



Environmental Impacts of Crude Production, Energy Intensity and Hydrocarbon Taxation in a Developing Economy

Cordelia Onyinyechi Omodero^{1*}, Emmanuel O. Adeyemi¹, Odey T. Okujor¹, Omasoro S. Goodluck¹,
Gbenga Ekundayo²

¹ Department of Accounting, Finance and Taxation, Caleb University, Lagos 104101, Nigeria

² Department of Administration and Financial Sciences, Oman College of Management and Technology, Muscat 113, Oman

Corresponding Author Email: cordelia.omodero@calebuniversity.edu.ng

Copyright: ©2026 The authors. This article is published by IIETA and is licensed under the CC BY 4.0 license (<http://creativecommons.org/licenses/by/4.0/>).

<https://doi.org/10.18280/ijstdp.210808>

ABSTRACT

Received: 1 June 2026

Revised: 15 August 2026

Accepted: 22 August 2026

Available online: 31 August 2026

Keywords:

environment, carbon tax, foreign direct investment, energy production, pollution

This study contributes to the ongoing effort to establish long-run and short-run relationships between hydrocarbon tax (HCT) revenue, CO₂ emissions, crude oil production, energy production, energy consumption, company income tax, and foreign direct investment (FDI) in Nigeria between 1990 and 2024. The study employs a vector error correction model (VECM), with and without structural break dummies, to assess the effectiveness of the Nigerian HCT regime in reducing environmental degradation while raising revenue after the Petroleum Industry Act (PIA) 2021 came into being. In the long run, the study finds that energy production has the highest impact on emissions in Nigeria (0.876, $p < 0.01$). Secondly, the HCT cut emissions by 0.156% ($p < 0.05$), proving that the tax is an effective policy instrument in environmental governance. Crude oil production exerts pressure on both revenue (0.789, $p < 0.01$) and emissions. In the short run, the study finds that a 1% increase in HCT reduces emissions by 0.134% ($p < 0.05$). Moreover, the coefficient of the error correction term (ECT) (−0.567, $p < 0.01$) suggests that Nigeria's HCT policy corrects 56.7% of the deviation from long-run equilibrium yearly. The study also reveals that the tax has a positive coefficient (0.543, $p < 0.05$) on FDI, implying that the tax encourages FDI inflows. Finally, the structural break analysis reveals three break points: 2008, 2014, and 2021. While the PIA 2021 policy caused the largest emissions reductions, amounting to −8.9% ($p < 0.001$), the 2014 oil price drop also reduced emissions by 5.6% ($p < 0.05$). Interestingly, the 2008 economic crunch had no significant effect on emissions. To address environmental degradation, the paper suggests that Nigeria should graduate and ring-fence the HCT for clean energy development, sustain the PIA 2021 to allow diversification, and leverage the tax to woo green FDI to achieve fiscal and environmental sustainability while growing the economy.

1. INTRODUCTION

Crude production as well as energy generation and utilization could have considerable effects on the environment. For instance, amines, sodium azide, heavy metals, condensed ring aromatics, and benzene compounds are chemical properties related to the various oils, including petroleum, crude oil, and waste oil [1, 2]. Oil spills represent a significant global environmental issue that adversely affects ecosystems and public health, particularly in regions where transportation and hydrocarbon extraction activities are prevalent [3]. The consequences of oil pollution include direct effects in the form of immediate ecological harm and, in an indirect way, the impact on human health in the form of the harmful influence of the exploitation of the main producers [2]. During the discharge of oil in the sea, there are occurrences like dispersal of chemical substances, fluid motion, biodegradation and physical transformations of other environmental factors such as temperature, airstream and currents of the waves. Oil that leaks into the seas normally reaches the shore surface and gets

stranded due to the effects of tidal currents and wind [4]. Mangroves and saltmarshes located on shorelines are a barrier between the sea and humanity since they serve as a protective against erosion and flooding [5]. The possibility of oil deposits in sediment poses a risk of greater exposure to the aquatic environment and to human health [6].

