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Fuel subsidies and Carbon Emission: Evidence from asymmetric modelling

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Abstract

It is expected that fuel subsidy removal should hinder carbon emissions growth through low energy consumption channels amid higher energy prices. However, outliers in this theoretical disposition make empirical proof of the fuel subsidy-carbon intensity apt and primitive. Despite established fuel subsidy abolishment gains for climate and economic welfare, the relevance, magnitude and policy implications remain dimly. This paper employs the non-linear autoregressive distributed lag (NARDL) estimation procedure to gauge the contemporaneous influence of fuel subsidy for carbon intensity in Nigeria. Findings revealed that fuel subsidy removal inversely relates to Nigeria's carbon emission in the short-run and long run. The study recommends complementary policy option that ensures additional financial savings to the government should be invested in public sector growth that can cushion the effect of relative income loss to the citizenry. The Nigerian government should ensure measures are kept in place to discourage over-consumption of alternative energy (for example, coal) that could also threaten the green economy paradox.

Keywords: Fuel Subsidy, Carbon Emission, Non-linear ARDL, Nigeria

JEL Codes: C22; E31; N57; Q54

1.0 Introduction

This paper examines the relevance, magnitude and policy implications of fossil fuel subsidy removal for carbon emission in Africa's largest oil-producing nation, Nigeria. This examination of the fuel subsidy-carbon emission relations is essential for some factors. With government fossil-fuel subsidies expected to boost residents' fossil fuel consumption, and in turn, leads to high carbon intensity, it becomes apt to have evidence-based research that modulates policy guidelines on the share of government ordinances towards environmental sustainability. In tandem with the carbon curse theory of Friedrichs and Inderwildi (2013), the growth trajectory of carbon-emission is favoured by the oil-rich nation due to; (a) subsidies on domestic fuel consumption; (b) extractive emissions; (c) fuel-related crowding-out effects, and (d) feeble incentives for pollution abatement strategies. This study explores less understood and understudied fuel subsidy-carbon emission relations to reach conclusions capable of informing policymaking and research on the subject. The relevance, magnitude and policy implications of fuel subsidy as an instrument to gauge carbon emission has remained *a prior* unclear and in need of study. This study aims to address this need.

The scholarly debate to phase out fuel subsidies as a precursor to low greenhouse gas emission and increased fiscal savings have received less attention across African borders. Most studies in this area have been cross-continental panel studies and, as far as we know, no country-specific research in Africa or African panel study has covered this ground, leaving a gap in the literature of energy and environmental economics in Africa. Over and above, discontinuing fossil-fuel subsidy ensures consumers (domestic residents) purchase fossil fuel at a price that is at par with international oil market (establishing marginal social benefit to be equal to the marginal social cost). The empirical relevance and the magnitude to which the existence or removal of fossil-fuel subsidy influences carbon dioxide (CO_2) emission remain dimly discerned. Efforts towards reducing greenhouse gas emissions have seen continuous call for the phasing out of fossil-fuel subsidy to understand better changing environmental conditions (Kellner, 2020). Proponents of fossil fuel phase out argued that it encourages uneconomical energy consumption, impede substitutions from non-renewable to renewable energy options, hinders low carbon transitions and many more deep-rooted green energy transition issues. This paper answer the call for a better understanding of the need to phase out fossil fuel subsidy, the expected magnitude of changes in carbon emission as induced by fossil fuel existence and policy guidelines in the environmental pursuit management in Africa largest oil producer and most populous nation, Nigeria.

Nigeria creates an interesting platform to establish a clear line of thought on fuel subsidies' relevance in controlling greenhouse gas emissions with her largest African oil exporter features while embarking on large fuel subsidy for a long time until it was abolished recently. Considering that growth policies are country or regions specified in the face of structural rigidities of host nations and attendant heterogeneous influences of government policies on carbon emission, it then becomes apt to appropriate data and methodology to establish a clear line of thought in the fuel subsidy-carbon intensity relationship to reach conclusions that are most inclined to the development objectives of each nation. Only studies by Akinyemi, Alege, Ajayi, Amaghionyeodiwe, and Ogundipe (2015); Osunmuyiwa and Kalfagianni (2017) came close to the examination of fuel subsidy-environmental quality relationship in Nigeria. Other studies in this regards are done across borders[1]. It is not even entirely clear the implication of recent fuel subsidy removal means for the growth of carbon emission amidst structural ambiguities plaguing the country (Nwachukwu & Chike, 2011). It is expected that fuel subsidies will augment carbon emission because of the citizenry's rising purchasing power (Aldy & Stavins, 2012) but the empirical proof of the expected relationship remains less understood and underexplored in Nigeria. This study empirically examines the contemporaneous influence of fuel subsidy for carbon emission in Nigeria, having in mind remarkable exceptions of outliers where subsidy reforms on fossil fuel consumption still reduce carbon emissions.

This paper contributes to the literature of carbon dioxide abatement by further estimating the causal mechanisms offuel subsidy-carbon emission in Nigeria. Until recently, Nigerians have purchased fuel very much lower than the international oil market price (Lin & Atsagli, 2017). The implication is that the residents' marginal social benefits are higher than the marginal social cost incurred. These phenomena favour increased fuel consumption and invariably encouraged higher carbon emission leading to environmental degradation (uni-directional causality from fuel subsidy to environmental quality) (Rečka & Ščasný, 2016). Contrastingly, the shabbiness of our environment (flooding, insufficient natural resources endowments, extinction of wildlife,

[1](see Abila, 2010; Puzzolo, Pope, Stanistreet, Rehfuess, & Bruce, 2016; Vedenov & Wetzstein, 2008; Wu, Colson, Escalante, & Wetzstein, 2012 for some examples)

uncultivable or scarce arable land to farm etc.) can in some ways explains government willingness to extend subsidies to the citizens, in an attempt to lessen poverty and generate a condition sustainable for affordable public consumption (Soile & Mu, 2015). This phenomenon exemplifies uni-directional causality from environmental quality to fuel subsidy. The empirical credence establishing this theoretical disposition in Nigeria remains ambiguous. Given magnitude of fuzziness on the reverse causation dimensions to sustainability of the environment and pervasive role of fuel subsidy, this study conducts Granger causality test to establish a clear line of thought to inform policy direction and research on the subject.

