributing to the field of energy economics, Shi [16] conducted a SWOT analysis on the future of energy mix in ASEAN while Fan and Hao [17] empirically investigated the relationship amongst renewable energy consumption, economic growth and foreign direct investment. Wang et al. [18] conducted a multidimensional assessment of the development of renewable energy at the regional levels while Wu et al. [19] explored the influence of environmental regulation and environmental decentralization affect green total factor energy efficiency and Shi et al. [20] constructed a methodological framework for the quantification of freshwater consumption and scarcity footprints of hydrogen from water electrolysis. However, the relevant research question for the present study is whether there exists an economic feasibility for the substitution of renewable energy for non-renewable energy in the quest to attain sustainable energy consumption.

Since the 1970s when the oil crisis first ignited the interest of researchers on investigating the possibility of substitution between the different forms of energy, the subject of inter-fuel substitution has developed to be an important research area within the general field of energy economics. Empirical studies on inter-fuel substitution are generally focused on two broad categories known as inter-factor and inter-fuel substitution. The former focuses on investigating the possibility of substituting energy for other primary factors of production such as labour and capital while the latter is aimed at investigating the substitution possibilities among competing energy fuels. Credit for the seminal paper goes to Berndt and Wood [6] who investigated the substitution possibility between energy and the primary factors of labour and capital in the US manufacturing sector for the period 1947–1971. Other notable early contributors to the subject include Fuss [21] on the Canadian manufacturing sector, Pindyck [22] on 10 advanced economies,

Magnus [23] for Netherland and Uri [24] for India.

Since then several other authors have contributed to the subject with focus on developing countries growing in the late 2000s starting with the works of Ma et al. [25]; Smyth et al. [26]; Zha and Ding [27] and Xie and Hawkes [28]. These earlier contributions on developing countries focused only on China. However, subsequent contributions on developing countries have also been extended to other countries such as the works of Wesseh et al. [7] on Liberia; Lin et al. [29] on Ghana; Lin and Ahmad [30] on Pakistan, Wesseh and Lin [31] on economic community of west African states (ECOWAS), Wesseh and Lin [32] on Egypt, Bello et al. [33] on Malaysia, Solarin and Bello [34] on Brazil, Lin and Ankrh [35] on Ghana, Khalid and Jalil [36] on Pakistan, Lin and Raza [37] on Pakistan, and Bello et al. [38] on Malaysia. With specific reference to Nigeria the few notable studies on inter-fuel substitution include Adeyemo et al. [39]; Isola and Oderinde [40]; Lin and Atsagli [41]; and Lin And Ankrh [35].

Methodologically, authors have adopted various functional forms which include the generalized type of Cobb and Douglas cost function of Diewert [42]; the transcendental (*trans-log*) cost and production functions developed by Christensen et al. [43,44]; the constant elasticity of substitution (CES) function, and the Normalized Quadratic (NQ) cost function with different estimation procedures that include the Ridge Regression (RR) technique and the different variations of the maximum likelihood approach such as the Full Information Maximum Likelihood (FIML), Iterative 3-Stage Least Squares (I3SLS), Iterative Zellner's Generalized Least Squares (IZGLS) and the Seemingly Unrelated Regression (SUR) employed to conduct empirical investigation of the substitution possibilities between the different competing energy fuels. The results of these studies have however not been unanimous as outcomes vary between substitution and complementary relationships among the different energy fuels.

For instance, Fuss [21] established a substitution relationship between energy fuels of electricity, oil, natural gas and coal but a complementary relationship between motor gasoline and electricity. Similarly, Uri [24] also reported contrasting results between the fuels with a substitution relationship between oil and coal while establishing complementarity between oil and electricity. In the same vein, Hall [45] established substitutability between gas and coal for United Kingdom and Germany while electricity was found not to be substitutable for petroleum in Canada, Japan, US, and Italy. Vlachou and Samouilidis [46] confirmed substitutability between liquid fuel and electricity and between solid fuel and electricity but complementarity between solid fuel and liquid fuel in Greek while Taheri [47] confirmed that oil, coal and electricity were substitutes but oil and gas were complements for the US manufacturing sectors.

