**Premium Motor Spirit Consumption and Environmental Sustainability in Nigeria**

**Abstract**

Human activities globally have resulted in environmental degradation, which poses a threat to resource sustainability for the benefit of future generations. Intergovernmental and private organizations have championed the concept of environmental sustainability as a strategy to preserve the environment for intergenerational use. This research employed Linear and Non-linear Autoregressive Distributed Lag or Bounds Test to Co-integration model, incorporating disaggregated energy consumption sources – petroleum motor spirit and hydroelectricity – along with population growth, to investigate the progress of environmental sustainability efforts in Nigeria. The paper analyzed a time series data for Nigeria ranging from 1982 to 2022. The findings indicate that PMS consumption and population growth consumption patterns constitute a significant threat to environmental sustainability in Nigeria, both in the long and short term, whereas hydroelectricity consumption enhances environmental sustainability. It also reveals that the coefficients the decomposed are not statistically significant at 5% threshold. Policy developers are advised to regularly review and update comprehensive programs that promote the widespread adoption and utilization of renewable energy consumption as a dominant component in the energy mix.

**Key words: Premium Motor Spirit, Environmental sustainability, population growth rate and hydroelectricity**

1. **Introduction**

The concept of environmental sustainability has become a preoccupation of global leaders and members of the academic community, and this is fueled by the growing concern caused by greenhouse gas emissions. The outcomes of several research have revealed that nations are currently experiencing the negative impact of environmental pollution resulting from anthropogenic activities - energy consumption (Yahaya et. al., 2023), Population growth (Kelly et.al., 2024), and economic growth (Omodero and Uwalomwa, 2021) inclusive. Nigeria, for instance, is already grappling with the consequences of climate change, including desertification, flooding, and coastal erosion. The 2012 Niger Delta floods, linked to climate change, caused widespread destruction to house, farmland, crops, and property, as well as loss of lives (Hassan et al., 2020). Furthermore, in 2014, a windstorm in the southwest region of Nigeria was reported to have demolished approximately 5,000 houses across four states, according to the National Emergency Management Agency.

These unintended negative environmental impacts have prompted Nigerian government to participate in global collaborative fora focusing on mitigating the devastating human and environmental consequences of rising global greenhouse gas emissions- Paris Agreement, United nations Conference of Parties (COP), Intergovernmental Panel on Climate Change (IPCC), Tokyo Protocol. Consequently, Nigerian government has domesticated international agreements, enacted domestic legislation, implemented policies, and introduced stricter regulations to realize this goal. Unfortunately, Nigeria continues to grapple with significant obstacles in the production and distribution of energy to power its economic and growth agenda. This energy scarcity has compelled the ambitious population to resort to poor-quality energy sources to power their daily economic activities, leading to negative environmental consequences such as land degradation and climate change (Nwozor et al., 2019). Additionally, the development and enforcement of environmental regulations require huge financial burden on individuals, legal entities and government (Kalagbor et al., 2022).

The substantial portion of Nigeria's economy that operates within the informal sector often relies on small-scale transportation modes, such as motorcycles and tricycles, which primarily utilize PMS (Aliyu et al., 2020). Involvement in myriad economic activities increase the income levels of the upsurging population causing speedy rise in vehicle ownership and corresponding increase in PMS consumption. Consumers are primarily interested in the services that energy enables, such as refrigeration, hot water, air conditioning, and powering machines and computers. Energy consumption is the main factor in the operating costs of most devices (Das et al., 2022). Many Nigerians are using old and less efficient appliances and vehicles which constitute continuous increase in PMS consumption ( Nsoke et al., 2021). The heavy dependence on PMS consumption has since become a major source of concern despite the environmental sustainability effort as it greatly impacts the environment in areas such as air pollution and environmental degradation.

Nigeria’s rapidly growing population, faces the dual challenge of meeting its increasing energy needs while protecting its environment. This speedy increasing demographic trend has impact on the consumption of premium motor spirit and other form of energy. Despite being endowed with abundant energy resources, the nation has been struggling with energy poverty in its pursuit of individual and national economic goals. The populace and the need to commute across locations cause a high demand for transportation which increase the number of vehicles nationwide. This, in turn, exacerbates traffic congestion, causing idling vehicles that further drive-up PMS demand. Furthermore, a larger population corresponds with heightened demand for goods and services, requiring more freight transportation that heavily relies on PMS-powered trucks, further contributing to overall PMS consumption (Pooladsanj et al., 2023).

The contemporary sustainable development agenda underscores the importance of improving the liveability, intelligence, resilience, health, and sustainability of the environment and incorporating green technologies into industrial operations could reduce greenhouse gas emissions (Rahimifard & Trollman, 2018). This trend is evident in certain highly industrialized nations, where the environmental consequences of industrialization are believed to be ameliorated by the increasing adoption of green technologies (Luken & Castellanos‐Silveria, 2009). This assertion is corroborated by Bala et. el., (2021) stating how application of renewable energy has proven to improve the environment.

Despite the usefulness of clean energy in realizing the environmental sustainability agenda, Nigeria continues to use fossil fuel as source of energy and srevenue to power and finance the economy. A recent empirical investigation in Sub-Saharan Africa indicates that rising crude oil prices negatively impact the environment (Olayungbo & Umechukwu, 2022). This is attributed to the fact that spikes in crude oil prices incentivize the production and exportation of fossil fuels, which may subsequently experience price declines, ultimately leading to increased consumption (Ojide et. al., 2022). As a result, heightened fossil fuel consumption exacerbates greenhouse gas emissions, thus undermining environmental sustainability.

This study investigates the impacts of renewable and non-renewable energy consumption on environmental quality, accounting for variations in population growth in Nigeria. The study has two main objectives: to assess the effects of renewable energy consumption on environmental sustainability efforts in Nigeria, and to explore the role of population within this context.

This study offers several significant contributions deviating from previous research that examined the environmental impacts of either aggregated energy consumption or renewable energy use in isolation. This work fills an important knowledge gap by holistically analysing the effects of both premium motor spirit (PMS) consumption and the environment-enhancing role of renewable energy consumption on environmental sustainability, while also underscoring disparities associated with population dynamics in Nigeria.