Despite recent advancements in the environmental degradation literature in Nigeria, policymakers and society are still at a loss explaining environmental changes emanating from increased carbon emission. Nigerian are unable to assess the country's current economic performance within the ecological degradation discourse. For a long time, the growth equation leading to gross domestic product (GDP) has omitted the cost of environmental degradation when accounting for nominal growth. The inability to place current environmental performance within any historical context, the consequences of varying environmental challenges borne out of government actions and inactions, have led to the dilemma of whether society should continue the current trajectory of environmental pollution or glean towards a sustainable environment approach (Oyedepo, 2012). Important factors traceable to the environmental sustainability dilemma in Nigeria are many some of which are; (1) the sheer number of economic statistics on environmental discourse are not precise(Fayiga, Ipinmoroti, & Chirenje, 2018); (2) conflicting evidence in the literature of environmental sustainability in Nigeria (Lin, Omoju and Okonkwo (2015) found industrialisation to be inversely related to CO_2; however Ali, Law and Zannah (2016) found contradictory evidence) and (3) more prominently whether government subsidies induce variations in the environmental sustainability (an appraisal of marginal social benefits against the marginal social cost to the society which further aggravates ecological degradation). The historical examination and empirical clarity arising from these studies remain inadequate for policy and research purposes. Thus, creating a lacuna that this study intends to fill.

We referred to carbon intensity as growth in the carbon dioxide emission. For an operating and safe Nigeria, it is expected that gains from oil resources (economic and human welfare) do not invent equivalent greenhouse gas emission leading to environmental degradations. Since most oil-rich nations' political leaders are under intense pressure to subsidise oil largely because residents actively claim to collective ownership of natural resources and buy fuel below the international oil market price, fuel subsidy becomes institutionalised. The Nigeria economy has witnessed prolonged phases of fuel subsidies under past government until the President Muhammed Buhari regime cut short those extensive government ordinances. Quantitative implications of government subsidies and vice-versa for carbon dioxide growth have not been studied in Nigeria's environmental sustainability literature. Rather than a direct fiscal expenditure, fuel subsidies are opportunity cost since the marginal cost of fuel relative to world market prices remains insignificant. Subsidising fuel for domestic consumption does not entirely make aggregate oil revenue fall short of the production cost. Although, it leads to loss of export income.

We relied on the non-linear autoregressive distributed lag (NARDL) estimation procedure of Shin, Yu, and Greenwood-Nimmo (2014)to reach policy consistent outcomes on the fossil-fuel subsidy-carbon emission relations in Nigeria. Over time, research has established nonlinearity in oil prices (see Khraief, Shahbaz, Mahalik, & Bhattacharya (2021); Xu, Han, Wan, & Yin (2019); Dbouk & Jamali (2018) for some examples), making the adoption of conventional linear estimation procedures indeterminable and inappropriate to reach a plausible outcome on the subject. Unlike the ARDL bound cointegration procedure followed in Dey, and Tareque (2019), the NARDL estimation technique is useful in establishing both short-run and long-run asymmetric co-integrating characteristics the variables. The unrestricted error correction components present leading insights into the nonlinearity and non-stationarity properties of the model. This study found fuel subsidy removal inversely relates to carbon emission n Nigeria in the short-run and long run.

By providing new and insightful insight into the less understood and underexplored relationship between fossil-fuel subsidy and carbon emission in Nigeria, this study takes the lead and holistic approach in setting a clear line of thought to reach conclusions capable of redefining policy and research on the subject. Secondly, this study diverts from the conventional process of testing the fuel subsidy-carbon relation using orthodox linear estimation procedure which fails to account for nonlinearity in energy prices. Instead, we established asymmetric properties using the NARDL technique to reach theory and policy consistent empirical outcomes. Thirdly, this study is the first to clarify the fuzziness in the reverse causative structure of the fuel-subsidy-carbon emission relation using the granger causality test.

2.0 Literature Review

In direct response to the subsidy-carbon emission growth strategies worldwide, ample studies have examined these phenomena with their attendant cost-benefit analysis. Across borders, there is a growing list of studies on the subject matter. However, few studies toe the line of discourse in Nigeria; some of which are Akinyemi *et al.*(2015)Osunmuyiwa and Kalfagianni (2017); Dioha and Kumar (2020). In Akinyemi *et al.*(2015), empirical credence was leaned to the established relationship of fuel subsidy and environmental reforms in Nigeria. Using the Engle and Granger *two-step* estimation procedure, the authors found no support for subsidy-growth of Nigeria's carbon intensity. Osunmuyiwa and Kalfagianni (2017) found oil price shocks and cumulative pressure of financial organisations as a predictor of oil reforms hinged on fuel consumption subsidies. Dioha and Kumar (2020) found a carbon tax to lower carbon emission in Nigeria. Several other studies have examined the growth trajectory of carbon emission in Nigeria along various dimensions. Cosmas, Chitedze and Mourad (2019) examined the macroeconomic determinant of carbon emission in Nigeria using the linear and non-linear autoregressive distributed lag estimation procedure. The authors found GDP per capita significantly induces carbon dioxide emission in Nigeria. Lin and Atsagli (2017) in their analysis of energy consumption, inter-fuel and growth outcomes in Nigeria, found argued that government fuel subsidy removal and the attendant petroleum price ceiling will instigate other waves of efficient use of electricity by the concerned industries. The newfound efficiency of the domestic industries will, in turn, leads to labour and capital efficiency and effectiveness. In other findings, Giwa, Nwaokocha and Odufuwa (2017) found evidence for natural gas vehicles as a panacea for halting carbon intensity in Nigeria. In a separate result, Shobande and Shodipe (2019) leaned empirical credence to carbon policy discourse in the United States, China and Nigeria using the dynamic stochastic general equilibrium model. The authors found that strong carbon policies are prerequisite to decarbonisation strategies. Emodi, Emodi, Murthy and Emodi (2017)'s study corroborates the findings of Shobande and Shodipe (2019) despite representing their findings within the Long-range Energy Alternative Planning (LEAP) model. Nonetheless, Elum and

Momodu (2017) argued that social and political bottlenecks are the significant impediments to a green Nigeria. Other studies on fuel subsidy discuss in Nigeria but are not explicitly examining the fuel subsidy induced carbon emission growth trajectories are acknowledged (see Akanle, Adebayo and Adetayo (2014); Nwachukwu and Chike (2011); Nwachukwu, Mba, Jiburum and Okosun (2013); Siddig, Aguiar, Grethe, Minor and Walmsley (2014); Soile and Mu (2015) for an extensive review).