Majority of the earliest empirical works on inter-fuel substitution were focused on the traditional four fuels of coal, oil, gas and electricity. However, with the realization that energy fuel mixes are largely dominated by fossils fuels with serious implications for resource and environmental sustainability, researchers are increasingly introducing renewable energy fuels into the frame of analysis. In this regard, Kumar et al. [48], investigated the relationships between non-renewable energy and renewable energy in 12 selected industries in the organization for economic cooperation and development (OECD) countries and found the relationship to be largely complementary. Wesseh and Lin [31] also found weak substitutability between non-renewable and renewable energy for ECOWAS.

Focusing on a component of renewable energy, Bello et al. [33] introduced hydropower in a study on three transition economies namely Malaysia, China and Thailand. Using the ridge regression procedure, the results show evidence of strong substitution between renewable energy represented by hydropower and non-

renewable energy represented by coal, gas and oil that are employed for generating electricity in those countries. Jones [49]; introduced biomass as the fifth fuel alongside the traditional fuels of coal, natural gas, oil, and electricity for the US into the analysis and found substantial evidence that biomass can substitute natural gas in US energy profile. In a similar study for US, Suh [50] was also able to establish substitutability between coal and biomass and between natural gas and biomass while a complementary relationship between biomass and electricity was established. In a somewhat different study, Solarin and Bello [34] extended the analysis by further introducing the concept of sustainable development in a study that investigate possibilities of substitution between fossil fuels and biomass in Brazil for the period 1980–2015. The study provided significant justification for substitutability relationships between biomass and the fossil fuels and that sustainable development index can reveal some of the inherent negative effects of fossil fuel consumption in the economy.

Considering Nigeria, Lin and Ankrh [35] is perhaps the only study to have incorporated the dynamics of renewable energy into the analysis. Using the ridge regression procedure, the authors found the existence of substitutability relationship between renewable and non-renewable energy while noting that output is primarily driven by capital and labour with both renewable and non-renewable playing insignificant roles in output generation. This present study is a departure from Lin and Ankrh [35] as it provides the estimates for the own-price elasticities for each of the energy inputs as well as the cross-price elasticities between them thereby providing a broader insight for price-based energy policies for the attainment of optimal energy balance.

Furthermore, based on the knowledge of the author, studies of this nature are limited as most of the previous studies have approached the analysis from the production side. The cost side which is employed in this study is superior to the production side because of the price dynamics as it allows for the estimation of not only the cross-price elasticities but also the own price elasticities of the energy factors. Moreover, past interfuel substitution studies on Nigeria did not include variants of renewable energy in their analysis. As far as the author is aware, it is perhaps only Lin and Ankrh [35] that have incorporated the dynamics of renewable energy in the empirical study of interfuel substitution for Nigeria. Hence, this study contributes to the existing literature by closing these noticed gaps.

3. Methodology

3.1. Model

The estimation procedures begin with the specification of the following cost function²

$$C(e) = f(P_e * E) \quad (1)$$

where $C(e)$ is the total cost of energy and P_e is the aggregate price of energy and E is to total energy input and it is assumed homothetic and weakly separable into its sub-components. The main energy components considered in this study for Nigeria are oil (o),

gas (g) and renewables (r).³ The cost function in equation (1) is thus is re-written as:

$$C(e) = f(P_o, P_g, P_r) * E \quad (2)$$

where P_o , P_g and P_r are the prices of oil, gas and renewables respectively. Consistent with the cost theory in microeconomics, the cost function is assumed to be homogenous, monotonous, positive as well as satisfying the curvature conditions. To be homogenous, the cost function has to be linearly homogenous in the prices of the inputs. Monotonicity requires that the first order derivative, which gives the input demand function, should not be negative. Positivity implies that the absolute calculated values are positive for all data points and the curvature condition is met when the cost function is a concave function of prices. A cost function that satisfy these theoretical regularity conditions is the translog cost function proposed by Christensen et al. [43,44] and it takes the following form:

$$\ln C(e) = \alpha_0 + \sum_{i=1}^n \alpha_i \ln P_i + \frac{1}{2} \sum_{i=1}^n \sum_{j=1}^n \alpha_{ij} \ln P_i P_j \quad (3)$$

where i and j represent the different energy input of oil, gas and renewables, P_i and P_j are energy prices while the α_s are the estimated parameters. Differentiating equation (3) with respect P_{ij} , the cost of individual input with respect to the total cost is obtained as:

$$\partial \ln C(e) / \partial \ln P_i = \partial C(e) / \partial P_i * P_i / C(e) = \alpha_i + \sum_j \alpha_{ij} \ln P_j \text{ for } i, j = o, g, r \quad (4)$$

Equation (4) is the conditional input demand input i and represents the individual share cost of each of the energy input relative to the total cost. Denoting the individual energy share cost as S_i , for $i = o, g, r$, equation (4) is expressed as:

$$S_i = \alpha_i + \sum_j \alpha_{ij} \ln P_j \quad (5)$$

Differentiating equation (5) relative to the prices of the inputs, the corresponding individual share cost for oil, gas and renewables are expressed as follows:

$$\text{Oil : } S_o = \alpha_o + \alpha_{oo} \ln P_o + \alpha_{og} \ln P_g + \alpha_{or} \ln P_r, \quad (6)$$

$$\text{Gas : } S_g = \alpha_g + \alpha_{go} \ln P_o + \alpha_{gg} \ln P_g + \alpha_{gr} \ln P_r, \quad (7)$$

$$\text{Renewables : } S_r = \alpha_r + \alpha_{ro} \ln P_o + \alpha_{rg} \ln P_g + \alpha_{rr} \ln P_r. \quad (8)$$

The absolute values for each of the cost-shares in equations (6)–(8) are obtained as follows:

$$S_o = \left(\frac{P_o E_o}{P_o E_o + P_g E_g + P_r E_r} \right); S_g = \left(\frac{P_g E_g}{P_o E_o + P_g E_g + P_r E_r} \right); S_r = \left(\frac{P_r E_r}{P_o E_o + P_g E_g + P_r E_r} \right). \quad (9)$$

where S_o , S_g , and S_r correspondingly represent the cost-shares for oil, gas, and renewables and $P_o E_o$, $P_g E_g$ and $P_r E_r$ are the corresponding total cost for each of the energy inputs. Equations (6) and (7) are systems of equations whose parameters are to be estimated simultaneously while fulfilling the following linear homogeneity conditions:

² Material, services and the traditional factors of capital and labour have been excluded due data constraints and the fact the energy factors are the main variables of interest. This also reduces the possibility of overparameterization as the number of estimable parameters are reduced. The weak separability assumption of the cost function permits this exclusion.

³ Coal is not included because its share in the energy consumption mix for Nigeria has become negligible accounting for less than 0.5% over the last four decades.

1. $\sum_{i=1}^n \alpha_i = 1$,
2. $\sum_{i=1}^n \alpha_{ij} = \sum_{j=1}^n \alpha_{ji} = 0$,
3. $\alpha_{ij} = \alpha_{ji}$

Restrictions 1 and 2 are the adding up criteria while restriction 3 is for the symmetry condition. The systems of equations (6)–(8) are appended with stochastic error terms to allow for econometric estimation as follows:

$$S_o = \alpha_o + \alpha_{oo} \ln P_o + \alpha_{og} \ln P_g + \alpha_{or} \ln P_r + v_o, \quad (10)$$

$$S_g = \alpha_g + \alpha_{go} \ln P_o + \alpha_{gg} \ln P_g + \alpha_{gr} \ln P_r + v_g, \quad (11)$$

$$S_r = \alpha_r + \alpha_{ro} \ln P_o + \alpha_{rg} \ln P_g + \alpha_{rr} \ln P_r + v_r. \quad (12)$$

where the error terms are assumed to possess the desired attributes of normal distribution with zero mean and constant variance.

