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Determinants Beyond Prices in Energy Source Substitution

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ABSTRACT

The goal of the present study was to analyze how market demand determinants especially the income of consumers versus prices of energy sources influence the energy source substitution process. The Autoregressive Distributed Lag (ARDL) technique was employed to assess the cointegration among consumption of natural gas, crude oil, solar energy, nuclear energy, coal, and wind energy, alongside their prices, alternative prices, per capita income, and energy intensity. The analysis used annual data from 1977-2019. Additionally, a poll of 217 random respondents examined current and preferred energy choices and the demand determinants influencing these choices. The ARDL results revealed complementary and substitution relationships between energy sources. While crude oil consumption was mostly unaffected by its explanatory variables, the consumption of natural gas, solar energy, and nuclear energy was significantly influenced by income, with income coefficients exceeding those of prices. Poll results indicated a preference order of solar energy, wind energy, natural gas, crude oil, nuclear energy, and coal for electricity generation. Higher-income consumers prioritized the convenience of lower prices, while lower-income consumers prioritized income. Among respondents, 40.9% cited lack of income as the main barrier to adopting cleaner energy sources, while 40.3% pointed to the prices of cleaner energy sources. Additionally, 23.2% chose the low cost of polluting energy sources as their reason. The study concluded that income, rather than price, is the most significant determinant in the shift to cleaner energy sources.

1. INTRODUCTION

People do not consume energy itself, but rather energy services (such as cooking, space heating or cooling, transportation, lighting, communication, etc.) which result in social, economic and even political satisfaction. These energy services can be provided by any of the multiple energy sources available, and based on consumers' preferences, substituted for each other to provide the same service(s) (Bodger *et al.*, 1989;

Odesola *et al.*, 2022). Energy source substitution, which is the replacement of any primary energy source for another, has in recent times become a more pronounced trend in the world energy scene, and a plausible threat to petroleum producers. Over the years, the issue of global warming has brought increased attention to the role of energy use in environmental degradation and climate change among a host of multiple negative environmental impacts. These environmental concerns – the larger picture being sustainable development – have encouraged environmentally conscious individuals to clamour for the reduction of the environmental impact of energy use, particularly through the adoption of cleaner energy sources.

The 2018 edition of BP's Energy Outlook foresees renewables as the most rapidly growing source of energy for power generation over the same time period, increasing solar power projections by 150 percent from its 2015 forecasts (BP, 2018). Unfortunately, the urgency of this substitution process has been largely undermined particularly due to the current measuring yard of price used in its prediction. Asides from the fact that the generally higher prices of alternative energy sources which have been the measuring yard for how much and how fast people will adopt these alternatives are fast falling, according to the basic consumer's theory, price is but one determinant of demand. Price can only really project how the quantity of a particular energy source increases or decreases. To understand how energy sources will be substituted for one another, other determinants of consumers' choices, especially consumers' income and preferences must be considered.

Marchetti and Nakicenovic (1979) suggested the Logistic Substitution Model (LSM) for describing the dynamics of technology substitution in long-run competition. The model results covered the noticed historical changes in world primary energy consumption and fraction share predictions up to 2050, which showed simple logistic growth and decline paths. No one energy source completely saturated the market because the dynamics created by the introduction of new energy sources and long-time frame lead to a maximum penetration level of about 60% to 70% per energy source (Marchetti, 1977; Marchetti and Nakicenovic, 1979; Marchetti, 2006). Using an energy-based dynamic systems model which considered the interaction between energy sectors and socio-economic sectors, Bodger *et al.* (1989) replicated results in (Marchetti and Nakicenovic, 1979) and discovered that the energy source which gets to the market first controls the larger share of the market. However, it will steadily lose market shares as a new option penetrates the market further and gains its lost shares; not necessarily due to a depletion of the stock reserve of the initial option, as is seen in the case of coal and oil for natural gas.

An inter fuel substitution analysis in the industrial sector of the United Kingdom and France was carried out by Renou-Maissant (2007) applying the linear logit and translog models to derive own and cross fuel price elasticity. According to the results, energy source price changes lead to energy source substitution, and reduced consumption of total energy. Chakravorty *et al.* (1997) proposed that the only viable energy solution to the threat of global warming is the adoption of solar energy sources. However, they stated that this transition to solar energy or any new energy source would be costlier than the conventional option, particularly due to the retrofitting of existing energy facilities and the costs on the part of consumers. That is, although other determinants of demand would move consumers to change demand, there will always be a cost constraint that can only be checked by technological advancement and increased efficiency of alternative energy sources and technologies, which is already on the way (Devezas *et al.*, 2008). In analysis, where authors found both complementary and substitution relationships between renewable and non-renewable energy sources in different industries, Kumar et al. (2015) highlighted that experimental studies on inter-fuel substitution, aimed at estimating the potential for transitioning between electricity and alternative fuels, had traditionally focused on fossil fuels. Halvorsen (1977), Hall (1986), Jones (1995), Bjørner and Jensen (2002), Stern (2010), and Abu *et al.* (2024) primarily examined fossil fuels, neglecting the substitutability of renewable energy sources for conventional fossil fuels. As technology advances, a significant substitution of non-renewable resources may take place over the very long term.

According to Fattouh *et al.* (2019), in 2014, US solar cost 17c/kWh (US cents per kilowatt hour), and wind 11c/kWh, on a premise of complete loading including the capital costs of construction, and with subsidies. However, IRENA (2018) estimated that as of 2019 the global cost of onshore wind and solar would decline to 5c/kWh and 6c/kWh, respectively, and the cost of wind is estimated to further decline to 4c/kWh by 2020, excluding the cost of dealing with intermittency on a plant-level basis (IEA, 2018; Fattouh *et al.* 2019; Lazard, 2019). Tagliapietra (2019) stated that the estimated improved cost competitiveness along with global policies and awareness of decarbonization has begun to alter and reshape the existing world energy market. The author proposed now as the best time for producer economies to embrace economic diversification, considering that before now, the only reason producer economies had for diversification was to avoid the impact of global oil price volatility. Now, however, the ambiguity surrounding the pace of the world's energy transition and the unsustainable nature of a nation's sole reliance on hydrocarbon rents imported rather than produced domestically should act as catalysts for producer economies to shift toward a more diversified, domestically oriented economy.

The energy outlook of different organizations like British Petroleum (BP), Equinor, International Energy Agency (IEA), ExxonMobil, and Shell have suggested different periods by which oil demand is expected to peak between the year 2020, and beyond 2050. While some researchers propose probable oil peak period(s), others believe that this specific date oil demand will be at its peak should not be as important as the fact that the demand will eventually peak. This is because, the substitution process is already ongoing, and even before the demand peaks, production might become uneconomical for producers with higher costs of production.

If producer economies take advantage of this transition to diversify their economies, global energy transition may end up being beneficial after all., which could facilitate future economic prosperity in any case (Hvidt, 2013). To do this, producer economies must understand the dynamics of the substitution process and the fact that the transition has already begun; although slow right now, it is faster than it was years ago. In a 2018 report on the outlook for producer economies, the IEA examined what changes in the energy market mean for Saudi Arabia, Russia, United Arab Emirates, Iran, Venezuela and Nigeria (IEA, 2018). The results of the analysis emphasized the importance of diversification initiatives to prepare these economies for the dynamics of the world energy market, and growing populations, particularly in Iraq, Saudi Arabia, and Nigeria. According to the idea depicted, resource abundance should be embraced as a blessing that it is (Gould and Al-Saffar, 2018).

This misconception of the price being the determining factor has influenced the plans of petroleum-producing economies who bank on the underdeveloped nature of cleaner energy source technologies, and their current high cost to deter their adoption. Interestingly, the environmental Kuznets theory suggests that with increasing income levels, people will be more inclined to consume environmentally friendly energy sources even if the cost is more than a percent increase in consumers' income, to ensure a cleaner and sustainable environment. The theory suggests that richer economic agents are more prone to invest in environmental and ecosystem restoration through the improvement of air quality and water systems and up-to the level of exporting wastes or pollution (Agarwal, 2022).

Unfortunately, previous studies on the subject of energy source substitution are very scanty and fragmental even though they underline the future of the world energy market. To understand how energy sources will be substituted for one another, other determinants of consumers' choices like income of consumers, consumers' preferences, consumers' expectations, number of buyers, and government regulations must all be considered to make accurate predictions, and plan accordingly. This present study focused specifically on price versus income, to ascertain the magnitude of their influence on energy source substitution through the analysis of the historic dataset, and consumers' choices. The study's objective was to ascertain if energy source substitution will also be dependent on demand determinants other than prices of energy sources.

2. METHODOLOGY

2.1. Data Source

The basic variables utilized are Natural gas (Ng), Crude oil (Cr), Solar energy (Se), Nuclear energy (Nu), Coal (Co) and Wind energy (Wi), and consumptions which serve as proxies for their demand; prices of the different energy sources Income per capita (I) to proxy consumers' income; and Energy intensity (Int) as a control variable. An annual time series dataset covering the period of 1977-2019 was used in estimating the model. The data utilized were derived from the British Petroleum (BP)'s statistics, World Development Indicators (WDI)'s, International Renewable Energy Agency (IRENA)'s, and International Monetary Fund (IMF)'s database. To carry out the cross-sectional analysis, a questionnaire was created and transmitted using the Google Forms tool via the internet.