In neighbouring Ghana, Wesseh, Lin and Atsagli (2016) using the computable general equilibrium model (CGE) to examine fuel subsidy removal and carbon intensity found removal of fuel subsidy to halt growth trajectory of carbon emission. Contrastingly, Wesseh and Lin (2016) found that fuel subsidy removal leads to a rise in the general price level, increases carbon intensity, and weakens household purchasing power, leading to Ghana's negative growth. The authors likened the resultant inverse relationship between fuel subsidy removal and carbon intensity in Ghana to the 'green paradox' and this undermine the expected linear and asymptotic relationship established in the fuel-subsidy-carbon intensity literature. Nathaniel and Iheonu (2019) used augmented mean group estimation procedure and found strong evidence for non-renewable energy complementing carbon dioxide growth trajectory in Africa.

The most elaborate and recent findings on the subsidy and carbon emission was written by Friedrichs and Inderwildi (2013). Their results argued that extractive emission, weaker incentives for pollution abatement strategies, fuel-related crowding out, and uneconomically extended subsidies are the determinants of the growth trajectory of carbon in oil-rich nations. Chepeliev and van der Mensbrugghe (2019) examined fossil fuel subsidy reform for emission reduction in twenty-five (25) countries with huge fossil fuel consumption subsidies in other related cross border findings. The authors found that the elimination of fuel subsidy is central to country-specific emission targets. Within the household welfare implications discourse in developing countries, Dennis (2016) found government benefits while private household suffers from fuel subsidy removal leading to financial gains for government and revenue loss to the households. In another vital cross border findings, Burniaux and Chateau (2014) argued that although fuel subsidy removal represents a significant leap toward climate change and economic benefit, it heterogeneous impact for all countries and regions are not the same. By implication, not all countries that remove fuel subsidy are better placed in the long-run. These findings were corroborated by the works of Monasterolo and Raberto (2019); Schwanitz, Piontek, Bertram and Luderer (2014). In their separate findings, they argued that phasing out fuel subsidy has a short climate and economic benefits and long-term consequences since the removal of fuel subsidy are associated with the anticipated reduction in world market prices which triggers another wave of carbon intensity. In Mundaca (2017) study, evidence was advanced for a reduction in subsidy as a prerequisite for less carbon emission in the MENA countries. In Tunisia and South Africa, Schmidt, Matsuo and Michaelowa (2017) examined the socio-technical perspectives of renewable energy in disrupting fossil fuel subsidy regimes. They found that the socio-technical perspectives to fossil fuel subsidies are central to subsidy reforms, policy design and structural transformation of environmental sustainability.

In other natural resources subsidy analysis, Xiang and Kuang (2020) examined the beneficiary of China coal subsidy at the industry level using a CGE model. The authors found that coal subsidies largely influence China's coal output with attendant challenges for overcapacity utilisation in China's coal industry. In other findings from their study, the coal subsidies destroy trade engagements since importation's incentive significantly fell. The environmental and welfare loss emanating from the coal subsidy are enormous, considering the vast and extensive use of coal as an alternative energy consumption mode. In other findings on subsidies of natural resources other than fuel, Lin and Kuang (2020) argued that regional differences contribute to China's industrial gas subsidy. Consumption and price mechanism are prominent factors influencing subsidy of industrial natural gas in China. In Latin America, Troncoso and Soares da Silva (2017) conducted an exploratory study on subsidy policies as a factor in reducing the use and attendant climate change implications of solid fuels. The authors found that subsidy to liquified petroleum gas influences transformation from solid fuel to clean fuels for cooking. Acheampong, Adams, and Boateng (2019) found evidence supporting inverse functional relationship among renewable energy, foreign direct investment, and carbon intensity in sub-Sharan Africa (SSA). Further findings revealed trade openness a linear and asymptotic relationship between trade openness and carbon intensity in SSA.

3.0 Materials and Methods

Data

This study relied on country-specific data for fuel subsidy and carbon intensity in Nigeria from 1980 through 2018. The choice of Nigeria is guided by the desire to limit attention to Africa most populous black nation and largest emitter of greenhouse gas in Africa (International Energy Agency (IEA), 2016) and by the availability of reliable data on aggregates of indices of fuel subsidy and carbon intensity in Nigeria.

Carbon intensity was measured with data on the carbon dioxide emission CO_2, as in Chaudhry, Ahmed, Shafiullah, and Huynh (2020); Nasir, Huynh, and Tram (2019); Eregha and Mesagan (2016); Nathaniel and Iheonu (2019). We introduced GDP per capita as used in the work ofNasir, Huynh, and Tram (2019); Xu and Lin (2018);Lin, and Xu (2018); Steenblik, Jones and Lang (2012) to capture the relative income distribution pattern in the country. The intuition is that as GDP per capita of the resident increases, their purchasing power increases and consumption activities mostly increase carbon emission-driven. Fuel subsidy was measured as the difference between the international market reference price and the end-user price as used in Lin and Ouyang (2014). On the one hand, at an end-user fossil fuel prices lower than the international market reference prices, fuel subsidy exists, and it is expected to influence the degree of uneconomical energy use that contributes to increased carbon emission. On the other hand, at the end-user price, which is equal to the international market reference price, there is no subsidy; thus, conscious use of resources that aid low carbon transition is expected. We also measured unobserved dimensions to fuel subsidy using energy used per capita as in Pineau (2007). The energy used per capita gives the household energy distribution pattern based on their per capita income level, which explains the need for subsidy for the household at the bottom of the per capita income distribution chart.POPrepresents population growth as a control variable indicating determinant of carbon emission other than the variables of interest as used in the work of Pham, Huynh, and Nasir (2020); Iheonu, Agbutun, Omenihu, Ihedimma and Osuagwu (2019). The magnitude by which fuel subsidy existence influences carbon emission is premeditated on the large and active population. Fuel subsidy in large populated countries will produce significant adverse effect on the environment compared to less populated economies with meagre carbon-induced economic needs. The variables of the study and their respective descriptions and sources are contained in Table 1.