3.2. Estimation technique: seemingly unrelated regression (SUR)

Equations (10)–(12) are systems equations with a high degree of correlation between the error terms v_o , v_g , and v_r as the share costs in the three equations sum to one while the error terms sum to zero which may then result to singular covariance matrix. This is the classic case of serial correlation and a clear violation of one of the key assumptions of the Ordinary Least Squares (OLS) estimation technique. In such instance, therefore, the estimation of the parameters with the standard least squares procedure becomes inappropriate as such estimates will be inefficient. An alternative approach is a variant of the maximum likelihood approach known as the seemingly unrelated regression (SUR).

The SUR is a technique of estimating the parameters of a set of equations that have contemporaneous cross-error correlation. It is so named because the set of equations appear to be unrelated but, in fact, they are interconnected through the error terms in each of the equations which appear to be seemingly different. Developed by Zellner (1962), the SUR technique has a number of advantages over the use of the single equation methods such as the OLS as it accounts for the contemporaneous correlations of the errors while allowing the k number of explained variables to have different sets of regressors. Unlike the single equation methods, the SUR technique estimates the parameters of all equations simultaneously, so that the parameters of each single equation also take the information provided by the other equations into account which leads to higher efficiency of the parameter estimates, because additional information is used to describe the system [51]. These efficiency gains increase with increasing correlation among the error terms of the different equations [52], as well as with larger sample size and higher multi-collinearity between the regressors [53].

In the case of the simultaneous equations presented in (10), (11) and (12), the SUR technique can be employed to simultaneously estimate the parameters of all the cost shares equations, whilst taken into account the correlations among the contemporaneous errors. To proceed, one of the equations is dropped and the parameters of the remaining two equations are estimated in a system of constrained symmetries where homogeneity restrictions are imposed. In this case, the third equation involving renewables has been dropped and the resultant estimable equation is expressed as:

$$S_o = \alpha_o + \alpha_{oo} \ln(P_o / P_r) + \alpha_{og} \ln(P_g / P_r) + v_o, \quad (13)$$

$$S_g = \alpha_g + \alpha_{go} \ln(P_o / P_r) + \alpha_{gg} \ln(P_g / P_r) + v_g, \quad (14)$$

In the system of equations (13) and (14), the variance-covariance matrix of the stochastic error terms is non-singular. The imposed linear homogeneity restrictions are then used to derive the estimates of the parameters of the omitted equation for renewable energy as follows:

$$\alpha_o + \alpha_c + \alpha_g = 1; \text{ such that } \alpha_o = 1 - \alpha_c - \alpha_g; \quad (15)$$

$$\alpha_{ro} + \alpha_{oo} + \alpha_{og} = 0; \text{ such that } \alpha_{ro} = -\alpha_{oo} - \alpha_{og}; \quad (16)$$

$$\alpha_{rg} + \alpha_{go} + \alpha_{gg} = 0; \text{ such that } \alpha_{rg} = -\alpha_{go} - \alpha_{gg}; \quad (17)$$

$$\alpha_{rr} + \alpha_{ro} + \alpha_{rg} = 0; \text{ such that } \alpha_{rr} = -\alpha_{ro} - \alpha_{rg}; \quad (18)$$

3.3. Elasticities

The estimated parameters of the seemingly unrelated regression procedure are used to obtain both the own price elasticities of each of the energy inputs and their cross-price elasticities. The own-price and the cross-price elasticities are respectively given as:

$$\eta_{ii} = \sigma_{ii} S_i; \text{ for } i = o, g, r. \quad (19)$$

$$\eta_{ij} = \sigma_{ij} S_j; \text{ for } i, j = o, g, r; i \neq j. \quad (20)$$

where σ_{ii} and σ_{ij} are respectively the Allen-Uzawa own and cross-price elasticity estimates and S_i and S_j are the share cost for the individual energy input. The Allen-Uzawa own-price elasticity estimate is obtained with the following formula:

$$\sigma_{ii} = \frac{\alpha_{ii} + S_i^2}{S_i^2}; \text{ for } i = o, g, r. \quad (21)$$

while the corresponding cross-price elasticity is defined as follows:

$$\sigma_{ij} = \frac{\alpha_{ij}}{S_i S_j} + 1; \text{ for } i, j = o, g, r; i \neq j. \quad (22)$$

For normal energy input, the own price elasticity estimate is expected to be negative, suggesting that the higher the input price the lower the amount that is employed in the production process and vice versa. The substitutability relationship between the energy inputs is determined by the cross-price elasticity estimates. Inputs are said to be substitutes when the cross-price elasticity is positive while negative estimates suggests complementary relationship between the energy pairs.