2.2. Data Scope

The study broadly covers the world energy market from the years 1977-2019, since the historical data set retrieved was only from 1977, and the forty-two (42) year period is sufficient to track the historical trajectory that explains energy source demand. The study also includes a cross-sectional primary data set and focuses on consumers of energy sources (natural gas, crude oil, solar energy, nuclear energy, coal and wind energy).

2.3. Data Analysis Technique

Utilizing energy source consumption dataset from BP (2019), the fraction share of energy sources and their consumption trends are depicted in Figure 1. Crude oil consumption is currently trending downwards while solar energy, wind energy and natural gas consumptions – the christened cleaner options – are increasing, even though not with the same magnitude. To further analyze the price and income effect on the substitution process, simple time series linear regression models using the bounds cointegration test with underlying Autoregressive Distributed Lag (ARDL) test equation were adopted instead of the Translog and Logit models, along with a poll analysis of 217 random respondents to analyze consumers' preferences, and factors that influence them.

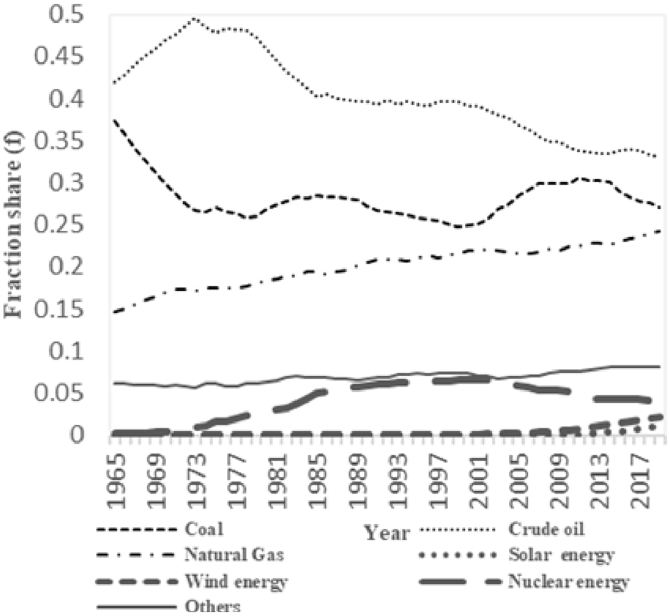


Figure 1: Trend of energy source market fraction shares (∑f=1) (BP 2019)

A questionnaire was developed to examine how consumers' preferences based on climate change concerns will influence consumers' choices among multiple energy sources. And to discover which influences consumers' energy source choice more between income and prices. The questionnaire was divided into three sections titled Biodata, Topical Knowledge, and Choices. Based on these, the focus was to discover if consumers prefer cleaner energy source options, and if they are willing to adopt environmentally friendly options based on different scenarios. The analysis of the questionnaire results was carried out using the Microsoft Excel spreadsheet. The results of both analyses were then compared, and conclusions were made on the influence of multiple demand determinants on the multiple energy sources.

2.4. Theoretical Framework

The consumer choice theory gives the best depiction of how a consumer would decide among multiple energy sources to maximize his satisfaction and minimize his expenditure, based on the various determinants of demand. When these choices are made, they influence the demand and supply mechanics that occur in the energy market as explained by the theory of demand and supply. To expatiate, the production function of an energy service – which could be any among transportation, residential/commercial heating, and electricity generation – is dependent on consumers' choices among multiple energy sources, which are in turn dependent on the determinants of demand. In explaining how consumers' choices influence the energy market, these theories are essentially interwoven and together define the study’s theoretical framework.

The production function of an Energy service (Es) represented in Equation (1) is function of labour (L), capital (K) and raw material, which is Energy source (E).

$$Es = f(K, L, E) \tag{1}$$

Assuming parameters Cr, Ng, Co, Se and Nu are the only energy sources (E) employed to produce energy services, the production function can be expanded as shown in Equation (2):

$$Es = f(K, L, (Cr, Ng, Co, Se, Nu)) \tag{2}$$

Each of these energy sources has its own demand function based on demand determinants which are broadly divided into:

i. The Market

ii. The State or Government

The demand is function of the market and state are expressed in Equation (3).

$$Demand\ \ for\ E = g(The\ market, The\ state) \tag{3}$$

This present study considers the State to be fixed, hence its implications are taken as negligible to obtain Equation (4). The market in no particular order is made up of the price of an energy source and its alternatives; the consumer’s income, taste and future expectations; and the number of buyers of all energy sources to give Equation (5).

$$Demand\ \ for\ E = g(The\ market) \tag{4}$$

$$\begin{aligned} Demand\ \ for\ E = g\ (&Price\ of\ E, \\ &Price\ of\ alternatives\ to\ E, Income\ of\ consumer, \\ &Taste\ of\ consumer, Expectation\ of\ consumer, \\ &No\ of\ buyers) \end{aligned} \tag{5}$$

The effect of the taste and expectation of a consumer, and several buyers on a consumer’s choice are dependent on the preference of individual consumers as expressed in Equation (6). When the consumer’s preference is adequately analyzed, the utility derived from the consumption of each energy source can then be derived using Equations (7) and (8).

$$\begin{aligned} &Taste\ of\ consumer, Expectation\ of\ consumer, \\ &\qquad No\ of\ buyers = h^*(Consumer's\ preference) \end{aligned} \tag{6}$$

$$Consumer's\ preference = Utility \tag{7}$$

$$\begin{aligned} &Demand\ \ for\ E = g\ (Price\ of\ E, \\ &Price\ of\ alternatives\ to\ E, Income\ of\ consumer, Utility\ of\ consumer) \end{aligned} \tag{8}$$

When a consumer has a fixed level of utility, such as when a consumer derives more satisfaction from a clean environment than from a polluted one, his optimization problem will be to minimize his expenditure on energy sources while still obtaining his desired clean environment. This optimization problem results in the type of demand function in Equation (8) which is influenced by a change in the utility level of the consumer and is referred to as the Hicksian (optimal) demand function. In reality, however, budget is more of a constraint than a fixed level of satisfaction, hence consumers would rather try as much as possible to maximize their utility, based on their fixed budget. This results in the Marshallian demand function which is not dependent on a change in the consumer's utility as stated in Equation (9).

$$Demand\ for\ E = g(Price\ of\ E,\ Price\ of\ alternatives\ to\ E, Income\ of\ consumer) \tag{9}$$

Hence, the energy service production function depending on the optimization choice of the consumer is either in Equation (10) or Equation (11).

$$\begin{aligned} Es = f(K, L, (&Price\ of\ E, \\ &Price\ of\ alternatives\ to\ E,\ Income\ of\ consumer, \\ &Utility\ of\ consumer)) \end{aligned} \tag{10}$$

$$\begin{aligned} Es = f(K, L, (&Price\ of\ E, \\ &Price\ of\ alternatives\ to\ E,\ Income\ of\ consumer)) \end{aligned} \tag{11}$$

In making supply decisions energy source producers consider the consumer's demand function, which is becoming more and more influenced by consumers' environmental consciousness. It has become essential that consumers' utility level from clean energy consumption and the environment be considered in analyzing the trend of consumers' energy source demand, to ensure better advised supply decisions.

In summary, consumers' choices affect demand and supply in the energy market. Due to this, producers make supply decisions based on consumers' choices. These choices are influenced by a number of demand determinants including consumers' preferences, which are not usually included in quantitative demand analysis since it is analyzed qualitatively. Presently, environmental consciousness is increasing among consumers, and they prefer a cleaner and more sustainable environment. The number and effectiveness of employable energy sources to derive the same energy services are also increasing. As the income of consumers increases, their budget set will enlarge, and their optimization problem will be more of expenditure minimization to derive their preferred clean environment, giving rise to the Environmental Kuznets curve. If this happens, prices will be insufficient indicators of a change in demand, and the utility consumers derive from consuming the different energy sources along with their income will give better indications. Without an adequate command of the procedure, it can be mathematically strenuous to convert a consumer's preference derived qualitatively to a quantitative utility function. However, since demand is still dependent on a consumer's preference, it should still be able to explain and predict this demand trend even in its qualitative form.

2.5. Regression Analysis

2.5.1. Stability test

The ADF (Augmented Dickey-Fuller) unit root test was the adopted testing method, with the test equation in Equation (12):

$$\Delta V_{(t)} = \theta_{(t)} + \infty_{(Trend)} + \mu V_{(t-1)} + \sum_{i=1}^{P} \sigma \Delta V_{(t-i)} + \varepsilon_{(t)} \tag{12}$$

Where: V represents each variable, θ is a unit-root constant coefficient, ∞ is the unit-root trend coefficient, μ, σ are unit-root slope coefficients, ε is an error term.