Table 1: Description of Variables

Abbreviation	Description	Source	Motivating Study?
CO_2	Carbon Dioxide Emission	World Development Indicator, (WDI)	Chaudhry, Ahmed, Shafiullah, and Huynh (2020); Nasir, Huynh, and Tram (2019); Eregha and Mesagan (2016); Nathaniel and Iheonu (2019)
GDP	GDP per capita	World Development Indicator, (WDI)	Nasir, Huynh, and Tram (2019); Xu and Lin (2018);Lin, and Xu (2018); Steenblik, Jones and Lang (2012)
EC	Energy use per capita	International Energy Agency (IEA)	Lin and Ouyang (2014)
$FUEL_{SUB}$	Fuel Subsidy	International Energy Agency (IEA)	Pineau (2007)
POP	Population Growth Rate	World Development Indicator, (WDI)	Pham, Huynh, and Nasir (2020); Iheonu, Agbutun, Omenihu, Ihedimma and Osuagwu (2019)

Model

In accounting for carbon dioxide abatement as induced by fuel subsidy in Nigeria, this paper builds upon the IPAT model of Dietz and Rosa (1994)to explain the fuel subsidy-environmental quality relationship. Since the IPAT model of Dietz and Rosa (1994) lay significant emphasis on population, affluence and technology for the desired environment, we express the functional form of the model in equation (1):

$$i = P^{*}A^{*}T \quad \textbf{(1)}$$

Where$i$ is the environmental impact, P is the population size, A is per capita economic output (usually referred to as affluence), and T is the impact of per-unit activity (referred to as technology).

Dietz and Rosa (1994) in application and extension, estimated technology by taking ration of environmental impact vis a vis the product of population size and economic output. This notion can be expressed algebraically as:

$$T = i/(P^{*}A) \quad \textbf{(2)}$$

Considering the importance of the stochastic term in the model, Dietz (1994) reformulated the model in a stochastic form:

$$i = aP^{b}A^{c}T^{d}e \quad \textbf{(3)}$$

i, P, A and T remain environmental impact of population growth, per capita economic activity and impact per unit economic activity. For the model, b, c and d are the output elasticities, while a and e are residual terms.

In this study, we follow Dietz and Rosa (1994) argument of the modification of the IPAT model by incorporating economic variables measuring fossil fuel subsidies with associative control variables as factors that influence Nigeria's carbon intensity. The functional form of the model for this study is specified as:

$$CO_2 = (GDP, EC, FUEL_{SUB}, POP) \quad \textbf{(4)}$$

where CO_2 implies carbon emissions (k_t), a proxy for carbon intensity, $GDP$is gross domestic product (GDP) per capita, EC is energy use per capita, $FUEL_{SUB}$ is the prevailing government subsidy(the difference between the market reference price and the end-user price) and POP is the population growth rate as a control variable intervening in the model.

The empirical strategy estimates the baseline equation using the Non-Linear Auto-Regressive Distributed Lag (NARDL) approach to cointegration. We favoured the NARDL estimation procedure of Shin et al. (2014) because it possesses the ability to reveal hidden cointegration properties that conventional linear ARDL estimates may not reveal because of unobserved factors. The NARDL establishes the relevance of both positive and negatives shock effect on the response term. The dynamic relationship is specified as:

$$InCO_{2t} = \alpha + \varphi InGDP_t + \rho InEC_t + \theta InFUEL_{SUB_t} + \gamma InPOP_t + \varepsilon_t \quad \textbf{(5)}$$

Where all variables remain as earlier defined. ln gives the semi-derivative functions of the aggregates indices used as regressors in the environmental quality model, α gives the value of the explained variation when all the explanatory variables are zero; $\varphi, \rho, \theta$and γ are output elasticities of the carbon intensity model; ε_t is the idiosyncratic error component of the model.

Consistent with Shin, Yu and Greenwood-Nimmo (2014) and Pesaran, Shin and Smith (2001), we expressed Equ (5) in the NARDL framework that includes the convergence term;

$$InCO_{2t} = A + \sum_{t=39}^{z=1} \varphi InGDP_t + \sum_{t=39}^{z=1} \rho InEC_t + \sum_{t=39}^{z=1} \theta InFUEL_{SUB_t} + \sum_{t=39}^{z=1} \gamma InPOP_t + ECT_{-1} + \mu_{it} \quad \textbf{(6)}$$

Where all variables remain as earlier defined except, ECT_{-1} which gives the convergence term of the carbon intensity model.

Consequent on the above, we test the hypothesis that

H_0: Fuel subsidy does not statistically induce variations in carbon emission in Nigeria.

Causal Dynamics of Fuel Subsidy and Carbon Emission in Nigeria

The conventional bi-variate causality model specified below will be employed to examine the direction of causality between fuel subsidy and carbon intensity in Nigeria. In the spirit of Granger (1969), we regress the dependent variable "CO_2" on its own period lagged values and on the lagged values of explanatory variables of the carbon intensity model. We proceed to test the null hypothesis that the estimated coefficients of the period lagged values of "CO_2" are jointly zero. By standard Gaussian assumptions, failure to reject the null hypothesis of the independent causal relationship is assumed to be equivalent to failure to reject the hypothesis that the explanatory variables do not Granger cause "CO_2". By extension, the following regression gives the equation to be tested:

$$CO_{2_t} = \propto_o + \sum_{i=1}^{p_1} \beta_i CO_{2_{t-1}} + \sum_{j=1}^{p_2} \beta_j GDP_{t-j} + \sum_{k=1}^{p_3} \beta_k EC_{t-k} + \sum_{l=1}^{p_4} \beta_l FUEL_{SUB_{t-1}} + \sum_{m=1}^{p_5} \beta_m POP_{t-m} + \mu_t$$

To test the non-Granger causality from GDP, EC, OIL_P and POP to CO_2, we test the nullity of all coefficients, $\beta_i, \beta_j, \beta_{k,} \beta_l$ and β_m.