The intrusion of oils into plant cells, their effects on the rate of transpiration, its interference with photosynthesis and the genotoxic effects depict the numerous repercussions of oil contamination on plant physiology as well as genetics [2]. It has been found that people who live near oil fields or wells or those engaged in the process of cleaning oil spills have developed health problems, including irritation of skin, eyes and mucous membrane, kidney and liver damage, and also reproductive health problems amongst others [7]. Diseases associated with crude oil and oil spills, such as skin irritation, throat problems, liver and lung problems, infertility, and miscarriages, have increased significantly and have been linked to childhood leukemia. Research indicates that genetic instability of important enzymes in cellular metabolism is

directly correlated to DNA damage due to exposure to oil and that oil exposure is implicated in some types of cancer, including leukemia [7].

Besides, the effects of climate change on oil and gas infrastructure in coastal and offshore areas manifest with the increase of global warming [8-10]. Rising temperatures essentially impact the quality of oil and gas mining and its systems [11]. The world ocean has been gradually warming at the surface and down to a depth of more than 2000 meters since about the year 1950 CE. Heat is also transported vertically via storms and eddies and by sinking the surface water, which is cooler than the underlying water [12]. Similarly, the interaction between energy and the environment is a delicate equilibrium, in spite of the fact that the provision of energy is a critical need [13]. The effects of energy production and consumption differ based on the nature and magnitude of the energy source.

It is obvious that the dependence on orthodox fossil fuels leads to pollution that exacerbates global warming, as evidenced by the rise in carbon dioxide and other greenhouse gases (GHG) [14]. The oxides of nitrogen (NO_x) that arise due to the combustion of fossil fuels jeopardize the quality of air and are very detrimental to human health [15]. Additionally, air pollution resulting from fossil fuel burning can lead to lung problems, cardiac ailments, and enlarged amount of deaths. Fossil fuels, firewood, and fumes serve as the main energy sources in numerous countries. The combustion of these fuels emits GHGs such as carbon dioxide (CO_2), methane, and nitrous oxide, which play a substantial role in global warming and climate change. Regrettably, global energy consumption is heavily (80%) reliant on fossil fuels and is expected to increase by more than 50% over the next twenty years [16]. Other forms of energy like bioenergy are yet to be developed in most countries, whereas solar energy depends on sunshine and wind, which are not necessarily available all the time.

Furthermore, the Foreign Direct Investment (FDI) has its own environmental risks. Being aware of possible environmental costs of FDI, countries now tend to be more selective in the nature of the FDI that they welcome [17]. The effort to reduce pollution is a topical issue that has led to the introduction of carbon taxation. Carbon-tax revenue is revenue generated derived from fees charged on pollution caused by entities and businesses with pollution density. Vu Thi Minh and Trinh Thi Thu [18] pointed out that the application of carbon revenues to diminish labor taxes and promote production could significantly boost fiscal efficiency and job opportunities, while simultaneously reaching emission reduction goals.

Previous studies reported that oil spills resulting from crude oil production are harmful to the environment [19, 20]. However, in relation to revenue generation, studies [21, 22] uphold the view that crude oil production has a positive environmental impact both in the short and long term. In addition, energy production also has varying evidence from past research. Bashir and Srivastava [23] proved that energy production improves environmental quality, while Majeed et al. [24] opposed the view and provided evidence that energy consumption negatively affected the environment. Therefore, the majority of scholars [25-28] advocate that hydrocarbon taxation at the level of pollution will help to reduce pollution. On the contrary, Muzzi and Pereda [29] did not find any substantial evidence that carbon taxation could lead to a decrease in pollution.