The null and alternative hypotheses are given in Equation (13):

$$\begin{aligned} &H_0: \mu = 0\ (Unit\ root) \\ &H_1: \mu < 0\ (No\ Unit\ root) \end{aligned} \tag{13}$$

2.5.2. Cointegration analysis

Following the unit root test, cointegration tests to analyze long-run relationship involving the explanatory and explained model's variables were carried out where necessary. The generic form of the adopted test equation –the Autoregressive Distributed Lag (ARDL) equation of the Bounds cointegration test– is given in Equation (14):

$$\Delta logE_{(t)} = \alpha_{(t)} + \omega logE_{(t-1)} - \gamma logP_{E(t)} + \beta logP_{altE(t)} + \delta logI_{(t)} + \psi logEff_{(t)} + \sum_{i=1}^{p} \varphi_i \Delta logE_{(t-i)} - \sum_{j=0}^{q} \rho_i \Delta logP_{E_{(t-j)}} + \sum_{j=0}^{q} \emptyset_i \Delta logP_{altE_{(t-j)}} + \sum_{j=0}^{q} \lambda_i \Delta logI_{(t-j)} + \sum_{j=0}^{q} \Omega_i \Delta logInt_{(t-j)} + \varepsilon_{(t)} \quad (14)$$

Where: α is regression constant coefficient, ω is explained variable lag period slope coefficients, γ, β, δ and ψ are long-run slope coefficients, φ, ρ, ∅, λ and Ω are short-run slope coefficients, ε is an error term.

The null and alternative hypotheses are given in Equation (15):

$$\begin{aligned} &H_0: \omega = \gamma = \beta = \delta = \psi = 0 \ (No\ cointegration) \\ &H_1: \omega \neq \gamma \neq \beta \neq \delta \neq \psi \neq 0 \ (Cointegration) \end{aligned} \quad (15)$$

2.5.3. Error correction model

Thee error correction term which determines the pace at which the explained variables returned to equilibrium after the explanatory variables change, was identified for each model. The Error Correction Model (ECM) extracted from the ARDL model is Equation (16).

$$\pi ECT_{(t-1)} = \alpha_{(t)} + \omega logE_{(t-1)} - \gamma logP_{E(t)} + \beta logP_{altE(t)} + \delta logI_{(t)} + \psi logInt_{(t)} \quad (16)$$

To verify the cointegration result, the coefficient of the ECT must be negative, less than one in absolute value, and statistically significant.

2.5.4. Model specification

The demand function adopted was the Marshallian demand function because the utility variable was analyzed qualitatively outside of the demand function. The general implicit regression model is expressed in Equation (17).

$$\begin{aligned} Demand\ for\ E = g(&Price\ of\ E, \quad Price\ of\ alternatives\ of\ E, \\ &Income\ of\ consumer, Energy\ intensity) \end{aligned} \quad (17)$$

where

$$E = g(P_E, P_{altE}, I, Int) \quad (18)$$

Explicitly, Equation 19 is obtained.

$$E_{(t)} = \alpha_{(t)} - P_{E(t)}^{\gamma} + P_{altE(t)}^{\beta} + I_{(t)}^{\delta} + Int_{(t)}^{\psi} + \varepsilon_{(t)} \quad (19)$$

Taking the natural log of the demand function in Equation (19), a new equation is obtained in Equation (20).

$$logE_{(t)} = \alpha_{(t)} - \gamma logP_{E(t)} + \beta logP_{altE(t)} + \delta logI_{(t)} + \psi logInt_{(t)} + \varepsilon_{(t)} \quad (20)$$

Equations (21) to (26) define the different energy sources.

$$\begin{aligned} logCr_{(t)} = \alpha_{(t)} &- \gamma logPCr_{(t)} + \beta_2 logPNg_{(t)} + \beta_3 logPCo_{(t)} + \beta_4 logPSe_{(t)} \\ &+ \beta_5 logPWi_{(t)} + \beta_6 logPNu_{(t)} + \delta logI_{(t)} + \psi logInt_{(t)} + \varepsilon_{(t)} \end{aligned} \quad (21)$$

$$\begin{aligned} logNg_{(t)} = \alpha_{(t)} &- \gamma logPNg_{(t)} + \beta_1 logPCr_{(t)} + \beta_3 logPCo_{(t)} + \beta_4 logPSe_{(t)} \\ &+ \beta_5 logPWi_{(t)} + \beta_6 logPNu_{(t)} + \delta logI_{(t)} + \psi logInt_{(t)} + \varepsilon_{(t)} \end{aligned} \quad (22)$$

$$\begin{aligned} logCo_{(t)} = \alpha_{(t)} &- \gamma logPCo_{(t)} + \beta_1 logPCr_{(t)} + \beta_2 logPNg_{(t)} + \beta_4 logSe_{(t)} \\ &+ \beta_5 logPWi_{(t)} + \beta_6 logPNu_{(t)} + \delta logI_{(t)} + \psi logInt_{(t)} + \varepsilon_{(t)} \end{aligned} \quad (23)$$

$$\begin{aligned} logSe_{(t)} = \alpha_{(t)} &- \gamma logPSe_{(t)} + \beta_1 logPCr_{(t)} + \beta_2 logPNg_{(t)} + \beta_3 logPCo_{(t)} \\ &+ \beta_5 logPWi_{(t)} + \beta_6 logPNu_{(t)} + \delta logI_{(t)} + \psi logInt_{(t)} + \varepsilon_{(t)} \end{aligned} \quad (24)$$

$$\begin{aligned} logWi_{(t)} = \alpha_{(t)} - \gamma logPWi_{(t)} + \beta_1 logPCr_{(t)} + \beta_2 logPNg_{(t)} + \beta_3 logPCo_{(t)} \\ + \beta_4 logPSe_{(t)} + \beta_6 logPNu_{(t)} + \delta logI_{(t)} + \psi logInt_{(t)} + \varepsilon_{(t)} \end{aligned} \tag{25}$$

$$\begin{aligned} logNu_{(t)} = \alpha_{(t)} - \gamma logNu_{(t)} + \beta_1 logPCr_{(t)} + \beta_2 logPNg_{(t)} + \beta_3 logPCo_{(t)} \\ + \beta_4 logPSe_{(t)} + \beta_5 logPWi_{(t)} + \delta logI_{(t)} + \psi logInt_{(t)} + \varepsilon_{(t)} \end{aligned} \tag{26}$$

α is the regression's constant coefficient, γ, β, δ and ψ are the regression's slope coefficients, and ε is the error term.

PCr is price of Crude oil, *PNg* is price of Natural gas, *PCo* is price of Coal, *PSe* is price of Solar energy, *PWi* is price of Wind energy, *PNu* is price of Nuclear energy, *I* is income per capita, *Int* is energy intensity.

2.6. Poll Analysis

2.6.1. Model specification

The model specifications are expressed in Equations (27) to (31).

$$\begin{aligned} [Taste\ of\ consumer, Expectation\ of\ consumer, \\ No\ of\ buyers = h^{*}(Consumer\ preference)] \end{aligned} \tag{27}$$

$$\begin{aligned} Consumer\ preferene\ for\ E = h(Taste\ of\ consumer, \\ Expectation\ of\ consumer, No\ of\ buyers) \end{aligned} \tag{28}$$

$$\begin{aligned} Demand\ \ for\ E = g(Price\ of\ E, \\ Price\ of\ alternatives\ to\ E, Income\ of\ consumer, \\ Utility\ of\ consumer) \end{aligned} \tag{29}$$

$$Consumer's\ preference = Utility \tag{30}$$

$$\begin{aligned} Demand\ \ for\ E = g(Price\ of\ E, \\ Price\ of\ alternatives\ to\ E, Income\ of\ consumer, \\ Consumer's\ preference) \end{aligned} \tag{31}$$

Where:

$$\text{Demand for E = E} \tag{32}$$

$$\begin{aligned} E = g(\ \overline{Price\ of\ E}, \overline{Price\ of\ alternatives\ to\ E}, \\ Income\ of\ consumer, Consumer's\ preference) \end{aligned} \tag{33}$$

Considering price of the energy source and alternative energy source(s) to be fixed, the demand function for the energy source becomes Equation (34).

$$E = f(\ Income\ of\ consumer,\ \ Consumer's\ preference) \tag{34}$$

3. RESULTS AND DISCUSSION

3.1. Regression Analysis

3.1.1. Crude oil consumption

Short-run estimates

The lagged periods for crude oil consumption have no significant impact on the current period of crude oil consumption and are the same as natural gas price, coal price, crude oil price, solar energy price, income per capita and energy intensity. On the other hand, nuclear energy price at the first lag period, and wind energy at level have positive impacts on crude oil consumption at 10% and 5% Level of Significance (LOS), respectively (Marchetti and Nakicenovic, 1979; Marchetti, 2006;).