Empirical Strategy

In accounting for the dynamic interactions between fuel subsidy and carbon intensity in Nigeria, we reported descriptive statistics to show, describe and summarise the data in a way that is meaningful and also to know if the data are normally distributed through their averages and Jarque-Bera values (Gujarati & Porter, 2009). We proceed to estimate the unit root test to ascertain stationary of the variables. We relied on the Augmented Dickey-Fuller (ADF), Philip Perron Test and the KPSS Test confirmatory test for stationarity analysis. The time series unit root test is based on estimates of:

$$\Delta Y_t = \alpha_i + \eta y_{t-1} + \delta_t + \sum_{k=1}^{k_i} \theta_i^{(k)} \Delta y_{t-k} + \varepsilon_t$$

$$\varepsilon_t \sim idN(0, \theta_\varepsilon^2) = 1,2, \ldots \ldots .N, t = 1,2 \ldots \ldots T \quad \textbf{(7)}$$

Where $y_t$denotes the y variable observed for the *N* entities in the *T* periods, and $\Delta$is the difference operator. The unit root test involves the null hypothesis $H_0 : \rho_i = 0 \; \forall i$against the alternative $H_A : \rho_i = \rho < 0 \; \forall i$.

For robustness and heteroskedasticity consistency, we estimated the Kwiatkowski, Phillips, Schmidt, and Shin (1992) (KPSS) test reconfirmation test for stationarity due to its richness in time series data stationarity confirmation. The KPSS unit root test reports a null hypothesis of no unit root in any of the series estimated. Given the residuals obtainable from the individual ordinary least square (OLS) regressions of a constant, or on a constant and a trend, the KPSS unit root test requires only the specification of the form of the OLS regressions: whether to include only individual-specific constant terms, or whether to include both constant and trend terms. In particular, the KPSS appears to over-reject the null of stationarity and may yield results that directly contradict those obtained using alternative test statistics (see Hasan and Koenker (1997); Said and Dickey (1984) for discussion and details).

We then proceed to estimate the non-linear Autoregressive distributed lag (NARDL) estimation procedure to account for the asymmetric relationship. The NARDL, as in Shin *et al.* (2014)determines the nonlinearity, simultaneously analyses the short-run and long-run asymmetries among the impulses.The NARDL produce valid results irrespective of whether the variables are integrated at the order I(0), I(1) or I(0)/I(1). The NARDL methodology ascertains hidden cointegration among impulses often escaped by the linear models. The jargon of hidden cointegration was promulgated by Granger (2002), which entails that in linear settings, cointegration may be absent between two-time series; whereas, in a non-linear setting, cointegration can be deciphered between their positive and negative components (Katrakilidis & Trachanas, 2012). The NARDL methodology is superior to smooth transition ECM and Markov-switching ECM as it jointly estimates cointegration and asymmetries. This approach also produces valid results for data with large samples size (Granger, 2002; Katrakilidis and Trachanas (2012)Rahman and Ahmad (2019). The asymmetries in carbon intensity highlighted by studies utilising NARDL include Abdlaziz, Rahim and Adamu (2016); Hoang, Lahiani and Heller (2016); Ibrahim (2015); Meo, Chowdhury, Shaikh, Ali and Masood Sheikh (2018). We estimate the Granger Causality Test ofGranger's (1969) to account for the causal relationship among the variables of interest.

4.0 Results

Descriptive Statistics

The result of the descriptive statistics can be seen in Table 2 below. The results indicate that the mean and the median values of all the variables fall within their minimum and maximum values. This implies that all the variables, i.e. carbon emission, energy consumption, gross domestic product, oil price and population growth; indicate a high tendency of the normal distribution. All the variables are positively skewed, which implies that that the distribution has a long right tail. The kurtosis statistics showed that all the variables were platykurtic, suggesting that their distributions were flat relative to a normal distribution as the values are less than three (3). The Jarque-Bera statistics shows that the series is normally distributed since the p-values of all the series are not statistically significant at 5% level. Thus, informing the acceptance of the alternate hypothesis that says each variable is normally distributed.

Table 2: Descriptive Statistics

	CO_2	EC	GDP	$FUEL_{SUB}$	POP
Mean	4.83	2.86	4.31	0.85	7.79
Median	4.85	2.85	4.41	1.30	7.79
Maximum	5.03	2.90	5.74	2.16	7.99
Minimum	4.55	2.82	2.84	-0.82	7.59
Skewness	0.16	0.02	1.02	1.06	0.12
Kurtosis	2.61	1.34	2.72	1.87	2.52
Jarque-Bera	3.84	2.99	2.96	4.48	2.39
Probability	0.15	0.22	0.23	0.11	0.30

Source: Author, 2020
Note: Descriptive statistics were taken before the variables were transformed into logarithm forms. The Jarque-Bera test whether a given series follow a normal distribution or not. It tests the null hypothesis that a given series is normally distributed.

Test of Multicollinearity

In order to test for multicollinearity among the independent variables (carbon emission, energy used per capita, GDP, fuel subsidy, and population growth), the correlation matrix is calculated. The correlation matrix was reported in Table 3. It is evidenced from this analysis that no correlation exists between the variables making results emanating from the study largely reliable.

Table 3: Correlation Matrix

	CO_2	EC	GDP	$FUEL_{SUB}$	POP
CO_2	1				
EC	-0.0058	1			
GDP	0.0737	0.0498	1		
$FUEL_{SUB}$	0.6029	-0.0075	0.1065	1	
POP	-0.0091	0.0219	0.4366	-0.0156	1

Source: Author, 2020

The result of the correlation matrix in Table 3 shows that the correlation coefficients among the variables are negatively correlated. Since the correlation between the variables is less than 0.95, hence, there is no tendency for multicollinearity among such variables (Baltagi, Bun, & Sarafidis (2015); Wooldridge, 2007). Explicitly, energy used per capita is negatively correlated with carbon dioxide emission (-0.0058). GDP per capita is positively correlated with carbon dioxide emission (0.0737), and energy used capita (0.0498). Fuel subsidy is positively correlated with carbon dioxide emission (0.6029), negatively with the energy used capita (-0.0075) and positively GDP capita (0.1065). Population growth is negatively correlated with carbon dioxide emission (-0.0091), positively with energy used capita (0.0219), positively with GDP capita (0.4366) and negatively with Fuel subsidy (-0.0156).