**Research Hypotheses**

The study objective is to analyse the complex interplay between PMS consumption and environmental sustainability in Nigeria. To achieve this, the following hypotheses will be tested:

1. **H1:** There is a positive and significant relationship between PMS consumption and CO2 emissions in Nigeria.
2. **H2:** Renewable energy consumption has negative and significant impact on environmental sustainability in Nigeria.
3. **H3:** Population growth has positive and significant impact on PMS consumption in Nigeria.
4. **H4:** There is an asymmetric relationship between the decomposed independent variables and dependent variables as unit of consumption changes.
5. **Review of Literature**

The Environmental Kuznets Curve analysis originates from the inverted U-shape curve developed by Kuznets in 1955. This was initially meant to analyse the correlation between per capital income and income inequality but consequently gain prominence when it was applied in the analysis of environmental issues (Zhi et al., 2023). The theory was subsequently applied in testing the hypothesis on the impact of economic growth on the environment as noted by Panayotou (Şentürk et al., 2020). The EKC is typically shown in stages as shown below:



Figure 1: Environmental Kuznets Curve

The outcome of research carried out by economist Simon Kuznets in the 1950s and 1960s set the premise for understanding the linkage between economic growth and environment. They clarify that as a country develops, the environment initially records high level of degradation to a threshold, thereafter, the pollution starts to decline (Zhi et al., 2023).

The three stages of Environmental Kuznets Curve Analysis comprise of the pre-industrial economy which is characterized by abundant natural resources but less waste. The second stage is the industrial economy marks by diminishing natural resources increasing pollution and reducing ecosystem regeneration, ineffective environmental regulations and insufficient conservation financing. And the post-industrial economy is characterized by advancement in technology, provision of industrial services, effective compliance with environmental regulations resulting to an improved environmental condition (Zhang et al., 2022). The post-industrial economic stage demonstrates the institutionalization of rising income levels, high capacity to reduce pollution via the utilization of awareness strategy causing the adoption of cleaner technology that guarantees an environment with good condition.

The application of the theory is not generic for all nations. The outcome of a study carried out by Ficko & Bončina (2018) revealed that CO2 emission have increased and later fall in advanced nations like Japan and United States which is linked to the dynamism of market and economic structure such as income distribution, urbanization, infrastructure rather than sacrifices for environmental preservation. Considering the nature of fluctuating pollution of traditional pollutants such as sulphur, the theory does not apply to greenhouse gas emissions (Pham et al., 2020).

Criticisms of Environmental Kuznets Curve (EKC)

Environmental Kuznets Curve lacks global applicability, as there may not be a genuine overall decrease in pollution worldwide (Carson, 2009). Affluent nations often outsource highly polluting industries, such as clothing and furniture manufacturing, to less developed countries still undergoing industrialization (Wang et al., 2014). This implies that as underdeveloped countries progress, they may face a lack of suitable destinations to offload their environmental contaminants. The effort to clean the environment while growing the economy cannot continue indefinitely, as there may not be enough places to dispose of waste and polluting activities (Ogunbiyi et al., 2020). Grossman and Krueger, who provided the first clear evidence that economic growth is accompanied by improved environmental quality, referred to the Kuznets curve, noting the lack of "empirical support for the notion that environmental quality consistently declines as the economy expands."

The discharge of carbon emissions contradicts the EKC because most pollutants, such as lead and sulphur, are location-specific in their impacts, leading to greater incentive and faster action regarding those specific types of pollution (Stern, 2014). This may work for a nation improving, where the small benefit of removing these pollutants directly improves people's lives, but significant effects do not stem from reducing carbon dioxide emissions in a local area. This is a tragedy of the commons, where the best strategy is for everyone to pollute and no one to clean up, resulting in the worst outcome for all participants (Rashid, 2024).

Scholars disagree on the long-term shape of the curve stating that as the "inverse U" as a more "N" shape, where pollution increases with growth, declines after a GDP threshold is reached, and then increases again as national wealth rises further (Bertinelli et al., 2011). Although disputed, these findings highlight the question of whether pollution actually declines steadily as a nation's wealth reaches a certain level, or if it merely shifts to poorer developing countries. Levinson concludes that the environmental Kuznets curve alone is an insufficient basis for either a no-action or government-action pollution policy.

**Energy Consumption and Environment**

Omodero and Uwalomwa (2021) employed multiple regression analysis to examine the impact of energy consumption and carbon dioxide emissions on Nigeria's economic growth from 2008 to 2019. CO2 emissions were positively and significantly associated with energy consumption resulting from economic expansion, suggesting that Nigeria's economy is growing amidst high energy consumption and levels of environmental pollution. Yahaya et. al. (2023) reiterate how environmental degradation has increased alongside human production and consumption activities in Nigeria as a result energy consumption. Similarly, Achuo et al. (2022) investigated the impact of energy use on environmental degradation, focusing on greenhouse gas emissions and the contribution of natural resources. Using panel data from 173 countries between 1996 and 2020, they employed robust methods and fixed-effect regression models with the Driscoll-Kraay approach. Their key findings suggest that the emissions causing the greenhouse effect were from non-renewable sources.

A related study by Benard et al (2018) examined the impact of energy use and CO2 emissions on Nigeria's economic growth using an ARDL approach. The study found that energy use and carbon emissions were significant determinants of Nigeria's economic growth in the short run. Similarly, Ibrahim and Cudjoe (2020) employed the Vector Error Correction Model to examine the environmental effects of energy use in Nigeria from 1990 to 2018. Their results show a strong and persistent relationship between Gross Domestic Product and carbon dioxide emissions in Nigeria. Additionally, they found that charcoal consumption has a continued trend to reduce CO2 emissions, while fuel wood consumption may have a long-run positive impact on CO2 emissions. The researchers also established that the use of gas oil impairs CO2 emissions, while the use of natural gas and fuel oil has a deterring.