In the short run 1% decrease in the price of wind energy in the earlier year, and nuclear energy in the current year will result in crude oil consumption fall by 0.03%, and 0.01%, respectively. This implies that they are substitutes to Crude oil in the short run. Although their substitution effect is minimal since crude oil consumption is price inelastic to all of them. Income per capita has a detrimental but insignificant effect in the short run. The R-squared is 78%, F value 4.23 (p-value = (0.0010)) is significant, and Durbin Watson value of 1.58 proves that the serial correlation is not present in the model.

Bounds cointegration test

The calculated F value of 5.9904 is above the upper bounds test. The critical value of the upper bound of 4.43 is at 1% significance level. Due to the rejection of the null hypothesis of no cointegrating relationship, crude oil consumption is cointegrated, with the prices of all energy sources, income per capita, and energy intensity. Therefore, there arises a long-run relationship involving the explained and explanatory variables. The Error Correction Term, CointEq (-1), with a coefficient estimate of -0.8628 in Table 1, implies that 86% of adjustment is occurring quickly toward long-run equilibrium. That is, the system returns to equilibrium within a length of time at a speed of 86%. The t-statistics is -3.9720 with a significant coefficient.

Table 1: Error correction terms for crude oil consumption

Variable	Std. Error	t-Statistic	Coefficient	Prob.
CointEq(-1)	0.217221	-3.971997	-0.862800	0.0007

Long-run estimates

For the long-run evaluation, wind energy price has a favourable impact at 1% LOS. A 1% decrease in the price of wind energy equals 0.03% decrease in crude oil consumption. Wind energy price has approximately the same effect on crude oil consumption in both short- and long- run while the effect of Income per capita is insignificant both in the long- and short-run.

Specified model:

The developed specific model is appropriately defined by Equations (35) to (40).

$$logCr_{(t)} = \alpha_{(t)} - \gamma logPCr_{(t)} + \beta_2 logPNg_{(t)} + \beta_3 logPCo_{(t)} + \beta_4 logPSe_{(t)} + \beta_5 logPWi_{(t)} + \beta_6 logPNu_{(t)} + \delta logI_{(t)} + \psi logInt_{(t)} + \sum_{i=1}^{p} \varphi_1 \Delta logCr_{(t-i)} - \sum_{j=0}^{q} \rho_1 \Delta logPCr_{(t-j)} + \sum_{j=0}^{q} \emptyset_2 \Delta logPNg_{(t-j)} + \sum_{j=0}^{q} \emptyset_3 \Delta logPCo_{(t-j)} + \sum_{j=0}^{q} \emptyset_4 \Delta logPSe_{(t-j)} + \sum_{j=0}^{q} \emptyset_5 \Delta logPWi_{(t-j)} + \sum_{j=0}^{q} \emptyset_6 \Delta logPNu_{(t-j)} + \sum_{j=0}^{q} \lambda_1 \Delta logI_{(t-j)} + \sum_{j=0}^{q} \Omega_i \Delta logInt_{(t-j)} + \varepsilon_{(t)} \quad (35)$$

$$\partial CointEq_{t-1} = \alpha_{(t)} - \gamma logPCr_{(t)} + \beta_2 logPNg_{(t)} + \beta_3 logPCo_{(t)} + \beta_4 logPSe_{(t)} + \beta_5 logPWi_{(t)} + \beta_6 logPNu_{(t)} + \delta logI_{(t)} + \psi logInt_{(t)} \quad (36)$$

$$logCr_{(t)} = \partial CointEq_{t-1} + \sum_{i=1}^{p} \varphi_1 \Delta logCr_{(t-i)} - \sum_{j=0}^{q} \rho_1 \Delta logPCr_{(t-j)} + \sum_{j=0}^{q} \emptyset_2 \Delta logPNg_{(t-j)} + \sum_{j=0}^{q} \emptyset_3 \Delta logPCo_{(t-j)} + \sum_{j=0}^{q} \emptyset_4 \Delta logPSe_{(t-j)} + \sum_{j=0}^{q} \emptyset_5 \Delta logPWi_{(t-j)} + \sum_{j=0}^{q} \emptyset_6 \Delta logPNu_{(t-j)} + \sum_{j=0}^{q} \lambda_1 \Delta logI_{(t-j)} + \sum_{j=0}^{q} \Omega_i \Delta logInt_{(t-j)} + \varepsilon_{(t)} \quad (37)$$

Estimated model:

$$logCr_{(t)} = -0.01 + 0.03 logPWi_{(t)} + 0.03 \Delta logPWi_{(t-1)} + 0.01 \Delta logPNu_{(t)} \quad (38)$$

$$\partial CointEq_{t-1} = -0.01 + 0.03 logPWi_{(t)} \quad (39)$$

$$logCr_{(t)} = 0.86 CointEq_{t-1} + 0.03 \Delta logPWi_{(t-1)} + 0.01 \Delta logPNu_{(t)} \quad (40)$$

3.1.2. Natural gas consumption

Short-run estimates

The first lagged period of natural gas has a positive impact on the current period of natural gas consumption while the first lagged period of natural gas price hurts consumption along with solar energy price at level (Bodger *et al.,* 1989). Whereas crude oil price at level, wind energy price at first lag period, and Income per capita have favourable impacts on its consumption. For the short-run evaluation, as the consumption in the previous year increases by a percent, natural gas consumption in the current period rises by 0.21%. A 1% decrease in the price of natural gas and solar energy will result in 0.08% and 0.01% rise in natural gas consumption, making the natural gas consumption inelastic to these prices. Natural gas consumption is also inelastic although positively to the prices of crude oil in the current period, and wind energy in the previous period. A 1% increase in any of them will both result in 0.03% increase in Natural gas consumption. Finally, natural gas is a normal (necessary good), with a percent increase in income per capita resulting in 0.08% increase in natural gas consumption. All of these are in the short run. The R-squared is 99.9%, F value 3460.6 (p-value = (0.0000)) is significant, and Durbin Watson value of 2.33 proves that the serial correlation is not present in the model.

Bounds cointegration test

The calculated F value of 0.78 is below the lower bounds test. The critical value of the lower bound of 2.26 is at 10% significance level. Accordingly, the null hypothesis of no cointegrating relationship cannot be disproved. That is Natural gas consumption is not cointegrated with the prices of all energy sources, income per capita, and energy intensity. Therefore, there is no long-run relationship involving the explained and explanatory variables. The Error Correction Term, Coint Eq (-1), with a coefficient estimate of -0.7872 in Table 2, implies that 79% of the shock in the short run would fizzle out within a length of time. The t-statistics is -8.752913 with a significant coefficient.

Table 2: Error correction terms for natural gas consumption

Variable	Std. Error	t-Statistic	Coefficient	Prob.
CointEq(-1)	0.089934	-8.752913	-0.787185	0.0000

Specified model:

The developed specific model is appropriately defined by Equations (41) and (42).

$$\boldsymbol{logNg}_{(t)} = \alpha_{(t)} + \sum_{i=1}^{p} \varphi_1 \Delta logNg_{(t-i)} - \sum_{j=0}^{q} \rho_1 \Delta logPNg_{(t-j)} + \sum_{j=0}^{q} \emptyset_1 \Delta logPCr_{(t-j)} + \sum_{j=0}^{q} \emptyset_3 \Delta logPCo_{(t-j)} + \sum_{j=0}^{q} \emptyset_4 \Delta logPSe_{(t-j)} + \sum_{j=0}^{q} \emptyset_5 \Delta logPWi_{(t-j)} + \sum_{j=0}^{q} \emptyset_6 \Delta logPNu_{(t-j)} + \sum_{j=0}^{q} \lambda_1 \Delta logI_{(t-j)} + \sum_{j=0}^{q} \Omega_i \Delta logInt_{(t-j)} + \varepsilon_{(t)} \quad (41)$$

Estimated model:

$$\boldsymbol{logNg}_{(t)} = 1.32 + 0.21 logNg_{(t-1)} - 0.08 logPNg_{(t-1)} + 0.03 logPCr_{(t)} - 0.01 logPSe_{(t)} + 0.03 logPWi_{(t-1)} + 0.08 logI_{(t-1)} \quad (42)$$

3.1.3. Coal consumption

Short-run estimates

At first lag period, Coal consumption has a positive effect on current period coal consumption. As consumption in the previous period rises by 1%, coal consumption in the present period will rise by 0.58%. Although this is a positive relationship, it is inelastic. Coal price has a negative (0.03) but insignificant impact on coal consumption with a p-value 0.11. Crude oil and nuclear energy prices have positive impacts on coal consumption (Renou-Maissant, 2007). A percent decrease in the price of crude oil and nuclear energy will lead to 0.03% and 0.02% decrease in coal consumption respectively. These relationships are inelastic and suggest that crude oil and nuclear energy are substitutes of coal. In contrast, natural gas price and energy intensity have negative impacts on coal consumption. This suggests that natural gas complements coal. As natural gas price and energy intensity reduce by 1%, the consumption of coal increases by 0.04% and 0.01%, respectively. Income per capita has no significant effect on coal consumption. All these are in the short run. The R-squared is 96.2% and F value is 26.8 (p-value = 0.0000), which is significant, and Durbin Watson value of 1.84 proves that the serial correlation is not present in the model.