Unit Root Test

The outcomes of the ADF, PP, and the KPSS confirmatory test are shown in Table 4.

Table 4: Unit Root Test

Variables	@LEVEL			@FIRST DIFFERENCE			ORDER OF INTEGRATION
	ADF	**PP**	**KPSS**	**ADF**	**PP**	**KPSS**	
	Intercept {Trend & Intercept}	**Intercept {Trend & Intercept}**	**Intercept {Trend & Intercept}**	**Intercept {Trend & Intercept}**	**Intercept {Trend & Intercept}**	**Intercept {Trend & Intercept}**	
CO_2	0.4323 {0.5727}	0.6823 {0.8839}	0.6673 {0.8822}	0.7722* {0.2828}**	0.5266* {0.7838}*	0.7783* {0.8929}*	I(1)
EC	-1.6232 {0.8822}	-1.6883 {0.8892}	-1.6723 {0.4323}	-1.7828* {0.8266}*	-1.9939* {0.9393}*	-1.7883* {0.6728}*	I(0)
GDP	-1.9923 {0.7919}	-1.5627 {0.7893}	-1.7389 {0.7892}	-1.7828* {0.8992}*	-1.8288* {0.6883}*	-1.7734* {0.7883}*	I(1)
$FUEL_{SUB}$	0.8828 {0.6232}	0.6282 {0.9893}	0.6372 {3.7722}	0.6627* {0.6727}*	0.8838* {0.6838}*	0.7838* {0.7883}*	I(1)
POP	-1.8837 {0.7828}	-1.6839 {0.0023}	-1.6728 {0.5627}	-1.7288* {0.7782}*	-1.7838* {0.8893}*	-1.7888* {0.9939}*	I(1)

Source: Author, 2020

T-Stat values of intercept estimates are reported in the text box while T-Stat values of trend & intercept estimates are in the parentheses; $* P < 0.01$, $** P < 0.05$ respectively

All tests confirmed that variables are non-stationary at levels but are stationary at first difference except energy used per capita, which was stationary at level. These empirical outcomes did uncover not only the non-stationary properties of all the variables but also established the covariance nature of the data set under investigation. We proceed to estimate the non-linear ARDL to establish the asymmetric relationship between the variables of interest. This is indispensable in this research because the estimation strategy's choice is consistent with the data behaviour and in consonance with contemporary NARDL-centric literature (see Kisswani, 2017; Mathur & Shekhawat, 2018; Pal & Mitra, 2016; Sharma & Kautish, 2019 for some examples).

Lag Selection Criteria

The issue of finding the appropriate lag length for each of the underlying variables in the ARDL model is fundamental because we seek Gaussian error terms. For optimal lag length selection, we rely on the Schwartz information criteria to obtain the lag length value that minimizes the Information Criterion (in our own case, the Schwartz Criteria (SC)) and at which the model does not have autocorrelation is the optimal lag length in Table 5.

Table 5: Lag Length Selection

Lag Length	**SC**
1	1.452*
2	2.663
3	3.877

Source: Author, 2020

NOTE: $* \; P < 0.01$, $** \; P < 0.05$ respectively

Based on the result in table 5, the lag length, which minimizes SC, is lag one and thus our optimal lag length. Given our optimal lag length, we proceed to test for the long-run relationship between the variables.

Bounds Test

To investigate the presence of long-run relationships among the variables, the bound testing under Pesaran *et al.* (2001) procedure is used. We rely on the F-test to examine the assumptions of no cointegration among the variables against the premise of its existence, denoted as:

$H_0: \beta_1 = \beta_2 = \beta_3 = \beta_4 = \beta_5 = \beta_6 = 0$, i.e., there is no cointegration among the variables.

$H_1: \beta_1 \neq \beta_2 \neq \beta_3 \neq \beta_4 \neq \beta_5 \neq \beta_6 \neq 0$, i.e., there is cointegration among the variables.

Table 6: Bound Test Result

F-Statistics	1%		5%		10%	
5.463	Lower bound	Upper bound	Lower bound	Upper bound	Lower bound	Upper bound
	3.41	4.68	2.62	3.79	2.26	3.35

Source: Author, 2020

NOTE: $* \ P < 0.01$, $** \ P < 0.05$ respectively

Given the Bound Test result in Table 6, the F-statistic value should be compared with the Pesaran critical value at traditional levels of significance. It is noted by Narayan (2005), the current critical values reported in Pesaran *et al.* (2001) cannot be used for small sample sizes because they are predicated on the premise of the existence of large sample sizes. Narayan (2005) provided a set of critical values for sample sizes ranging from 30 to 80 observations. They are $2.496 - 3.346$ at a 10% level of significance, $2.962 - 3.910$ at a 5% level of significance, and $4.068 - 5.250$ at a 1% level of significance. Since the F-statistic 5.463445, is lower than the lower bound critical value, we thus reject the null hypothesis and conclude that all the variables in the model have co-movements in the long-run in Nigeria. From the result, we can hence estimate the long-run relationship between carbon intensity and the explanatory variables.

Table 7: NARDL Long-Run Estimates

Dependent variable: CO_2

Variable	Coefficient	t-statistics	Probability
EC	0.137	-0.819	0.021**
GDP	1.044	4.608	0.000*
$FUEL_{SUB}$	-0.187	-0.623	0.039**
POP	0.055	0.414	0.023
C	2.952	0.877	0.000
R-squared	0.656	**Durbin Watson Stat**	1.914
Adjusted R-Square	0.875	**F-statistic(Prob)**	75.906

	(0.000*)

Source: Author, 2020

NOTE: $* \ P < 0.01$, $** \ P < 0.05$ respectively

The Adjusted R-Square in Table 7 shows that the model's explanatory variables explain 87.5% variation in the dependent variable (environmental quality) in the long-run, while the remaining 12.5% was determined outside the model. The F-statistic (75.906) was statistically significant at 1% level, indicating that the model was significant. The Durbin-Watson statistic (1.914) shows that the model had no serial correlation problem because it was within the acceptance range of 1.5-2.5 (see Dufour & Dagenais, 1985; Durbin, 1960).