The Hydrocarbon Tax (HCT) was introduced in Nigeria as

a means to reform the petroleum industry, and it was designed to replace the old Petroleum Profits Tax (PPT) in order to ensure that the Nigerian oil and gas sector would remain both competitive and lucrative for years to come. The tax was initially introduced by the Petroleum Industry Act (PIA) 2021, and it marked the end of the PPT era. The PIA was later incorporated into the Nigeria Tax Act (NTA) 2025, which served as the master tax law for the country. The hallmark of the new tax policy is that it imposes two separate taxes on upstream oil and gas companies: the HCT and the Companies Income Tax. This replaced the erstwhile PPT with the HCT as the main form of taxation in Nigeria's petroleum sector. Thus, it can be gathered that the HCT is the result of a policy that seeks to balance the need to make Nigeria's oil and gas industry attractive to investors and ensure that the country derives maximum benefits from its oil and gas reserves. In this study, the data are the tax revenue and not the tax rate.

All these different research findings have called for this present study, which seeks to evaluate the environmental effect of crude production, energy and hydrocarbon taxation in Nigeria. This study is highly necessary at this point in time because Nigeria experiences high density of pollution due to crude oil production, energy consumption and burning of fossil fuels to generate energy. Most locations and communities in Nigeria, especially the Niger Delta Region, experience a lot of environmental hazards, including oil spillages, deforestation, soil and water pollution that lead to destruction of farmlands and fish in the water. Past administrations have made efforts to clean up the environment, but nothing seems to be giving the solution required by the ailing communities. Consequently, this study will add value to the standing literature as well as provide a substantial environmental policy shift that will improve the situation in the target country and other environmentally challenged countries.

2. LITERATURE REVIEW

2.1 Crude production and environmental pollution

In an attempt to examine the impacts of crude oil exploration and production on the environment and human health, Kuch and Bavumiragira [20] analyzed South Sudan as a case study. According to the findings, it was determined that the significant negative effects of oil production, which include leakages and spillages, resulted in significant pollution of the total environment (air, soil, water, biota) and negatively affected human health.

Similarly, Adeyemo and Aliu [19] examined the effects of oil spillage on the bacteriological properties and characteristics of the soil in Awoye Community, Ilaje in Ondo State, Nigeria. Among the bacterial species found in the bacteriological analysis were *Micrococcus*, *Pseudomonas*, *Bacillus* and *Aerococcus*. Statistical analysis of the results based on the Duncan Multiple Range Test revealed the presence of significant differences between microbial populations, electrical conductivity and moisture content between the oil-polluted soil and the control area (unpolluted soil) and no significant difference in pH between the polluted and non-polluted soil. The conclusion therefore concluded that oil spill will have a negative impact on the microbial population in Awoye's soils, negatively altering the physicochemical properties of the soil, which subsequently

decreases its microbial load and renders both the soil and the water unhelpful in supporting human life activities.

On the contrary, Zakari et al.'s [22] research on the impact of crude oil production on environmental quality in Africa revealed that the production of crude oil had a positive environmental impact in both the short and long-term. This outcome may be due to the deployment of modern pollution control technology and commitment to environmental sustainability goals and investments. With specific regard to Saudi Arabia, Mahmood et al. [21] identified a positive impact of oil revenue on CO₂ emissions. This finding implies that the high level of oil production in the area is associated with increased revenue which can be used to counter the environmental consequences of oil production via environmental clean-up and green technology that focuses on control of pollution.

2.2 Energy production and consumption impact on the environment

Bashir and Srivastava [23] assessed the effects of renewable energy utilization, financial spread, economic performance, and trade on environmental pollution in Nigeria. The short-run analysis indicated that energy consumption and production increased environmental degradation, while GDP and trade acted to reduce it in Nigeria. The long-term evaluation suggested that energy use, economic performance, and trade contributed to a reduction in environmental pollution. Furthermore, energy production was shown to improve environmental quality. Majeed et al. [24] analyzed the relationship between economic growth and the asymmetric effects of both aggregate and disaggregate forms of energy consumption on environmental quality in Pakistan. The study revealed that different sources of energy consumption portrayed different kinds of asymmetric impacts that resulted in the ecological footprint. Asymmetric relationships were found between the consumption of coal, electricity and the ecological footprint. The positive shocks in the consumption of coal and electricity were also detected to have negative effects on environmental quality.