4. Data analysis and discussion of results

The datasets consist of annual energy and price series for Nigeria for the period 1987 to 2016.⁴ The energy series which comprise of oil, gas and renewable energy are annual energy consumption in million Btu obtained from the Independent Statistics and Analysis section of the Energy Information Administration, United States (U.S.) [54]. The oil series comprises of petroleum and other liquids

⁴ The chosen period is mainly determined by data availability.

consumption and includes all domestic use and international bunkering of refined products, refinery fuel as well as direct combustion of crude oil and refinery by-products. The gas series excludes natural gas converted to liquid fuels but includes derivatives of coal as well as natural gas consumed in Gas-to-Liquids transformation while the renewable energy series captures all energy consumed from hydroelectricity, biomass, geothermal energy, solar energy and wind energy sources.

The price series were scooped from the BP's Statistical Review of World Energy [9] with the gas prices expressed in US dollars per million Btu while the oil prices are of the Nigerian Forcados expressed in US dollars/bbl. The producer price index, obtained from the Nigeria's National Bureau of Statistics [55]; is used as a proxy for renewables as its made up of more than one components. The approach of using a composite price index to represent a composite variable is in congruent with Yang et al. [56]; Lin and Li, [57]; and Li and Lin [58].

Prior to the commencement of the estimation of the parameters, the reliability of the data is validated with an appraisal of the descriptive statistics of each of the series in the equation and the results are presented in Table 1. The results show that renewable has the highest prices for the energy series. Though, the producer price index is employed to proxy the price of renewable, this indicates indicate that the cost of renewable is still higher than the conventional energy sources of gas and oil. All energy price series are positively skewed and have positive kurtosis with only oil price normally distributed.

In terms of the energy inputs, oil has the largest consumption figure with a mean consumption volume of 0.5773 (quad Btu) and a maximum volume of 0.9066 (qua Btu). This is followed by gas with mean of 0.3178 (quad Btu) and maximum of 0.6989 (quad Btu) while renewables has a mean consumption figure of 0.0574 (quad Btu) with maximum value of 0.0829 (quad Btu). This reflects the dominance of the nonrenewable energy in the energy consumption profile of the country. Both the oil and gas series are normally distributed, while all the energy input series are positively skewed with positive kurtosis. Though, the seemingly unrelated regression procedure ensures that the parameters are consistent even if some series are not normally distributed (Zellner, 1962; [52], the variables are nevertheless converted to their natural logarithms before estimation to attain more efficient and consistent estimates.

After the descriptive statistics, the technique of the seemingly unrelated regression technique is used to obtain the parameters in the systems of equations (13) and (14) for the share costs for oil and gas and the results are presented in Table 2. The results of the parameter estimate for the deleted renewable equation obtained using the adding-up and symmetry restrictions are presented in Table 3. From the results, it is noted that the null hypothesis that there is no interrelation between the systems of cost share

Table 1
Descriptive statistics.

Statistics	Energy Prices			Energy Inputs		
	Gas Price	Oil Price	RE Price	Gas	Oil	RE
Mean	5.1016	45.499	55.858	0.3178	0.5773	0.0574
Median	3.4052	26.729	37.793	0.2296	0.5540	0.0565
Maximum	11.601	114.21	183.85	0.6989	0.9066	0.0829
Minimum	1.8628	12.623	0.9800	0.1372	0.4315	0.0338
Std. Dev.	3.1953	34.414	53.024	0.1848	0.1201	0.0110
Skewness	0.7707	0.9219	0.8674	0.9675	1.5765	0.4140
Kurtosis	2.0910	2.3817	2.6572	2.5266	4.6340	3.4776
Jarque-Bera	4.0027	4.728*	3.909	4.9601*	15.763***	1.1423
Probability	(0.135)	(0.094)	(0.146)	(0.0837)	(0.0004)	(0.5649)
Observations	30	30	30	30	30	30

Source: Author's computation

Table 2
Parameter estimates of cost share equations: Gas and Oil.