The results indicate that in the long-run, energy used per capita is positive and statistically significant at 5%. This implies that a percentage increase in energy used per capita will induce a 0.137 per cent increase in Nigeria's carbon dioxide emission. This results reaffirm greater energy consumption and increase carbon emission relations as observed in the work of Cheng and Yao (2021); Adekunle (2020). Also, GDP per capita is positive and statistically significant at 1%. This implies that a percentage increase in GDP per capita will induce a 1.044 per cent increase in carbon dioxide emission in Nigeria. As residents GDP per capita (measure welfare and income redistribution) increases, more energy consumption that compounds carbon emission is observed. This explains the positive relationship between these key macroeconomic indices in consonance with the observations of Akalpler and Hove (2019) in their study in India. Also, the fuel subsidy is negatively and statistically significant at 5%. This implies that a percentage increase in the difference between the international market reference price and the end-users price will induce a 0.187 per cent decrease in carbon dioxide emission in Nigeria. This key finding is the thrust of this study, and this result could be due to consumers relatively less fossil-fuel consumption cost that place them at on a better footing and permits higher consumption. The marginal cost of purchasing the fuel when a subsidy is in place is lesser than the marginal social benefits to the consumers. This essential finding could justify the need to phase out subsidy, just like President Muhammed Buhari's present administration has done. This will permit an easy transition to a low carbon economy when combustible fossil fuel consumption reduces due to par between the end-users price and the international oil market reference price. This essential finings aligns with the findings of Wesseh, Lin, and Atsagli (2016) in their environmental and welfare assessment of fossil fuel removal in Ghana; Li and Sun (2018) in their low carbon economy and fossil fuel removal in China; Dartanto (2013) in their fuel subsidy reduction and its implications for fiscal balance and poverty in Indonesia. Also, population growth is positive and statistically significant, at 5%. This implies that a percentage increase in population growth will induce a 0.055 per cent increase in carbon dioxide emission in Nigeria. Although less understood and less explored, population growth exerts a more significant influence of carbon emission in a country or region. In the submission of Pham et al. (2020), population and urbanisation were reported to have a short term positive influence and long term negative influence on environmental degradation in twenty-eight (28) European countries.

Table 8: NARDL Short-Run Estimates

Dependent variable: CO_2

Variable	Coefficient	t-statistics	Probability
EC	0.103	0.797	0.034**
GDP	0.785	5.314	0.000*
$FUEL_{SUB}$	-0.141	-0.637	0.035**
POP	-0.041	-0.413	0.023**
CointEq(-1)	-0.752	-6.699	0.000*
R-squared	0.832	**Durbin Watson Stat**	1.893
Adjusted R-Square	0.892	**F-statistic(Prob)**	53.552 (0.000*)

Source: Author, 2020

NOTE: $* P < 0.01$, $** P < 0.05$ respectively

The co-integrating term CointEq(-1) coefficient in Table 8, which gives the error correction term, was also found to be negative and significant at 1%. The error correction term, which denotes the speed of adjustment towards long-run equilibrium is 75.20 per cent. This explains that the whole system can achieve short-run equilibrium at a speed of 75.2%. The Adjusted R-Square shows that the model's explanatory variables explain 89.2% variation in the dependent variable (environmental quality) in the short-run, while the remaining 10.8% was determined outside the model. The value of the F-statistic (53.552) was statistically significant at 1% level, indicating that the model was significant. The value of the Durbin-Watson statistic (1.893) shows that the model had no serial correlation problem because it was within the acceptance range of 1.5-2.5 (see Dufour & Dagenais, 1985; Durbin, 1960).

The results indicate that in the short -run, energy used per capita is and GDP per capita is positive and statistically significant at 5% and 1% respectively. This implies that a percentage increase in energy used per capita and GDP per capita will induce a 0.103 and 0.785 per cent increase in carbon dioxide emission in Nigeria. These short-run positive relations in the energy use, GDP per capita and carbon emission relations could be due to the size of the Nigeria economy compared to other African countries. Nigeria has the largest population in Africa and also the largest exporter of crude, which fetches her a sizeable return on oil sales that boost GDP per capita. This affluence in terms of population and income places the country energy consumption on a growth path that is synonymous to high emitting countries, although less than the highly industrialized nation. This result is similar to those found in the work of Akalpler and Hove (2019). Also, fuel subsidy and population growth are negatively and statistically significant at 5% respectively. This implies that a percentage increase in fuel subsidy and population growth will induce a 0.141 and 0.041 per cent decrease in carbon dioxide emission in Nigeria. This short-run negative fuel subsidy and carbon emission can be explained by the energy reforms surrounding the subsidy extension's implementations and the social benefits to the consumers. The population seems irrelevant in the carbon intensity debate in the short-run. This may also be due to early-stage assessment of the influence of population and urbanization on CO_2, which may be misleading. As time goes on, pollution from the large population will compound to obvious and readily noticeable disturbances.

Table 9: Serial Correlation Test

Breusch-Godfrey Serial Correlation LM Test:			
F-statistic	0.846	Prob. F(3,25)	0.443
Obs*R-squared	2.237	Prob. Chi-Square(3)	0.327

Source: Author, 2020

NOTE: $* \ P < 0.01, ** \ P < 0.05$ respectively

Given the probability value of 32.68 percent, we fail to reject the null hypothesis and conclude that our model is free from serial correlation inTable 9.