Bounds cointegration test

The calculated F value of 2.13 is below the lower bounds test. The critical value of the lower bound of 2.26 is at the 10% significance level. Accordingly, the null hypothesis of no cointegrating relationship cannot be disproved. That is coal consumption is not cointegrated with the prices of all energy sources, income per capita, and energy intensity. Therefore, there is no long-run relationship involving the explained and explanatory variables. The Error Correction Term, CointEq (-1), with a coefficient estimate of -0.4186 in Table 3, implies that 42% of the shock in the short-run would fizzle out within one period of time plus. The t-statistics is -2.9179 with a significant coefficient.

Table 3: Error correction terms for coal consumption

Variable	Std. Error	t-Statistic	Coefficient	Prob.
CointEq(-1)	0.143448	-2.917867	-0.418562	0.0067

Specified model:

The developed specific model is appropriately defined by Equations (43) and (44).

$$\boldsymbol{logCo_{(t)}} = \alpha_{(t)} + \sum_{i=1}^{p} \varphi_1 \Delta logCo_{(t-i)} - \sum_{j=0}^{q} \rho_1 \Delta logPCo_{(t-j)} + \sum_{j=0}^{q} \emptyset_1 \Delta logPCr_{(t-j)} + \sum_{j=0}^{q} \emptyset_2 \Delta logPNg_{(t-j)} + \sum_{j=0}^{q} \emptyset_4 \Delta logPSe_{(t-j)} + \sum_{j=0}^{q} \emptyset_5 \Delta logPWi_{(t-j)} + \sum_{j=0}^{q} \emptyset_6 \Delta logPNu_{(t-j)} + \sum_{j=0}^{q} \lambda_1 \Delta logI_{(t-j)} + \sum_{j=0}^{q} \Omega_i \Delta logInt_{(t-j)} + \varepsilon_{(t)} \quad (43)$$

Estimated model:

$$\boldsymbol{logCo_{(t)}} = -0.01 + 0.58 logCo_{(t-1)} + 0.03 logPCr_{(t)} - 0.04 logPNg_{(t-1)} + 0.02 logPNu_{(t)} - 0.01 logInt_{(t)} \quad (44)$$

3.1.4. Solar energy consumption

Short-run estimates

The first, second, and third lag periods of solar energy consumption have negative impacts on the current period of solar energy consumption. As solar energy consumption in these previous periods decrease, that of the current period increases by 0.8%, 0.58%, and 0.37%, respectively. At its first lag period, the price of solar energy hurts solar energy consumption. As the previous period's price of solar energy decreases by a percent, its consumption increases by 1.08%, suggesting that solar energy is own price elastic as expected. Crude oil, Wind energy, and nuclear energy prices also have negative impacts on solar energy consumption. As each price rises by 1%, solar energy consumption falls by 0.25%, 0.13%, and 0.11%, respectively. Solar energy consumption is inelastic to these prices, and the negative relationship suggests that crude oil, wind energy, and nuclear energy are complements to solar energy (Chakravorty *et al.*, 1997). Natural gas is seen to be a substitute for solar energy with its positive impact at the 5% current period. A percent decrease in natural gas price will result in an inelastic 0.25% decrease in solar energy consumption. The impact of income per capita on solar energy consumption is insignificant at 15% significance level. However, a percent increase in income per capita will result in 0.56% increase in Solar energy consumption. All these are in the short run.

Bounds cointegration test

The calculated F value of 51.46336 is above the upper bounds test. The critical value of the upper bound of 4.24 is at 1% significance level. Accordingly, the null hypothesis of no cointegrating relationship cannot be disproved, which means that Crude oil consumption is cointegrated with the prices of all energy sources, income per capita, and energy intensity. Therefore, the explained and explanatory variables have a long-term relationship. The Error Correction Term (CointEq (-1)) with a coefficient estimate of -2.7436 in Table 4, implies that 274% of adjustment is occurring toward long-run equilibrium. That is, the system returns to equilibrium during less than a length of time at a speed of 274%. The t-statistics is –20.8169 with a significant coefficient.

Table 4: Error correction terms for solar energy consumption

Variable	Std. Error	t-Statistic	Coefficient	Prob.
CointEq(-1)	0.131797	-20.816909	-2.743605	0.0000

Long-run estimates

In the long run, prices of solar energy, crude oil, wind energy and nuclear energy have significant negative effects on the consumption of solar energy. As the prices decrease by one percent, Solar energy consumption increases by 0.05%, 0.18%, 0.05%, and 0.04%, respectively. The effect of coal price is insignificant in the long run. However, natural gas price and Income per capita have positive impacts. A percent increase in natural gas price and income per capita will result in 0.17% and 0.21% increase in solar energy consumption, respectively. In the long run, solar energy is a normal (necessary) good, a substitute for natural gas, and a complement to all other energy sources except coal.

Specified model:

The developed specific model is appropriately defined by Equations (45) to (50).

$$logSe_{(t)} = \alpha_{(t)} - \gamma logPSe_{E(t)} + \beta_1 logPCr_{(t)} + \beta_2 logPNg_{(t)} + \beta_3 logPCo_{(t)} + \beta_5 logPWi_{(t)} + \beta_6 logPNu_{(t)} + \delta logI_{(t)} + \psi logInt_{(t)} + \sum_{i=1}^{p} \varphi_1 \Delta logSe_{(t-i)} - \sum_{j=0}^{q} \rho_1 \Delta logPSe_{(t-j)} + \sum_{j=0}^{q} \emptyset_1 \Delta logPCr_{(t-j)} + \sum_{j=0}^{q} \emptyset_2 \Delta logPNg_{(t-j)} + \sum_{j=0}^{q} \emptyset_3 \Delta logPCo_{(t-j)} + \sum_{j=0}^{q} \emptyset_5 \Delta logPWi_{(t-j)} + \sum_{j=0}^{q} \emptyset_6 \Delta logPNu_{(t-j)} + \sum_{j=0}^{q} \lambda_1 \Delta logI_{(t-j)} + \sum_{j=0}^{q} \Omega_i \Delta logInt_{(t-j)} + \varepsilon_{(t)} \quad (45)$$

$$\partial CointEq_{t-1} = \alpha_{(t)} - \gamma logPSe_{E(t)} + \beta_1 logPCr_{(t)} + \beta_2 logPNg_{(t)} + \beta_3 logPCo_{(t)} + \beta_5 logPWi_{(t)} + \beta_6 logPNu_{(t)} + \delta logI_{(t)} + \psi logInt_{(t)} \quad (46)$$

$$logSe_{(t)} = \partial CointEq_{t-1} + \sum_{i=1}^{p} \varphi_1 \Delta logSe_{(t-i)} - \sum_{j=0}^{q} \rho_1 \Delta logPSe_{(t-j)} + \sum_{j=0}^{q} \emptyset_1 \Delta logPCr_{(t-j)} + \sum_{j=0}^{q} \emptyset_2 \Delta logPNg_{(t-j)} + \sum_{j=0}^{q} \emptyset_3 \Delta logPCo_{(t-j)} + \sum_{j=0}^{q} \emptyset_5 \Delta logPWi_{(t-j)} + \sum_{j=0}^{q} \emptyset_6 \Delta logPNu_{(t-j)} + \sum_{j=0}^{q} \lambda_1 \Delta logI_{(t-j)} + \sum_{j=0}^{q} \Omega_i \Delta logInt_{(t-j)} + \varepsilon_{(t)} \quad (47)$$

Estimated model:

$$logSe_{(t)} = 0.11 - 0.05 logPSe_{E(t)} - 0.18 logPCr_{(t)} + 0.17 logPNg_{(t)} - 0.05 logPWi_{(t)} - 0.04 logPNu_{(t)} + 0.21 logI_{(t)} + 0.8 \Delta logSe_{(t-1)} - 1.08 \Delta logPSe_{(t-1)} - 0.25 \Delta logPCr_{(t)} + 0.25 logPNg_{(t)} - 0.13 \Delta logPWi_{(t-1)} - 0.11 \Delta logPNu_{(t)} \quad (48)$$

$$\partial CointEq_{t-1} = 0.11 - 0.05 logPSe_{E(t)} - 0.18 logPCr_{(t)} + 0.17 logPNg_{(t)} - 0.05 logPWi_{(t)} - 0.04 logPNu_{(t)} + 0.21 logI_{(t)} \quad (49)$$

$$logSe_{(t)} = 2.74 CointEq_{t-1} + 0.8 \Delta logSe_{(t-1)} - 1.08 \Delta logPSe_{(t-1)} - 0.25 \Delta logPCr_{(t)} + 0.25 logPNg_{(t)} - 0.13 \Delta logPWi_{(t-1)} - 0.11 \Delta logPNu_{(t)} \quad (50)$$

3.1.5. Wind energy consumption

Short-run estimates

At the first lag period, wind energy consumption has a positive effect on the current period of wind consumption. As consumption in the earlier period rises by 1%, wind energy consumption in the current period will increase by 0.93%. Although this is a positive relationship, it is still inelastic. Wind energy price has no significant effect on its consumption (Fattouh *et al.*, 2019). The first and second lag periods of crude oil price have a positive effect on the current period of wind energy consumption. A percent decrease in the price of crude oil in the first and second lag periods results in 1.43% and 2.19% decrease in wind energy consumption. These values suggest that wind energy consumption is positively crude oil price elastic. That is crude oil is a substitute to wind energy. At first and second lag periods, natural gas has a unfavourable effect on wind energy consumption which is the same impact as nuclear energy price has on current wind energy consumption in its first lag period. As the first and second lag periods of natural gas price and first lag period of nuclear energy price decrease by 1%, wind energy consumption increases by 2.1%, 1.8%, and 0.3%, respectively. The income per capita has no significant effect on wind energy consumption. All these are in the short run. The R-squared is 99.8% and F value 447.2 (p= 0.0000), which is significant, and Durbin Watson value of 2.02 proves that the serial correlation is not present in the model.