	Parameter	t-stat
cost share equation for GAS		
α_{gas}	0.0311	0.940
$\alpha_{gas-gas}$	-0.0111	-0.712
$\alpha_{gas-oil}$	0.0049	0.296
α_{gas-re}	0.0062	—
R^2	0.194	
cost share equation for OIL		
α_{oil}	0.8519***	24.33
$\alpha_{oil-oil}$	0.0469**	2.637
$\alpha_{oil-gas}$	0.0048	0.296
α_{oil-re}	-0.0518	—
R^2	0.816	
Breusch-Pagan test	5.211** (0.0224)	
F-test	3.342* (0.0731)	

* Indicates 10% level of statistical significance, ** indicates 5% level of statistical significance, *** indicates 1% level of statistical significance, Figures in parentheses are the probability values.

Source: Author's computation

equations cannot be accepted owing to the significance of the Breusch-Pagan test at 5% level of significance. This underscores the appropriateness of adopting the seemingly unrelated regression procedure to obtain the parameter estimate. Furthermore, the F-test, which test for the overall goodness of fit of the systems of equations is also statistically significant.

It should be pointed out that the parameter estimates presented in Tables 1 and 2 essentially represent the cost share equations specified in equations (6)–(8) for the energy inputs oil, natural gas and renewables respectively. Each of these equations must, on average, satisfy the positivity assumption of cost equations. Thus, given the estimated parameters and the average values of the logged energy prices, the positive cost share values are obtained as follows:

$$S_o = 0.8519 + 0.0469*(3.5554) + 0.0048*(1.4481) - 0.0518*(3.2828) = 0.856 \quad (23)$$

$$S_g = 0.0311 + 0.0049*(3.5554) - 0.111*(1.4481) + 0.0062*(3.2828) = 0.0528 \quad (24)$$

$$S_r = 0.1171 - 0.0518*(3.5554) + 0.0062*(1.4481) + 0.04552*(3.2828) = 0.0913 \quad (25)$$

The positive cost share equations obtained from the estimated parameters are consistent with the estimates obtained from studies such as Shahiduzzaman and Alam [59] on Australia, Li and Lin [58] on China, and Bello et al. [38] on Malaysia.

Equipped with the parameter estimates of the systems of cost share equations, the own and cross-price elasticities of the energy inputs are calculated using equations (19) and (20) respectively. The results presented in Table 4 are obtained at the mean share cost values for each of the energy input. In terms of the own-price elasticity, both oil and gas have negative estimates conforming to the microeconomic a priori price-quantity inverse relationship while the own-price elasticity estimate for renewables is found to be positive which is not consistent normal law of demand. The result of the negative own price elasticity estimates for coal and gas

Table 3
Parameter estimates of cost share equations: Renewable.

cost share equation for RE		
α_{re}	0.11708	—
α_{re-re}	0.04552	—
α_{re-gas}	0.00624	—
α_{re-oil}	−0.0518	—

Note: The estimated parameters are derived from the imposed linear homogeneity restrictions.

Source: Author's computation

Table 4
Own and cross price elasticities.

	Elasticities	Standard errors
Own-Price Elasticity		
η_{gas}	−1.230***	0.01586
η_{oil}	−0.089***	0.01056
η_{re}	0.553	0.44115
Cross-Price Elasticity		
$\eta_{gas-oil}$	0.712***	0.02971
η_{gas-re}	0.0029***	0.00005
$\eta_{oil-gas}$	0.042***	0.00183
η_{oil-re}	0.0008***	0.00002
η_{re-gas}	0.0012***	0.0001
η_{re-oil}	0.0043***	0.0009

Note: Elasticities are obtained at the mean cost shares for the fuel inputs where $S_{gas} = 0.052$, $S_{oil} = 0.856$, and $S_{re} = 0.091$ are respectively the mean cost-shares for gas, oil, and renewable energy respectively. *** indicates 1% level of statistical significance.