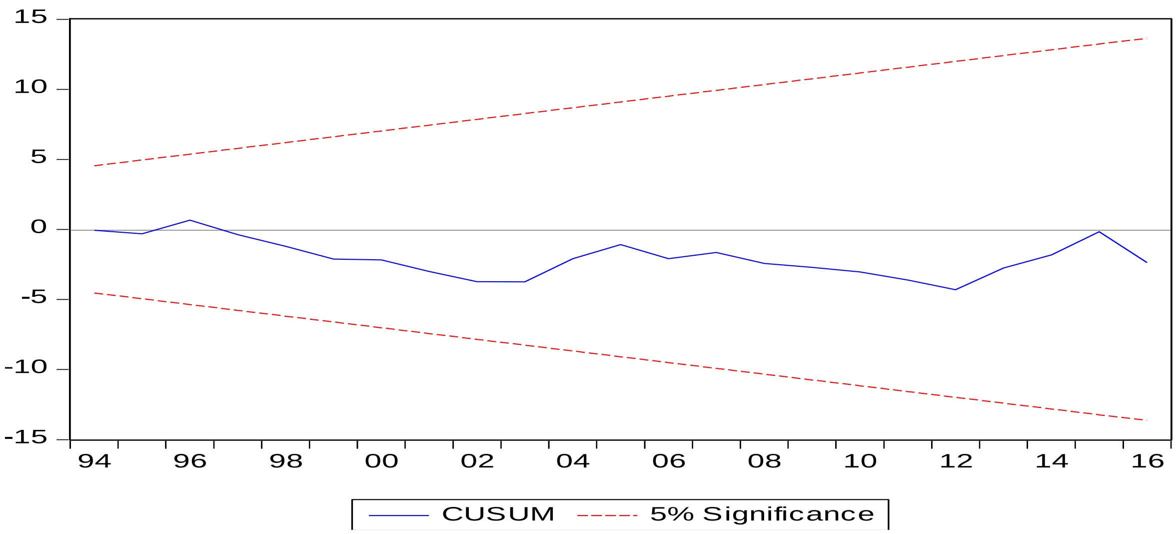

Fig. 1*: CUSUM Stability Test*

Source: Author, 2020

Figure 1 shows that the CUSUM line is within the critical bounds of 5 per cent of significance, indicating that the model has structural stability.

Granger Causality Estimates

The pairwise Granger Causality test results are given in Table 10.

Table 10: Granger Causality Results

Null hypothesis: X does not Granger Cause Y	F-Statistics	Probability
$CO_{2_t} \rightarrow GDP_t$	1.8339	0.1760
$GDP_t \rightarrow CO_{2_t}$	0.2475	0.0190**
$CO_{2_t} \rightarrow EC_t$	5.7459	0.4170
$EC_t \rightarrow CO_{2_t}$	0.7742	0.133
$CO_{2_t} \rightarrow FUEL_{SUB}$	3.8083	0.0510
$FUEL_{SUB} \rightarrow CO_{2_t}$	13.6670	0.001*
$CO_{2_t} \rightarrow POP_t$	0.1476	0.7010
$POP_t \rightarrow CO_{2_t}$	4.3221	0.038*

Source: Author, 2020

NOTE:$*\ P < 0.01$, $**\ P < 0.05$ respectively

Table 10 indicated that there is unidirectional causality from GDP per capita to carbon emission in Nigeria. Hence, GDP per capita granger causes carbon emission in Nigeria. Also, unidirectional causality from fuel subsidy to carbon emission in Nigeria. Therefore, fuel subsidy granger causes carbon emission in Nigeria. It is reported in other findings that there exists a unidirectional causality from population growth to carbon emission in Nigeria. Hence, population growth granger causes carbon emission in Nigeria.

5.0 Conclusions, Policy and Suggestion for Further Research

The large and active body of research on carbon dioxide abatement in Nigeria has been discussed along various dimensions, but the implications of fuel subsidy for carbon emissions' growth trajectory remain grossly understudied. Since fuel subsidy has been abolished in Nigeria, carbon intensity has not reduced. This reality contradicts the predicted inverse relationship between fuel subsidy removal and carbon emission growth. In this study, an attempt was made to assign empirical weights to the fuel subsidy-carbon intensity relationship to reach conclusions capable of redefining policy and research on the subject. We modelled the fuel subsidy-carbon intensity relationship and found evidence for causal dynamics among the variables of interest. Data were obtained from the World Bank and International Energy Agency statistical databases of various issues up till 2018. We employed the non-linear autoregressive distributed lag estimation procedure and found fuel subsidy removal halt growth of carbon emission in the long-run. The long-run results were similar to Akinyemi et al. (2015) findings in Ghana. Short-run estimates also revealed that fuel subsidy removal inversely relates to carbon emission in Nigeria. The short-run results are in tandems with the separate findings of Galinato and Yoder (2010); Shobande and Shodipe (2019); Siddig *et al.*(2014). The Granger causality result provides evidence of unidirectional causality from energy use per capita, fuel subsidy changes, and population growth to carbon emission. These findings align with the submission of van der Ploeg (2013).

Based on this study's findings, we recommend complementary policy option that ensures additional financial savings to the government should be invested in public sector growth that can cushion the effect of relative income loss to the citizenry. The Nigerian government should ensure measures are kept in place to discourage over-consumption of alternative energy (for example, coal) that could also threaten the green economy paradox. Further research on the fuel subsidy-carbon emission relation across oil-producing African nations can produce new and insightful evidence that could propel a joint African Union policy on social benefits, household energy use within an environmentally-friendly framework.

DECLARATION

Availability of Data and Material

"The dataset(s) supporting the conclusions of this article is available in the World BankDatabase and Internation Energy Agency (IEA) of various issue up to 2018(World Bank, 2018).https://data.worldbank.org/

https://www.iea.org/data-and-statistics?country=WORLD&fuel=Energy%20supply&indicator=Total%20primary%20energy%20supply%20(TPES)%20by%20source

Competing interests

The Authors has no competing interest

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Authors' Contributions

All the authors came up with a draft of their different perspective of what the introduction should look like and then I.A. merge the ideas into one single introduction showing the motivations of the study. I.A. also came up with the design and collated data from appropriate sources and developed the theoretical framework and model specifications with the attendant's *prior* expectation. I.O. developed the literature review and revised the entire manuscript after the preliminary draft with particular reference to the guidelines documented in authors guide on the Journal website, analysed the collated data and gave the corresponding interpretations while discussing the findings in the context of relevant literature.

Ethical Approval

This manuscript has not been published in whole or elsewhere; the manuscript is not currently being considered for publication in another journal. All authors have been personally and actively involved in substantive work leading to the manuscript and will hold themselves jointly and individually responsible for its content.

Consent to Participate

Materials, methods leading to the findings from the study does not require seeking third party approval from any group or individual (as the case may be)

Consent to Publish

Materials, methods leading to the findings from the study does not require seeking third party approval from any group or individual (as the case may be)

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