Bounds cointegration test

The calculated F value of 2.07 is below the lower bounds test. The critical value of the lower bound of 2.26 is at the 10% significance level. Accordingly, the null hypothesis of no cointegrating relationship cannot be disproved. That is wind energy consumption is not cointegrated with the prices of all energy sources, income per capita, and energy intensity. Therefore, the explained and explanatory variables have no long-run relationship. The Error Correction Term, CointEq (-1), with a coefficient estimate of -0.0943 in Table 5, implies that 9% of the shock in the short run would fizzle out within nine periods. The t-statistics is -0.2903 with a significant coefficient.

Table 5: Error correction terms for wind energy consumption

Variable	Std. Error	t-Statistic	Coefficient	Prob.
CointEq(-1)	0.086211	-1.093760	-0.094294	0.2903

Specified model:

The developed specific model is appropriately defined by Equations (51) and (52).

$$logWi_{(t)} = \alpha_{(t)} + \sum_{i=1}^{p} \varphi_1 \Delta logWi_{(t-i)} - \sum_{j=0}^{q} \rho_1 \Delta logPWi_{(t-j)} + \sum_{j=0}^{q} \emptyset_1 \Delta logPCr_{(t-j)} + \sum_{j=0}^{q} \emptyset_2 \Delta logPNg_{(t-j)} + \sum_{j=0}^{q} \emptyset_3 \Delta logPCo_{(t-j)} + \sum_{j=0}^{q} \emptyset_4 \Delta logPSe_{(t-j)} + \sum_{j=0}^{q} \emptyset_6 \Delta logPNu_{(t-j)} + \sum_{j=0}^{q} \lambda_1 \Delta logI_{(t-j)} + \sum_{j=0}^{q} \Omega_i \Delta logInt_{(t-j)} + \varepsilon_{(t)} \quad (51)$$

Estimated model:

$$logWi_{(t)} = 0.25 + 0.93\Delta logWi_{(t-1)} + 1.43\Delta logPCr_{(t-1)} - 2.14\Delta logPNg_{(t-1)} - 0.30\Delta logPNu_{(t-1)} \quad (52)$$

3.1.6. Nuclear energy consumption

Short-run estimates

At the first lag period, nuclear energy consumption has a favourable effect on the current period of nuclear energy consumption. As consumption in the earlier period rises by 1%, nuclear energy consumption in the current period will elastically rise by 1.35%. Nuclear energy price has no significant effect on nuclear energy consumption (Agarwal, 2022). Solar energy price and energy intensity at the first lag period, the natural gas price at level, and first differenced income per capita at level all have negative impacts on nuclear energy consumption. A percent decrease in any of these at the stated lag periods will result in 0.10%, 0.01%, 0.12%, and 0.29% increase in nuclear energy consumption. At first lag period of income per capita, however, the impacts on nuclear energy consumption is positive. A percent increase in income per capita will result in 0.35% increase in nuclear energy consumption. These results suggest that nuclear energy is a complement to solar energy and natural gas. In addition, nuclear energy is an inferior good at the current period of first differenced Income per capita, and a normal (necessary) good at first lag period of first differenced income per capita. At level, coal price, and wind energy price both have positive impacts on nuclear energy consumption. A percent decrease in any of them results in 0.16%, and 0.07% decrease in nuclear energy consumption. Coal and wind energy are seen as substitutes for nuclear energy in the current period. The R-squared is 99.8%, F value 330.6 (p= (0.0000)) is significant, and Durbin Watson value of 1.76 proves that the serial correlation is not present in the model.

Bounds cointegration test

The calculated F value is 1.89 which is below the lower bounds test. The critical value of the lower bound is 2.26 at the 10% significance level. This means that the null hypothesis of no cointegrating relationship cannot be rejected. That is Coal consumption is not cointegrated with the prices of all energy sources, income per capita, and energy intensity. Therefore, there is no long-run relationship between the explained and explanatory variables. The Error Correction Term, CointEq (-1), with a coefficient estimate of -0.0911 in Table 6, implies that 9% of the shock in the short run would fizzle out within nine periods. The t-statistics is -2.9446 with a significant coefficient.

Table 6: Error correction terms for nuclear energy consumption

Variable	Std. Error	t-Statistic	Coefficient	Prob.
CointEq(-1)	0.030924	-2.944625	-0.091060	0.0114

Specified model:

The developed specific model is appropriately defined by Equations (53) and (54).

$$logNu_{(t)} = \alpha_{(t)} + \sum_{i=1}^{p} \varphi_1 \Delta logNu_{(t-i)} - \sum_{j=0}^{q} \rho_1 \Delta logPNu_{(t-j)} + \sum_{j=0}^{q} \emptyset_1 \Delta logPCr_{(t-j)} + \sum_{j=0}^{q} \emptyset_2 \Delta logPNg_{(t-j)} + \sum_{j=0}^{q} \emptyset_3 \Delta logPCo_{(t-j)} + \sum_{j=0}^{q} \emptyset_4 \Delta logPSe_{(t-j)} + \sum_{j=0}^{q} \emptyset_5 \Delta logPWi_{(t-j)} + \sum_{j=0}^{q} \lambda_1 \Delta logI_{(t-j)} + \sum_{j=0}^{q} \Omega_i \Delta logInt_{(t-j)} + \varepsilon_{(t)} \quad (53)$$

Estimated model:

$$logNu_{(t)} = 0.16 + 1.35\Delta logNu_{(t-1)} - 0.12\Delta logPNg_{(t)} + 0.16\Delta logPCo_{(t)} - 0.10\Delta logPSe_{(t-1)} + 0.07\Delta logPWi_{(t)} - 0.29\Delta logI_{(t-1)} - 0.01\Delta logInt_{(t-1)} \quad (54)$$

3.2. Poll Analysis

The results of the questionnaire were analysed based on a plurality voting system (where the option with the most vote wins the poll, regardless of whether the fifty percent threshold is passed). A total of two hundred and seventeen (217) filled questionnaires were retrieved, of which one hundred and eighty one (181) – 83% pay for their energy services, while the remaining 17% do not. The random group of respondents consists of 54% male and 46% female. 2% of the respondents have a Doctorate degree or higher, 31% a Master's degree, 54% a Bachelor's degree, 12% a High school degree, and 1% attended a trade school as their highest education level. 35% of the 217 respondents are fully employed 8% are employed on a part-time basis, 31% are students, 0.5% retired, 20% self-employed, and 6% unemployed. Of this demographic, 92% know about global warming, 5% are not sure they know about global warming, and 3% do not know about global warming as presented in Figure 2. This suggests a largely informed demographics on global warming. To commemorate this, Figure 3 shows that 88.48% agree that global warming is really happening, 11.06% are neutral about the reality of global warming, and 0.46% (1 person strongly disagrees). As illustrated in Figure 4, 99% of the respondents would rather have a clean environment than a polluted one. In terms of energy sources, 86.6% of total respondents know solar energy as an energy source, 72.8% and 72.4% of total respondents know crude oil and natural gas, respectively as energy sources, 68.7% know coal, 61.8% know wind energy, and 49.3% Nuclear energy. 94% of the total respondents are familiar with electricity generation as an energy service, 59% of the total are familiar with transportation as an energy service, and 46% with heating. Of this demographic, 97.7% know that these energy sources are used to provide these energy services with no one disagreeing, while 2.3% are neutral on the matter. 83.3% are of the opinion that pollutants from these energy sources intensify global warming, 12% are neutral, and 3.7% disagree. From Figure 5, it is clear that most of the respondents think that pollutant-generating energy sources are not environmentally friendly. It is essential to note that most of the respondents, who are majorly students or fully employed, are largely between the ages of 20-30 years, with 54% having at least a Bachelor's degree, preferably a clean environment which they believe can be polluted by pollutant generating energy sources. The respondents' demographics based on monthly income are more diverse, with 39% having a net monthly income between $101–$400, 27% between $401–$1000, 20% less than $100, 10% between $1001–$4000, and 4% above $2000 as illustrated in Figure 6.