In a study conducted by Schneider (2021), the author investigated the interconnections among population growth, energy needs, and environmental sustainability in Africa. The researchers selected Nigeria as a representative case and established a comprehensive framework encompassing factors such as total population, energy consumption, per capita income, and the annual CO2 emissions from the power and heating sectors. The study analyzed data from 1971 to 2018, covering a significant time period. The empirical findings indicate a one-way Granger causality running from population to power use, income per capita, and CO2 emissions. Similarly, Lawal and Abubakar (2019) examines the effect of population growth on CO2 emissions in Nigeria Using time series data from 1975 to 2016 and found that population and technology are positively correlate with CO2 emissions, while affluence is negatively associated. The findings of Kelly et.al. (2024) have consistently demonstrated that increases in population have a significant impact on the environment.

Bala et. el. (2021) examines the Nigerian renewable energy regulatory system and qualitatively analysed using the doctrinal method, while empirical analysis relied on World Bank data from 2002 to 2021. The findings indicate that Renewable Energy Consumption significantly influences environmental sustainability. Gershon & Emekalam (2021) estimates the key determinants of renewable energy utilization in Nigeria over a twenty-four-year period using the Toda-Yamamoto method. The findings indicate that the desire to reduce pollution drives the adoption of renewable energy consumption in Nigeria. This source of clean energy had a negative impact on GDP from 1990-2007 due to inefficient technologies, but a positive impact from 2009-2015 as more affordable and efficient renewables were used (Ezanwa et. al., 2021). exploring wind or solar energy sources as potential substitutes, given Nigeria's ample renewable energy resources and harnessing these alternative energy sources could help reduce CO2 emissions while also supporting long-term economic growth (Gambo, et. al., 2018)

In a clear deviation from previous research that explored the impact of aggregated energy consumption on environmental degradation, without isolating the joint impact of PMS and renewable consumption, this study seeks to investigate the combined influence of renewable and non-renewable energy usage on environmental sustainability projects in Nigeria. This research is designed to use a single system to address the research gaps by investigating the unique impact of Premium Motor Spirit (PMS) and renewable energy consumption on environmental sustainability agenda in Nigeria, given the country's rapid population growth and increasing dependence on PMS consumption for micro and macro-economic growth.

1. **Methodology**

This study utilizes the Autoregressive Distributed Lag approach to Cointegration due to its comparative advantages over alternative methods. The model specification begins with the traditional production theory framework. The subsequent equation models CO2 emissions as the dependent variable, with its fluctuating values determined by energy consumption, population growth, and economic expansion.

…………………………………………………………(1)

Where:

Ct represents CO2 emissions per capita,

PMSt represents Premium Motor Spirit consumption per capita as economic improves,

Pt represents Population Growth

Therefore, C02 emission function can be written as:

……………………………………..(2)

The theoretical framework of this study is based on the Environmental Kuznets Curve hypothesis, which posits a non-linear relationship between economic growth and environmental degradation. Specifically, a quadratic function can be used to model the link between economic expansion and carbon dioxide emissions. Furthermore, the long-term relationships between CO2 emissions, petroleum, motor spirit consumption, and population growth are considered in the baseline logarithmic estimation model:

Where:

C02 represents per capita CO2 emissions,

Stands for Premium Motor Spirit consumption per capita

POP represents population growth

REC represents Renewable energy Consumption

 is the error term

From equation (3), is expected to be positive and negative sign is expected for  . Since population expansion increases PMS usage which in turn cause increase in CO2 emissions, and are strongly anticipated to be positive.

This study has three independent variables. These variables are: Premium Motor Spirit Consumption and Population Growth and hydroelectricity consumption which serves as proxy for renewable energy consumption while Carbon emission per capita represents the dependent variable. The data were sourced from the World Bank data base and the International Energy Agency.

This study utilizes the ARDL bounds testing approach to examine the relationship between the primary dependent variable and the primary independent variables. The ARDL framework of the estimation model is as follows:

The estimation method begins with equation 2, and ordinary least squares regression was primarily introduced to enable the Wald test to assess the joint significance of the coefficients associated with the lagged variables. The fundamental objective is to determine the potential for long-term relationships among the variables included in the analysis.

Hereof,  is the null hypothesis and it contains relevant facts on why there is non-existence of co-integrating associations among the included explanatory variables (regressors) and the only dependable variable (regressand). In similar pattern of expression, the alternative hypothesis is derived to be 

As per the established econometric tradition, the F-statistic is presented alongside the upper and lower critical values to provide a basis for drawing substantive conclusions, as observed in Pesaran et al. Consequently, if the F-statistic is found to exceed the upper critical value, it suggests the absence of cointegration, and the null hypothesis should not be accepted. In this economic context, it indicates the presence of a long-term association among the defined and included variables (Arize, 2017). Conversely, when the F-statistic values fall below the lower critical value, the null hypothesis will be readily accepted. If the experiment results show the F-statistic value falling within the range of the lower and upper limits, the test is deemed inconclusive (Merwe, 2021).  
Additionally, to determine the initial dynamics of the defined and included variables, as well as the initial adjustment rate towards the long-run outcome, the Error Correction Model was estimated as shown in the equation below.

**The Asymmetric Non-linear ARDL Model with Multiple independent variable thresholds**

To implement the non-linear autoregressive distributed lag model, I first follow the approach described by Bahmani‐Óskooee et al., (2018) and decompose the movement of the independent variables into their negative and positive components. This NARDL model enables me to examine whether changes in PMS consumption, Renewable energy consumption and population growth have asymmetric impacts on CO2 emissions, as suggested in (Ling et al., 2021). Building on the Bahmani‐Óskooee et al., (2018), the following NARDL model can be specified:

1. **Data Collection and Sources**

Time series data was used for Nigeria in this research ranging from 1982 to 2022. The information was collected from different data banks. The data for C02 emissions which is measured in millions of tons annually was retrieved from Carbon Dioxide Information Analysis Centre (CDIAC) and documented in the World Development Indicators of the World Bank (2023), Population growth is retrieved from National Population Commission and is measured in percentage. Hydro-electricity consumption is measured in million MWh per year and is retrieved from World Bank National Account Data and Premium Motor Spirit consumption is measured in Billion Liters per year and was retrieved from NNPC annual reports.