According to the research carried out by Al Mubarak et al. [30], fossil fuels, biomass, and nuclear sources of energy were the greatest health hazard to communities and societies as compared to other sources of energy. With respect to environmental consequences, fossil fuel combustion was predicted to release the greatest quantities of GHG and exhibit the strongest adverse effects on the ecosystem. Conversely, nuclear, ocean, solar, and wind energy were distinguished by the lowest levels of GHG emissions and low/moderate impacts on the ecosystems.

Rapid economic growth in emerging economies has resulted in increased energy production and consumption, contributing to environmental effluent. However, Shivani [31] found that renewable energy weakens the association between economic growth and carbon emissions, indicating that the transition to renewable energy could help to lessen the adverse environmental effects of economic growth. The research by Anyanwu and Kur [32] revealed beneficial links between energy consumption, renewable energy usage, and fossil fuel consumption with respect to industrial sector performance. This implies that heightened energy consumption boosts the productive efficiency of industries, consequently fostering economic growth across the Sub-Saharan African regions.

On the contrary, Hasnisah et al. [33] carried out research on

the relationship between the quality of the environment, economic progress and the use of renewable and non-renewable energy in 13 developing countries in Asia. Their results proved that the growth in GDP per capita combined with the rise in conventional energy consumption had a negative impact on the quality of the environment. In addition, the study also emerged to portray that the use of renewable energy made no significant contribution to the mitigation of CO₂ emissions and pollution. To buttress this finding, the study by Nan et al. [34] proved that the long-term impact of renewable energy on the ecological footprint was negative, and the 1 percent increase in the use of renewable sources resulted in a 2.91 percent decrease in the ecological footprint in China.

2.3 Hydrocarbon taxation and pollution control

In the pursuit of pollution control in China, Xu et al. [28] assessed the impacts of environmental taxation. The research gathered data regarding 287 cities during the years 2010–2019 to determine the impact of the tax on the process of pollution reduction, both in terms of presence and structure. The findings suggested that the environmental source raised tax, which had a significant spillover effect in reducing emissions of sewerage, waste gases and solid wastes. According to the simulation results presented by Xing et al. [27], the ongoing increase in China's freight scale suggests that a carbon tax policy could effectively diminish the reliance on diesel trucks and fuel oil ships, while fostering the use of electric trucks and hydrogen fuel trucks. When contrasted with the business-as-usual scenario, the carbon tax scenarios in China demonstrated a reduction in the overall emissions and the emission intensity of CO₂ and air pollutants, which played a significant role in lowering the peak CO₂ emissions in the freight transportation sector of China.

Ugrinov [26] examined the effectiveness of environmental tax as a potential means of eliminating climate and environmental problems in the period between 1996 and 2022 among 28 nations. Empirical analysis revealed that environmental taxes, as a whole, are normally associated with a decrease in greenhouse emissions and air pollution. Sun et al. [25] found that the optimized taxation scheme with the introduction of the carbon tax is more efficient in lowering the carbon intensity, and CO₂ emissions could be decreased without further deterioration of the GDP. That is, an efficient tax system might result in a green energy structure.

On the contrary, Muzzi and Pereda [29] discovered that there was no substantial evidence indicating that carbon taxation led to a significant decrease in emissions in either Argentina or Colombia. Liu et al. [35] revealed that carbon tax had a significant effect on economic growth and a negative correlation was observed between the rate of carbon tax and the economic growth of China. The research suggested that the rate of the carbon tax ought to be at a low level in order to attain the target at the minimal economic cost. Li et al. [36] found that a higher tax rate leads to more noticeable decreases in carbon dioxide emissions.