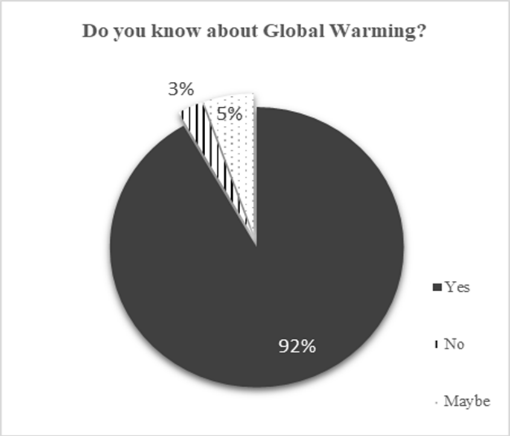


Figure 2: Respondents' knowledge of global warming

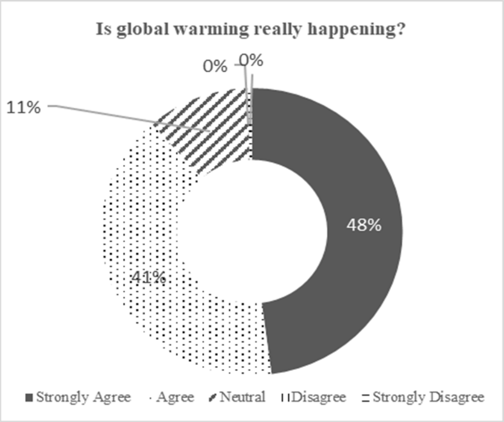


Figure 3: Respondents' thoughts on the reality of global warming

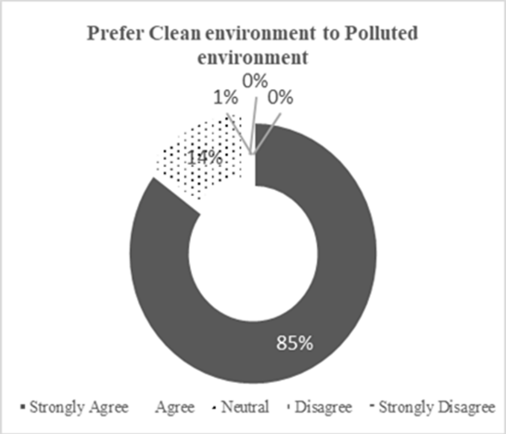


Figure 4: Respondents' environmental preference

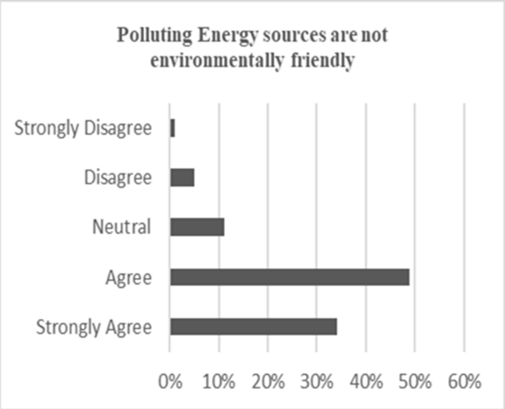


Figure 5: Respondents' thoughts on the environmental impact of polluting energy sources

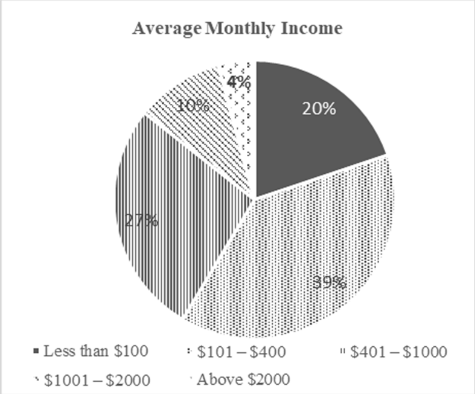
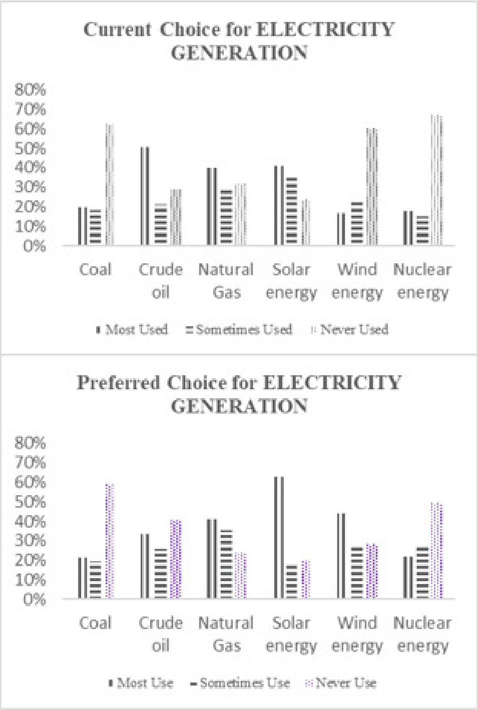


Figure 6: Average monthly income of respondents

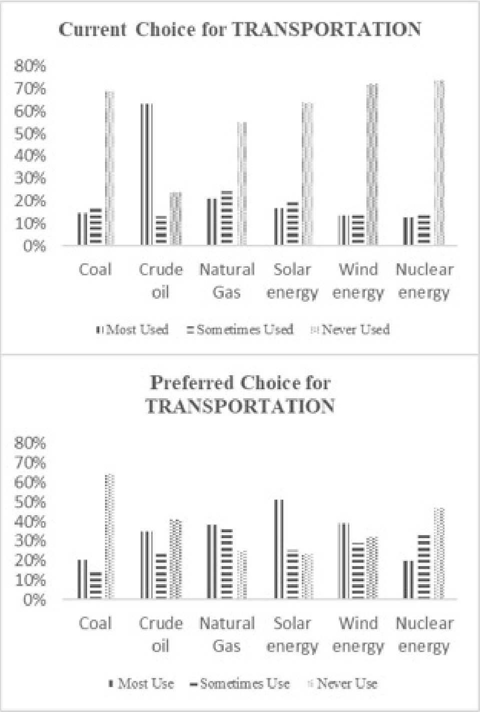
Considering respondents that pay for their energy services only, the following illustrations Figures 7 to 9 compare respondents' current energy source choice for electricity generation, transportation, and heating at current income levels, and respondents' preferred energy source choice considering environmental concerns, and at convenient income level. When asked why polluting energy sources are chosen over non-polluting ones, Fig shows that 40.9% of respondents agree that 'Insufficient income to adopt environmentally friendly energy sources' was their major reason, closely followed by 40.3% and 23.2% who agreed to 'high cost of environmental friendly primary energy sources' and 'low cost of non-environmental friendly energy sources', respectively as their reason. The responses were then analyzed per income levels as presented in Figure 11, and respondents with income level Above $2000 gave the low cost of conventionals, indifference to different energy sources and non-availability of cleaner options as their major reason (in that order), before the high cost of cleaner options. Insufficient income was not a determining factor for them. For respondents with the least income (less than $100 – $401-$1000), insufficient income was their major reason before the cost of energy sources. At an income level where respondents can conveniently purchase any of the energy sources where all energy sources provide approximately the same energy service, as seen in Figure 12, 87% agree, 11% were neutral, and 2% disagree with picking their preferred choice over their current choice. And in a case where the preferred choice provides a lesser amount of energy service compared to the current choice, Figure 13 shows that 60% agree to switching, 20% are neutral, and 20% disagree. When analyzed per income levels in Figure 14, a clear higher percentage of respondents per income level agree to substitute their current choices for their preferred choices which tend more towards cleaner energy options minus nuclear energy.

As illustrated in Figure 15 at the current income level, 44% of respondents agree to adopt more expensive cleaner options if the number of people adopting them increase, while 37% are uncertain. Finally, 84% agree to purchase cleaner energy sources if evidence of global warming as a result of polluting energy sources increase, and finally, 88% of the respondents expect that the adoption of non-polluting energy sources will result in a more sustainable environment. In summary, the respondent demographics is largely informed on global warming concerns and would prefer a sustainable environment. From the analysis, income is seen as the major hindrance to clean energy adoption, followed closely by cost. Other determinants of demand like a number of buyers and future expectations of buyers are seen to also influence consumers' choices.