1. **Results**

**Table 1. Descriptive Statistics**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Statistic** | CO2E | PMSC | POPG | REC |
| Mean | 90.14826 | 9.233237 | 2.595355 | 5.8895 |
| Median | 92.39355 | 7.663105 | 2.581974 | 5.705 |
| Maximum | 131.1133 | 21.72304 | 2.764062 | 8.76 |
| Minimum | 38.85728 | 2.974652 | 2.380007 | 1.86 |
| Std. Dev. | 26.26345 | 5.760761 | 0.102061 | 1.723058 |
| Skewness | -0.361917 | 0.80983 | -0.113311 | -0.284359 |
| Kurtosis | 2.254023 | 2.317032 | 2.06409 | 2.521689 |
| Jarque-Bera | 1.800697 | 5.149574 | 1.545476 | 0.920369 |
| Probability | 0.406428 | 0.07617 | 0.461747 | 0.631167 |
| Sum | 3605.93 | 369.3295 | 103.8142 | 235.58 |
| Sum Sq. Dev. | 26900.97 | 1294.268 | 0.406242 | 115.7882 |
| Observations | 40 | 40 | 40 | 40 |

**Source: Researcher’s computation**

Descriptive statistics were employed to ascertain the distribution of the raw data. This study will utilize the Jarque-Bera test, which combines measures of skewness and kurtosis to analyze normality. The Jarque-Bera statistic quantifies the deviation of the series' skewness and kurtosis from the normal distribution. If the p-value of the Jarque-Bera test is less than 0.05, the normality of the distribution is rejected; otherwise, it is accepted (Thadewald & Büning, 2024).

In the present case, all the probability values associated with each Jarque-Bera statistic exceed 0.05, indicating the distributions are normally distributed. Furthermore, the descriptive statistics showed that none of the distributions deviated significantly from the mean.

**Table 2. Unit Root Test**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Variables | Level | | 1st Difference | |
| Constant | Constant with Trend | Constant | Constant with Trend |
| LCO2E | -1.531218 | -2.735503 | -7.199308 | -7.114485 |
| 0.5075 | 0.2288 | 0.0000 (\*\*) | 0.0000 (\*\*) |
|  |  | I (1) | I (1) |
| POPG | -1.866923 | -1.600219 | -6.427500 | -6.964672 |
| 0.3433 | 0.7719 | 0.0001 (\*\*) | 0.0004 (\*\*) |
|  |  | I (1) | I (1) |
| LPMSC | -1.932495 | -2.865281 | -10.07606 | -6.270141 |
| 0.9984 | 0.1843 | 0.0000 (\*\*) | 0.0000 (\*\*) |
|  |  | I (1) | I (1) |
| LREC | -3.412918 | -3.522628 | -6.945508 | -6.970690 |
| 0.0165(\*\*) | 0.0508(\*\*) | 0.0000 (\*\*) | 0.0000 (\*\*) |
| I(0) | I(0) | I (1) | I (1) |

**Source: Researcher’s computation**

All other variables considered are integrated at I(1) while Renewable Energy Consumption as proxied by Hydroelectricity Consumption is integrated at I(0) and I(1) as contained on the unit root results Table 2 above. Following the suggestions of Pesaran et al. (2001) with regard to the estimation of I(1) and I(0) variables, the bound test for the co-integration test is estimated and reported in Table 3.

Table 3: Results of Bound Tests to Co-integration

|  |  |  |  |
| --- | --- | --- | --- |
| Variables | AIC Lag | F-Statistic | Outcome |
| *FCO2E (LCO2E, LREC, PMSC, POPG)* | 3 | 4.988895 | Cointegration |
| *Critical Value Narayan (2005)* | I (0) | I (1) |  |
| 5% | 2.79 | 3.67 |  |

**Source: Researcher’s computation**

The null hypothesis explained the existence of no co-integration against the alternative hypothesis of , which showed that co-integration existed.

Table 3 contains the outcome of calculated F-statistics where individual variables were assigned the position of dependent variables through normalization. Still on the table, *FCO2E (CO2E/LREC, LPMSC, POPG)* represents the F-statistics and has the value 4.9888. The upper bound critical value at 5% significant level is 3.6 (Narayan, 2005). Since the F-statistics is greater than the critical bound, it implies that the null hypothesis which has no co-integration is rejected. The study has also determined the co-integration nexus among the variables which guaranteed the estimation of equation (5).

**Table 4: ARDL Long Run Form and Bounds Test**

The Dependent Variable: D(LCO2E)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Variable | Coefficient | Std. Error | t-Statistic | Prob. |
| C | 4.152234 | 1.396524 | 2.973263 | 0.009 |
| LCO2E(-1)\* | -0.773477 | 0.165437 | -4.675365 | 0.0003 |
| LPMSC (-1) | 0.320412 | 0.112095 | 2.85839 | 0.0114 |
| D(LCO2E(-2)) | 0.519729 | 0.172805 | 3.007608 | 0.0083 |
| D(LCO2E (-3)) | 0.398984 | 0.181048 | 2.203745 | 0.0425 |
| D(LPMSC) | 0.480723 | 0.210512 | 2.283593 | 0.0364 |
| D(LPMSC (-3)) | 0.69201 | 0.236857 | 2.921643 | 0.01 |
| D(POPG (-3)) | 1.247562 | 0.498127 | 2.504507 | 0.0235 |
| D(LREC (-2)) | -0.433826 | 0.19645 | -2.208327 | 0.0422 |

**Source: Researcher’s computation**

The analysis in Tables 4 and 5 reveals a statistically significant relationship between Premium Motor Spirit consumption, population growth, and CO2 emissions. Specifically, a unit increase in PMS consumption and population growth is associated with a rise in CO2 emissions in the short term. Conversely, a unit increase in renewable energy consumption tends to reduce CO2 emissions by 4.3% in Nigeria during the same period.