Source: Author's computation

is consistent with the results from studies such as Tan and Lin [60] on Chinese energy sector, Hossain and Serletis [61] for the U.S transportation sector and Mugabe et al. [62] on the electricity sector in the U.S but contradicts the result from the study of Kim [63] which found the own-price elasticities of coal and natural gas to be positive for the Korean electricity sector. Kim [63] however concluded that the positive estimates of the own-price elasticities of coal and natural indicate that the model might be unstable.

However, the result of the positive own-price elasticity estimate is in contrast with the outcome of Kim [63]; which otherwise found that the own-price elasticity for renewable is negative for the Korean electricity sector. In addition to this, it is also noted that the price elasticity is also inelastic and non-significant. This is probably an indication that the renewable market in Korea is more advanced and developed than that of Nigeria. Current demand for renewables in Nigeria is still largely driven by non-market forces that rely mainly on environmental considerations and energy efficiency which sustain demand for renewable energy despite high price. For instance, the cost per unit of power of renewable energy which is in the range of \$0.26 to \$0.50/kWh remains significantly higher than that of grid electricity which ranges from \$0.10 to \$0.15/kWh [11]. This is why subsidies and feed-in tariffs are common features of the renewable energy market as they offset the difference to enable renewables to be price competitive. This is particularly so for Nigeria where finance for renewable energy remains a major issue as a large chunk of costs for years of use are incurred right after installation.

Turning to the cross-price elasticities, the estimates are not only positive but also significant. This suggests that the energy pairs are substitutes. This outcome is consistent with the findings of Lin et al. [29] for Ghana, Wesseh and Lin [32] for Egypt, and Lin and Ankrah [35] for Nigeria. With specific respect to the response of gas and renewable to changes in the price of oil, the cross-price estimates are respectively 0.712 and 0.004. This means that a 1% increase in

the price of oil would increase the consumption of gas by 0.712% and renewable energy by 0.004%. Similarly, the cross-price response in the consumption oil and renewable to a 1% price change in gas are 0.042% and 0.001% respectively. In terms of the changes in the price of renewables, the cross-price elasticity estimates with respect to gas and oil are 0.0029 and 0.0008 suggesting that a 1% increase in the price of renewables will lead to an increase in consumption of gas and oil by 0.0029% and 0.0008% respectively.

A few points need to be noted from the results. First is that varying the price of oil has the largest impact on the consumption of the remaining two energy inputs while changes in the price of renewable has the least impact. This is not surprising as it reflects the obvious fact crude oil is significantly vulnerable to price fluctuations which disrupt not only its own price but also that of related energy inputs. Second, renewable energy responds more to variations in price of oil than to variations in price of gas as evidenced in the estimates of the cross-price elasticities - 0.0043 for oil and 0.0012 for natural gas implying more substitutability between oil and renewable. This seems logical as natural gas is considered a cleaner energy source relative to oil and therefore more renewable energy is needed to compensate for the negative effect oil than needed for gas. This is also corroborated by the fact that the response of gas to variation in the price of renewable is larger than that of oil - a possible indication of the fact that natural gas is a cleaner fuel relative to oil and more of it (gas rather than oil) has to be substituted for renewable to maintain a relatively low-carbon energy profile for the country.

5. Conclusion: policy implications, study limitation and direction for future research

This paper has attempted to investigate the nature of relationship between renewable energy and the non-renewable energy of gas and oil in Nigeria by estimating not only the own price elasticities but also the cross-price elasticities between the energy pairs. Due to the presence of correlated errors among the systems of equations, the seemingly unrelated regression procedure has been employed to obtain the parameters using annual time series data spanning between 1987 and 2016. Overall, the results show that both gas and oil exhibit negative relationship with own prices while renewable energy has positive estimate with respect to own price. The cross-price estimates are positive for all energy pairs. A number of important policy implications can be inferred from these findings.