Current Choice for ELECTRICITY GENERATION

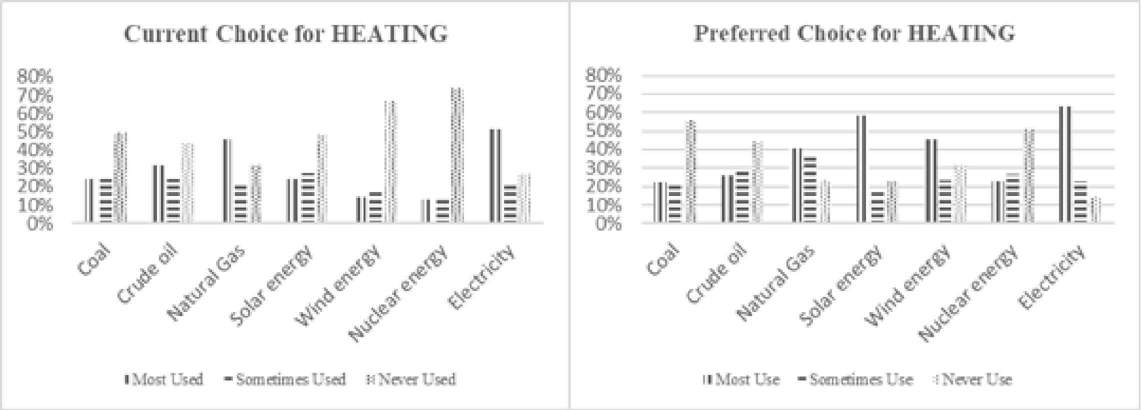
Preferred Choice for ELECTRICITY GENERATION

Figure 7: Respondents' 'current' and 'preferred' energy source choices for electricity generation


Current Choice for TRANSPORTATION

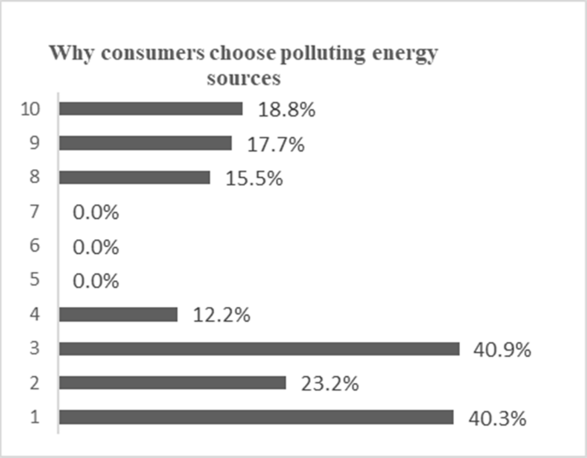
Preferred Choice for TRANSPORTATION

Figure 8: Respondents' 'current' and 'preferred' energy source choices for transportation


Current Choice for HEATING

Preferred Choice for HEATING

Figure 9: Respondents' 'current' and 'preferred' energy source choices for heating



Note:

*1= High cost of environmentally friendly primary energy sources
*2= Low cost of non-environmentally friendly energy sources
*3= Insufficient income to adopt environmentally friendly energy sources
*4= Low number of users of environmentally friendly energy sources
*5= Familiarity with non-environmentally friendly energy sources
*6= Comfortable with non-environmentally friendly energy sources
*7= Sceptical about newer environmentally friendly energy sources and their technology
*8= Indifferent as long as you get your energy service need met
*9= Underdeveloped nature of non-environmental polluting technology
*10= Nonavailability of environmentally friendly energy sources and their technology

Figure 10: Respondents' reasons for choosing polluting energy sources over cleaner ones

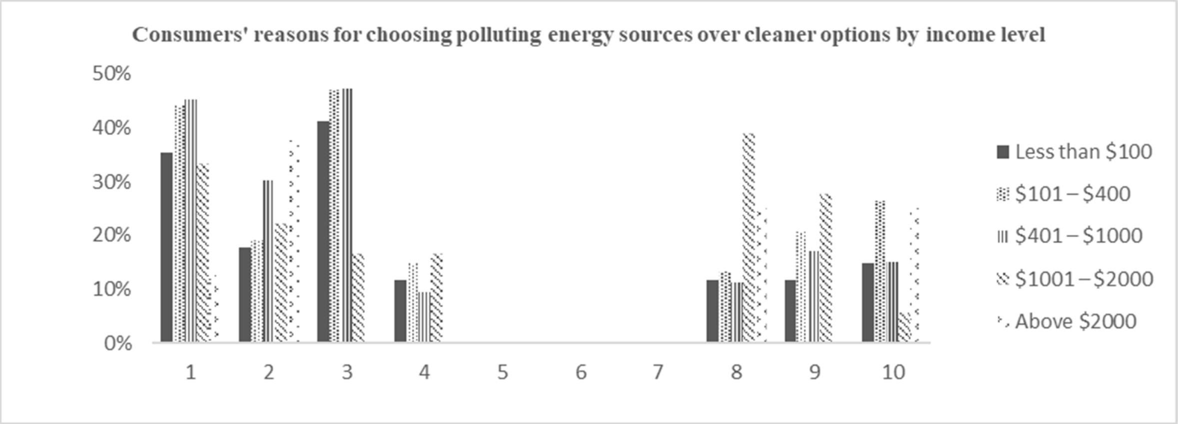


Figure 11: Respondents' reasons for choosing polluting energy sources over cleaner ones by income level

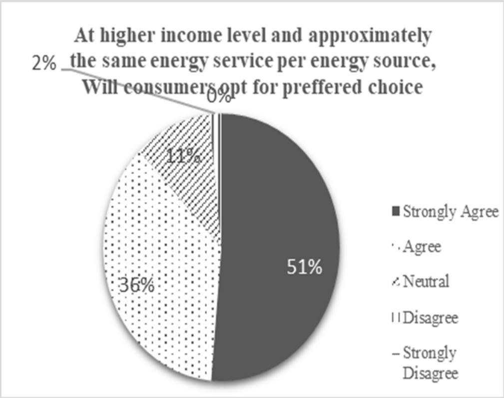


Figure 12: Influence of higher income level on Respondents' Preferred energy source adoption

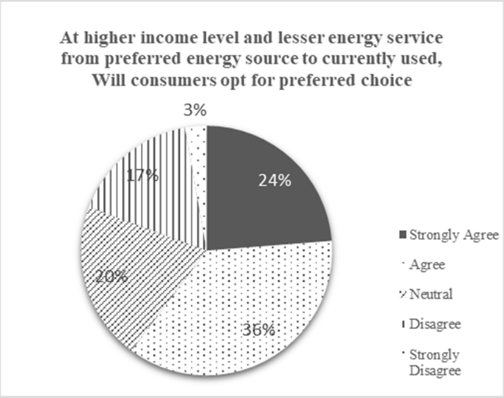


Figure 13: Influence of higher income level on Respondents' 'preferred' energy source with lesser energy service adoption

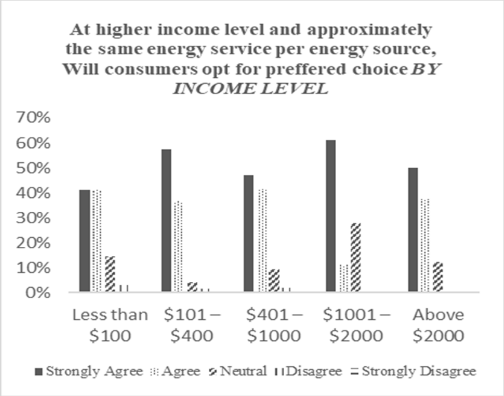


Figure 14: Influence of higher income level on Respondents' 'preferred' energy source adoption by income group

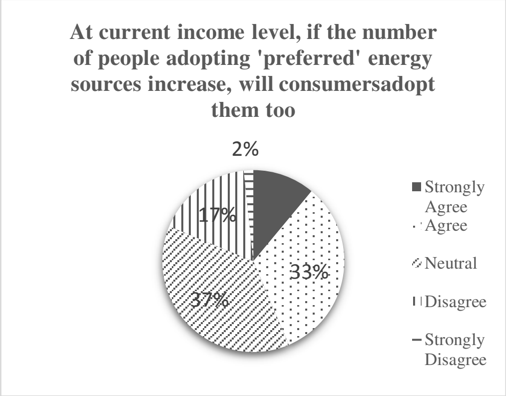


Figure 15: Influence of number of buyers on Respondents' 'preferred' energy source choice

4. CONCLUSION

Consumers' income influenced energy source substitution the most, followed by consumers' convenience with their current energy source, partly due to its lower cost, and finally the high cost of cleaner options. Other demand determinants, such as the number of buyers and consumer preferences, also played significant roles. Despite this, cleaner energy options were becoming more preferred, and energy intensity was decreasing with rising global incomes. Coal had lost market share to crude oil and was losing it to natural gas, even though it was cheaper. This suggested that cleaner options might not need to be cheaper before they dominate the market. In the foreseeable future, clean energy sources, particularly solar energy, would likely take on crude oil's current characteristic of being unaffected by consumers' income and general price fluctuations as their consumption levels rise. Cleaner energy sources were already available, increasingly accepted, more accessible due to technological advancements that reduced their costs, and more affordable with rising incomes. From a market perspective, global energy source substitution appeared inevitable. Therefore, governments of producer economies, such as Nigeria, must create and enforce policies that embrace energy source substitution. Such policies would help prepare and strategically position their economies for the future global energy landscape.

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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