**Table 5: ARDL Error Correction Result (4, 4, 4, 4) based on SIC.**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Variable | Coefficient | Std. Error | t-Statistic | Prob. |
| D(LCO2E(-2)) | 0.519729 | 0.14336 | 3.625357 | 0.0023 |
| D(LCO2E(-3)) | 0.398984 | 0.152819 | 2.610827 | 0.0189 |
| D(LPMSC) | 0.480723 | 0.162944 | 2.950228 | 0.0094 |
| D(LPMSC(-3)) | 0.69201 | 0.168023 | 4.118548 | 0.0008 |
| D(POPG) | 1.970286 | 0.914218 | 2.15516 | 0.0467 |
| D(POPG(-3)) | 1.247562 | 0.385608 | 3.235313 | 0.0052 |
| D(LREC(-1)) | -0.368917 | 0.1754 | -2.10329 | 0.0516 |
| D(LREC(-2)) | -0.433826 | 0.16086 | -2.69692 | 0.0159 |
| CointEq(-1)\* | -0.773477 | 0.138518 | -5.58396 | 0.0000 |

**Source: Researcher’s computation**

The analysis reveals that alongside the presence of a long-term relationship between the variables, certain changes also emerge. Notably, an Error Correction Mechanism has been incorporated in this research to control and enhance these alterations. This mechanism will reconcile the immediate dynamics embedded in the co-integration functions into a more static arrangement. Furthermore, the speed of correcting deviations from the long-term relationship, or the long-term adjustment, demonstrates that the cointegration coefficient is negative, statistically significant, and the absolute value is less than 1, which is theoretically anticipated. With the coefficient standing at 0.77 and the p-value at 0.000, this result indicates that the deviations are corrected at a rate of 77%.

Table 6 Diagnostic test for ARDL (3,4,1,0)

|  |  |
| --- | --- |
| R-squared | 0.728235 |
| Adjusted R-squared | 0.52441 |
| Breusch-Godfrey Serial Correlation LM Test | 0.099 |
| Heteroskedasticity Test: Breusch-Pagan-Godfrey | 0.2632 |
| Jarque-Bera Normality Test | 0.543402 |

**Source: Researcher’s computation**

The diagnostic test results are shown in Table, and all tests reveal that the model is stable, has no problem of autocorrelation and has a constant variance. The R2 result shows that the independent variables explain about 0.89% of the dependent variable.

Table 7: Asymmetric Analysis of Non-linear Autoregressive Distributed Lag Model

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  |  |  |  |  |
|  |  |  |  |  |
| Variable | Coefficient | Std. Error | t-Statistic | Prob. |
|  |  |  |  |  |
|  |  |  |  |  |
| LPMSC\_POS | 3.289703 | 1.275380 | 2.579390 | 0.0818 |
| LPMSC\_NEG | 0.991608 | 0.760372 | 1.304109 | 0.2832 |
| LREC\_POS | -1.950535 | 0.701294 | -2.781335 | 0.0689 |
| LREC\_NEG | 0.567854 | 0.287282 | 1.976642 | 0.1425 |
| POPG\_POS | -6.136570 | 3.164614 | -1.939121 | 0.1478 |
| POPG\_NEG | 0.043739 | 0.862076 | 0.050737 | 0.9627 |
| C | 6.769185 | 1.397500 | 4.843783 | 0.0168 |
|  |  |  |  |  |
|  |  |  |  |  |

**Source: Researcher’s computation**

After considering the results from the non-linear autoregressive distributed lag model as shown in table 7 above, both the POS and NEG coefficients of all the decomposed regressors are not statistically significant at 5% in the long run, hence, there is no asymmetric effects within the period under consideration.

The CUSUM and CUSUM OF SQUARE tests are employed to check how stable each residual is in model. The result is shown below

(A)



Figure: 3 CUSUM of SQUARES GRAPH

The CUSUM and CUSUM of squares tests indicated that the model's residual errors are within the

(B)

Figure: 2 CUSUM GRAPH

acceptable range, suggesting the model's reliability. This implies that the short-term coefficient is stable and consistent with the long-run relationship. Additionally, the CUSUM and CUSUM-of-squares statistics for the model remained within the 5% significance level, allowing the acceptance of the null hypothesis that all coefficients in the error correction model are stable.

1. **Discussion**

The consumption of Premium Motor Spirit and population growth have been found to be statistically significant factors that impact CO2 emissions in both the long-term and short-term. The positive coefficients associated with PMS consumption in both the short-term and long-term suggest that PMS consumption represents the most negatively influential variable in achieving environmental sustainability goals in Nigeria. This is synonymous with the pre-industrial and semi-industrial economy era of Environmental Kuznets Curve analysis characterized by abundant natural resources, growing industrial waste, and decreased ecosystem regeneration capacity, leading to higher ecological footprints and pollution, along with lax environmental regulations and limited conservation funding.

The findings suggest that hydroelectricity, a form of renewable energy, has a statistically significant impact on CO2 emissions in Nigeria, both in the short and long term. Specifically, a 1% increase in hydroelectricity consumption is associated with a 4.7% reduction in CO2 emissions over time. This aligns with the research conducted by Opeyemi, which indicates that the utilization of renewable energy can effectively mitigate environmental damage. Furthermore, the outcomes corroborate the findings of Somoye et al. (2018) demonstrating that renewable energy consumption protects the environment and preserves finite energy source. This aligns with post-industrial economy of Environmental Kuznets Curve analysis characterized by structural shifts toward technology-intensive industries and services, coupled with stricter environmental regulations, resulting in reduced environmental deterioration (Zhang et al., 2022). This stage is marked by a shift in economic capacity to mitigate pollution through the adoption of clean technologies, increased societal awareness, and institutional enhancements driven by rising income levels. similarly, this outcome aligns with the assertion of Gambo, et. al. (2018) - exploring wind or solar energy sources as potential substitutes, given Nigeria's ample renewable energy resources and harnessing these alternative energy sources reduces CO2 emissions while also supporting long-term economic growth.

The outcome of this research from the non-linear autoregressive distributed lag model that both positive and negative coefficients of all the decomposed regressors are not statistically significant at 5%, which implies that there is no asymmetric effect within the period under consideration. In other word, there is no meaningful difference in the impact of positive and negative changes in the independent variables on the dependent variables, essentially indicating a symmetric relationship at 5% but obviously shown asymmetric relationship at 10%. This shows that the relationship between PMS Consumption, Population growth and hydroelectricity consumption and CO2 emissions in Nigeria is linear within the period under consideration. The potential reason for this asymmetric relationship could as a result of short data points.