First, positive cross-price elasticities between renewable energy and non-renewable energies of oil and gas establish that the energy pairs are substitutes. This implies that Nigeria has the potential to switch from high carbon emitting non-renewable energy sources of oil and gas that currently dominate its energy consumption profile to less carbon emitting and sometimes carbon neutral renewable energy types. This is especially vital for the Nigeria as it will go a long way to help the country move away from its over reliant on oil with its associated adverse consequences on the country's economy.

Secondly, Nigeria can rejig its energy consumption profile towards more renewable energy without compromising its energy consumption requirement to keep its economy alive and prevent the negative environmental impacts of non-renewable energy usage. This implies that Nigeria can concurrently strive towards attaining its economic growth objectives through energy consumption and lowering carbon emissions by trading off carbon emitting non-renewable energy sources for the cleaner renewable energy sources.

The substitutability between renewable energy and non-renewable energy of oil and gas in the energy consumption

profile for Nigeria is equally germane for resource sustainability as, apart from making the economy vulnerable, excessive usage of non-renewable energy makes them prone to fast depletion whereas renewable energy is not subject to exhaustion as a result of usage. Thus, trading off oil and gas for renewable energy such as solar and hydro will promote the attainment of resource sustainability.

Furthermore, positive and non-significant own price elasticity estimate for renewable energy suggests that renewable energy resource is currently less responsive to market price. Though, renewable energy has significant potentials to thrive in Nigeria, the scale of development is still at the infant stage that requires external support from the government for its development. It is too early to allow the sector to be governed completely by the dictates of the free market system. As earlier noted, the current cost per unit of power of renewable energy which is in the range of \$0.26 to \$0.50/kWh remains markedly higher than that of grid electricity which ranges from \$0.10 to \$1.15/kWh. Therefore, government should support the producers of renewable energy with subsidy and feed-in tariffs to enable them to compete favorably with the producers of alternative energy resources. In order to further promote and develop the market for renewable, the government should design and develop an integrated renewable energy planning and investment that will promote investment in research, market development and regulation of renewable energy.

Apart from providing an enabling environment for the relevant stakeholders in the renewable energy sector, complementary policies that discourage the use of high-carbon emitting non-renewable energy sources should be incorporated. Such policies can be in the form of imposition of carbon tax on non-renewable energy sources. Nigeria has recently taken a step in the right direction by liberalizing the downstream petroleum sub-sector through total removal of subsidy as this will go a long way in freeing resources, that were hitherto used in subsidizing inefficiency in the sector, for use in other critical energy sectors such as the renewable energy sector. However, this should be followed up with carbon tax for maximum benefit not only for the environment but also for the economy.

It has to be noted, however, that most renewable energy facilities such as large-scale hydro-electric power plants are usually capital intensive in nature that requires huge amount of capital and considerable length of time to construct. In this regard, Nigeria should make efforts to expedite the construction of small renewable energy facilities such as the promotion of mini-hydro and solar photovoltaic projects to compensate for the long time required to complete the large scale renewable energy facilities. This can take the form of organizing training programs for the installation, operation, and maintenance of mini hydro and solar photovoltaic facilities that will involve the combined efforts of both the government and non-governmental organizations.

Though this study has investigated the substitution potential between renewable and non-renewable energy using the transcendental logarithm (*trans-log*) cost function which is considered superior to the other models such as the *trans-log* production function in that it permits the estimation of the own and cross-price elasticities of the fuel inputs, it is instructive, however, to note the limitations of this study. Though, there are precedents in the literature (e.g. Refs. [56–58]), one limitation of this study is the use of the price index to capture the price of renewable energy. This is a compromise method but acceptable as renewable is a composite variable and mostly indigenous with no standard international price. Furthermore, the aggregation of renewable energy as a single variable might conceal the distinctive features of the individual renewable energy sources which may have provided a more accurate policy decision. Based on this, it is recommended that

future contribution in this line research should give considerations to the individual renewable energy sources rather aggregating all as a single variable.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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