1. **Conclusion**

Environmental sustainability has become a critical focus for multinational corporations and global organizations. Researchers across various disciplines have conducted extensive academic investigations to optimize the utilization of environmental resources. Nigeria, as a member of the international community, has participated in discussions and forums aimed at proposing solutions and recommendations to reduce CO2 emissions and enhance global environmental quality. This study examines the relationship between petroleum consumption, renewable energy consumption, population growth, and environmental sustainability in Nigeria. The findings reveal several policy recommendations:

The research suggests that the consumption of Premium Motor Spirit is the most impactful factor hindering Nigeria's progress towards environmental sustainability. This indicates that the current PMS consumption pattern in Nigeria must be reversed to ensure progress towards the attainment of environmental sustainability goals. Therefore, government should implement a comprehensive PMS consumption reduction policy to mitigate future emissions and safeguard the environment for present and future generations.

Hydroelectricity consumption, which serves as a proxy for renewable energy consumption, was found to have a significant reducing impact on CO2 emissions. This suggests that Nigeria should consistently develop and review policies and programs that promote the rapid production and utilization of energy from renewable sources, aligned with the national goal of attaining environmental sustainability.

In conclusion, this research revealed that the consumption of fossil fuels, such as PMS, and population growth deplete non-renewable resources, reduce environmental quality, and undermine the concept of environmental sustainability. Conversely, the consumption of energy from renewable sources, such as hydroelectricity, improves the quality of the environment in Nigeria. However the data use for this analysis to capture the influence of renewable energy is limited to that of hydroelectricity consumption, it is essential that Nigeria acquires new and cleaner technologies from revenues generated from fossil. This will propel the attainment of environmental sustainability agenda in Nigeria.

**Recommendations**

Based on the finding that increasing hydroelectric power consumption can reduce CO2 emissions by 4.3% in Nigeria, experts should explore diverse innovations in advancing the development of hydroelectric technology that could further enhance efficiency and mitigate environmental impacts. Additionally, researchers should investigate the possibility of incorporating data from renewable sources such as solar and biomass to improve the quality of research outcomes.

The outcome of this research following the analysis from non-linear autoregressive distributed lag model revealed the non-existent of asymmetric relations between the decomposed regressors and regressand at 5% statistical significance. Indicating a linear relationship between PMS Consumption, Population growth and hydroelectricity consumption and CO2 emissions in Nigeria and potentially due to short data points. Researchers could carry out further investigation on decreasing and increasing asymmetric relationship between these sets of variables on data points extended beyond 1982-2022.

While the study provides insights into the relationship between PMS consumption and environmental sustainability, further research is needed to translate these findings into concrete policy recommendations. Future studies could focus on evaluating the effectiveness of various policy interventions.

Disclaimer (Artificial intelligence)

Option 1:

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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Details of the AI usage are given below:

1.

2.

3.

**References**

Achuo, E.D., Miamo, C.W. and Nchofoung, T.N. (2022). Energy Consumption and Environmental Sustainability: What Lessons for Posterity? *Energy Reports,* 8(40), PP. 12491–12502. <https://www.researchgate.net/publication/364100425_Energy_consumption_and_environmental_sustainability_What_lessons_for_posterity>

Aliyu, Y. A., Botai, J. O., Abubakar, A. Z., Youngu, T. T., Sule, J. O., Shebe, M. W., & Bichi, M. A. (2020). Atmospheric Air Pollution in Nigeria: A Correlation Between Vehicular Traffic and Criteria Pollutant Levels. *TechOpen eBooks*. <https://doi.org/10.5772/intechopen.86554>

Arize, A. C. (2017*).* A Convenient Method for The Estimation of ARDL Parameters and Test Statistics: USA Trade Balance and Real Effective Exchange Rate Relation. *International Review of Economics & Finance*, 50(3), PP. 75-84. <https://www.researchgate.net/publication/315926332_A_convenient_method_for_the_estimation_of_ARDL_parameters_and_test_statistics_USA_trade_balance_and_real_effective_exchange_rate_relation>

Asongu, S. A., Agboola, M. O., Alola, A. A. and Bekun, F. V. (2020). The Criticality of Growth, Urbanization, Electricity and Fossil Fuel Consumption to Environment Sustainability in Africa. [*Science of the Total Environment*](https://www.sciencedirect.com/journal/science-of-the-total-environment)*,* 712 (13), PP. 63-76. <https://www.sciencedirect.com/science/article/abs/pii/S0048969719363727>

Bahmani‐Óskooee, M., Harvey, H., & Niroomand, F. (2018). On the Impact of Policy Uncertainty on Oil Prices: An Asymmetry Analysis. *International Journal of Financial Studies* 6(1), pp. 12. Multidisciplinary Digital Publishing Institute. <https://doi.org/10.3390/ijfs6010012>

Bala, H., Abdullahi, A., Amran, N. A., Alhaji Sani, A. Y. A., Shafi'u, R. M., Sharri, H., and Idris, F. A. (2021). Gauging the Nexus of Policy and Regulatory Framework on Environmental Sustainability and Renewable Energy in Nigeria. *Yustisia Jurnal Hukum*, 13(3), PP. 283-297. <http://jurnal.uns.ac.id>

[Bernard](https://www.researchgate.net/profile/Anthony-Bernard-6?_tp=eyJjb250ZXh0Ijp7ImZpcnN0UGFnZSI6InB1YmxpY2F0aW9uIiwicGFnZSI6InB1YmxpY2F0aW9uIn19), A. O.,  [Ezenekwe](https://www.researchgate.net/profile/Uju-Ezenekwe?_tp=eyJjb250ZXh0Ijp7ImZpcnN0UGFnZSI6InB1YmxpY2F0aW9uIiwicGFnZSI6InB1YmxpY2F0aW9uIn19), U. R. and [Uzonwanne](https://www.researchgate.net/profile/Chinecherem-Uzonwanne?_tp=eyJjb250ZXh0Ijp7ImZpcnN0UGFnZSI6InB1YmxpY2F0aW9uIiwicGFnZSI6InB1YmxpY2F0aW9uIn19), C. (2018). Analysis of the effect of energy consumption, co2 emission on economic growth in Nigeria*. Journal of Social Sciences and Education,* 1(1)2018. [https://www.researchgate.net/publication/341103417\_analysis\_of\_the\_effect\_of\_energy\_consumption\_co\_2\_emission\_on\_economic\_growth\_in\_nigeria](https://www.researchgate.net/publication/341103417_ANALYSIS_OF_THE_EFFECT_OF_ENERGY_CONSUMPTION_CO_2_EMISSION_ON_ECONOMIC_GROWTH_IN_NIGERIA)

Bertinelli, L., Strobl, E., & Zou, B. (2011). Sustainable economic development and the environment: Theory and evidence. *Energy Economics* 34 (4), 1105. Elsevier BV. <https://doi.org/10.1016/j.eneco.2011.09.007>

Carson, R. T. (2009). The Environmental Kuznets Curve: Seeking Empirical Regularity and Theoretical Structur*e*. *Review of Environmental Economics and Policy,* 4 (1) P. 3. University of Chicago Press. <https://doi.org/10.1093/reep/rep021>

Das, H., Lin, Y., Agwan, U., Spangher, L., Devonport, A., Yang, Y., Drgoňa, J., Chong, A., Schiavon, S., & Spanos, C. J. (2022). Machine learning for smart and energy-efficient buildings. *Cornell University*.<https://www.researchgate.net/publication/365820296_Machine_Learning_for_Smart_and_Energy-Efficient_Buildings>

Ezenwa, N., Nwatu, V. and Gershon, O. (2021). Renewable Energy Consumption Shocks on CO2 Emissions and Economic Growth of Nigeria. *International Conference on Energy and Sustainable Environment, Earth and Environmental Science,* 665 (2021) 012013 doi:10.1088/1755-1315/665/1/012013

Ficko, A., & Bončina, A. (2018). Public Attitudes Toward Environmental Protection in The Most Developed Countries: The Environmental Concern Kuznets Curve Theory. *Journal of Environmental Management,* 231(1), PP. 968-981. <https://doi.org/10.1016/j.jenvman.2018.10.087>

Gambo, S. L., Binti Ishak, S. B., Ismail, N. W. & Idris, M. M. (2018). Energy Consumption, Environmental Emissions and Economic Growth: An Empirical Analysis in Nigeria. *Journal of Humanities and Social Science*, 23 (2), PP. 11-22. [www.iosrjournals.org](http://www.iosrjournals.org)

Gershon, O, and Emekalam, P. (2021). Determinants of Renewable Energy Consumption in Nigeria: A Toda Yamamoto Approach. *International Conference on Energy and Sustainable Environment, Earth and Environmental Science*. 665 (2021) 012005. doi:10.1088/1755-1315/665/1/012005

Hassan, I., Kalin, R. M., Aladejana, J. A., & White, C. J. (2020). Potential Impacts of Climate Change on Extreme Weather Events in The Niger Delta Part of Nigeria. *Hydrology*, 7(1), P.19. Multidisciplinary Digital Publishing Institute. <https://doi.org/10.3390/hydrology7010019>.

Kalagbor, A. N., Idowu, S. Ο., & Weldmeskel, E. M. (2022). Corporate Social Responsibility, Service Failures and Recovery Strategies for Sustainable Business: The Case of Nigeria. *Economic Insights – Trends and Challenges*, 2022(1), P.1. Oil & Gas University of Ploiesti. <https://doi.org/10.51865/eitc.2022.01.01>

Kelly, A. M. & Radler, R. D. N. (2024). Does Energy Consumption Matter for Climate Change in Africa? New Insights from Panel Data Analysis. [*Innovation and Green Development*](https://www.sciencedirect.com/journal/innovation-and-green-development), 3 (3), PP. 100-132. <https://www.sciencedirect.com/science/article/pii/S2949753124000092>

Kim, Y. G., Gupta, U., McCrabb, A., Son, Y., Bertacco, V., Brooks, D. J., & Wu, C.-J. (2023). Green Scale: Carbon-Aware Systems for Edge Computing. Cornell University. <https://www.researchgate.net/publication/369760384_GreenScale_Carbon-Aware_Systems_for_Edge_Computing>

Lau, C. K., Mahalik, M. K., Rather, K. N. & Gozgor, G. (2023). The Impact of Green Quality Of The Energy Consumption on Carbon Emissions in The United States. [*Economic Analysis and Policy*](https://www.sciencedirect.com/journal/economic-analysis-and-policy)*,* 80(1), PP. 850-860. <https://www.sciencedirect.com/science/article/pii/S0313592623002333>

Lawal, I. M. & Abubakar, M. (2019). Impact Of Population Growth On Carbon Dioxide (CO2) Emission: Empirical Evidence From Nigeria. *Jurnal Perspektif Pembiayaan dan Pembangunan Daerah,* 6 (6), PP. 1-6

Li, J., Liu, S., Qin, Y., Zhang, Y., Wang, N., & Liu, H. (2020). High Order Radiomics Features Based on T2 FLAIR MRI Predict Multiple Glioma Immunohistochemical Features: A More Precise and Personalized Gliomas Management. *Public Library of Science*, 15(1), PP.13-71. <https://doi.org/10.1371/journal.pone.0227703>

Ling, G., Razzaq, A., Y, G., Fatima, T., & Shahzad, F. (2021). Asymmetric And Time-Varying Linkages Between Carbon Emissions, Globalization, Natural Resources and Financial Development in China. *Environment Development and Sustainability*, 24 (5), p. 6702. <https://doi.org/10.1007/s10668-021-01724-2>

Liu, S., Hou, S., He, K., & Yang, W. (2017). L-Kurtosis and Its Application for Fault Detection Of Rolling Element Bearings. *Measurement* 116(1), PP. 523-532. <https://doi.org/10.1016/j.measurement.2017.11.049>

Luken, R. A., & Castellanos‐Silveria, F. (2009). Industrial Transformation and Sustainable Development In Developing Countries. *Sustainable Development*, 19 (3), pp. 167 <https://doi.org/10.1002/sd.434>

Merwe, S. van der. (2021*).* On Determining the Distribution of a Goodness-Of-Fit Test Statistic. *Cornell University*. <https://www.researchgate.net/publication/351119953_On_Determining_the_Distribution_of_a_Goodness-of-Fit_Test_Statistic>

Mesagan, P. E., Alimi, O. Y. and Adebiyi, K. A. (2018). Population Growth, Energy Use, Crude Oil Price, and the Nigerian Economy. Economic Studies (Ikonomicheski Izsledvania), 27 (2), PP.115-132. <https://www.iki.bas.bg/Journals/EconomicStudies/2018/2018-2/7_Nigeria-3_f-f.pdf>

Nguyen, T. T. H., Tu, Y., Diep, G. L., Tran, T. K., Nguyen Hoang Tien, N. H., & Chien, F. (2023*).* Impact Of Natural Resources Extraction and Energy Consumption on The Environmental Sustainability in ASEAN Countries. *Resource Policy*, 85(A)103713. <https://www.sciencedirect.com/science/article/abs/pii/S0301420723004245>

Nsoke, U. P., Ndu, O. M., & Ofoegbu, G. N. (2021). Accounting Practices and Its Effects on The Growth of Micro and Small-Scale Enterprises: Analysis from Nigeria. *Universal Journal of Accounting and Finance* 9(4), PP. 574. <https://doi.org/10.13189/ujaf.2021.090405>

Nwozor, A., Oshewolo, S., & Ogundele, O. (2019). Energy Poverty and Environmental Sustainability In Nigeria: An Exploratory Assessment. *IOP Conference Series Earth and Environmental Science*, 331(1)12033. <https://doi.org/10.1088/1755-1315/331/1/012033>

Ogunbiyi, M. E., Onifade, M. K., Afolabi, O. J., & Oroye, O. A. (2020*).* An Assessment of Solid Waste Transportation In Ado-Ondo/Ota Local Government Area, Ogun State, Nigeria. *Transport and Communications,* 8(2), P. 23. University of Zulia. <https://doi.org/10.26552/tac.c.2020.2.3>

Ojide, M. G., Agu, O. C., Ohalete, P., & Chinanuife, E. (2022). Nigerian Economic Policy Response To COVID‐19: An Evaluation of Policy Actors’ Views*. Poverty & Public Policy*, 14(1) pp. 69-72. <https://doi.org/10.1002/pop4.332>

Olayungbo, D. O., & Umechukwu, C. (2022). Asymmetric Oil Price Shocks and The Economies of Selected Oil-Exporting African Countries: A Global VAR Approach. *Economic Change and Restructuring*, 55(4), pp. 21-37. <https://doi.org/10.1007/s10644-022-09382-8>

Omodero, C. O. & Uwalomwa, U. (2021). Energy Absorption, CO2 Emissions and Economic Growth Sustainability in Nigeria. *International Journal of Energy Economics and Policy*, 2021, 11(4), PP. 69-74. DOI: <https://doi.org/10.32479/ijeep.11055>

Pham, N.-T., Trung-Kien, P., Cao, V. H., Tran, H. G., & Vo, X. V. (2020). The Impact Of International Trade On Environmental Quality: Implications For Law. *Asian Journal of Law and Economics*, 11(1). <https://doi.org/10.1515/ajle-2020-0001>

Pooladsanj, M., Savla, K., & Ιωάννου, Π. (2023). Ramp Metering To Maximize Freeway Throughput Under Vehicle Safety Constraints*.* *Transportation Research Part C Emerging Technologies* 154(3),104267.<https://www.researchgate.net/publication/373590656_Ramp_metering_to_maximize_freeway_throughput_under_vehicle_safety_constraints>

Rahimifard, S., & Trollman, H. (2018). UN Sustainable Development Goals: an engineering perspective. *International Journal of Sustainable Engineering*, 11(1) pp. 1-8. <https://doi.org/10.1080/19397038.2018.1434985>

Stern, D. I. (2014). The Environmental Kuznets Curve: A Primer. *Research Papers in Economics, Federal Reserve Bank of St. Louis.* <https://doi.org/10.22004/ag.econ.249424>

Schneider, N. (2021). Population Growth, Electricity Demand and Environmental Sustainability In Nigeria: Insights From A Vector Auto-Regressive Approach. *International Journal of Environmental Studies*. [(PDF) Population Growth, Electricity Demand and Environmental Sustainability in Nigeria: Insights from a Vector Auto-Regressive Approach (researchgate.net)](https://www.researchgate.net/publication/350859109_Population_Growth_Electricity_Demand_and_Environmental_Sustainability_in_Nigeria_Insights_from_a_Vector_Auto-Regressive_Approach)

Şentürk, H., Omay, T., Yıldırım, J., & Köse, N. (2020*).* Environmental Kuznets Curve: Non-Linear Panel Regression Analysis. *Environmental Modeling & Assessment,* 25(5) p. 633. <https://doi.org/10.1007/s10666-020-09702-0>

Thadewald, T., & Büning, H. (2024). Jarque-Bera Test and Its Competitors for Testing Normality: A Power Comparison. *Econstor*, 2004/9. PowerComparison.*Econstor*,2004/9 <https://www.econstor.eu/bitstream/10419/49919/1/668828234.pdf>

Villar, L. (2023). Nigeria Energy Overview: Country Analysis Brief. *Energy Information Administration*.<https://www.eia.gov/international/content/analysis/countries_long/Nigeria/nigeria.pdf>

Wang, L., Ding, X., & Wu, X. (2014). Environmental Kuznets Curve for Pollutants Emissions in China’s Textile Industry: An Empirical Investigation. *International Journal of Environmental Technology and Management* 17(1), PP. 14-20. <https://doi.org/10.1504/ijetm.2014.059457>

Yahaya, A., Mohammed, D. and Joseph Agaba, A. J. (2023). Energy Consumption, Economic Growth, and Environmental Quality Nexus in Nigeria. *Northwest Journal of Social and Management Science*s 4 (1), ISSN:3027-2661

Zhang, L., Xu, M., Chen, H., Li, Y., & Chen, S. (2022). Globalization, Green Economy and Environmental Challenges: State of the Art Review for Practical Implications. *Frontiers in Environmental Science*, 10(87), PP. 2-71. <https://doi.org/10.3389/fenvs.2022.870271>

Zhi, Z., Ding, Z., Geng, Y., Pan, L., & Wang, C. (2023). The Impact of Digital Economy on Environmental Quality: Evidence From China*. Frontiers in Environmental Science* 11(1), PP. 33-39. <https://doi.org/10.3389/fenvs.2023.1120953>