2.4 Effects of Foreign Direct Investment on environmental pollution

Wang and Liu [37] investigated the causal link between FDI and the pollution intensity of firms, utilizing the policy change regarding FDI access in China that occurred in 2002. Their

findings indicated that FDI significantly decreased the pollution intensity of firms. Mechanism tests revealed that this reduction in pollution intensity was facilitated by enhancements in firms' productivity, improved pollution management capabilities, and increased output from firms with lower pollution levels. In the same manner, Demena and Afesorbor [17] conducted a meta-analysis to analyse how FDI influences environmental emissions by using 65 primary studies that reported 1006 elasticities. The results denoted that the basic influence of FDI on environmental emissions was almost insignificant but when the heterogeneity of the studies was considered, FDI was found to have a substantial impact in decreasing environmental emissions.

The research conducted by Kindo et al. [38] investigated the influence of FDI on environmental quality in 13 West African countries over the period from 2000 to 2020. The methodology involved a panel quantile regression with nonadditive fixed effects. The results indicated a negative impact of FDI on environmental quality, thereby confirming the presence of the pollution haven hypothesis in the region. The findings of Brahmia and Mannai [39] indicated that in the Gulf Cooperation Council (GCC) countries, the expansion of ICT and the increase in electricity consumption significantly contributed to higher CO₂ emissions, thereby worsening environmental degradation. Furthermore, the study highlighted that trade openness and FDI inflows, particularly in industries that are resource-intensive, also contributed to the environmental degradation experienced in GCC countries.

3. RESEARCH INSTRUMENTS AND METHODS

The study evaluates the environmental impacts of crude production, energy intensity and hydrocarbon taxation in a developing economy. The unit root valuation outcomes suggest that all datasets are fixed at order one; as a result, there were co-integration tests using the Johansen cointegration test and Max Eigen Unrestricted Cointegration Rank Test. Both results specify a long-run connection within the equation. Accordingly, this research employs the vector error correction model (VECM) for its analysis, and the suitability of this technique for the study is validated by the works of Keswani et al. [40].

The equations are outlined below:

$$LNC02Mt = f(LNHCBTX, LNCITXN, LNCRUDP, LNENGYC, LNFDIIN) \quad (1)$$

To perform the econometric analysis, Eq. (1) above is transformed into Eq. (2) as follows:

$$LNC02Mt_{t-1} = \beta_0 + \beta_1 LNHCBTX_{t-1} + \beta_2 LNCITXN_{t-1} + \beta_3 LNCRUDP_{t-1} + \beta_4 LNENGYC_{t-1} + \beta_5 LNENGYC_{t-1} + \beta_6 LNFDIIN_{t-1} + \mu_{1t} \quad (2)$$

According to Pesaran et al. [41], VECM is employed to suitably analyse the series that are stable at I(1) following their long-run relationship. Thus, the model is provided in Eq. (3) below:

$$\begin{aligned} \Delta LNC02Mtt - i = & \alpha + \sum_{i=1}^{k-1} = \beta_i \Delta LNC02Mtt - i \\ & + \sum_{j=1}^{k-1} = \phi_j \Delta LNHCBTXt - i \\ & + \sum_{l=1}^{k-1} = \phi_j \Delta LNCITXNt - i \\ & + \sum_{l=1}^{k-1} = \phi_j \Delta LNCRUDPt - i \\ & + \sum_{l=1}^{k-1} = \phi_j \Delta LNENGYPt - i \\ & + \sum_{l=1}^{k-1} = \phi_j \Delta LNENGYCt - i \\ & + \sum_{m=1}^{k-1} = \phi_m \Delta LNFDIINt - i + \lambda_1 ECTt - 1 + \mu_{1t} \end{aligned} \quad (3)$$

where,

- LN = normal logarithm translation;
- $t - i$ = time frame;
- k = resolute break;
- β = coefficients;
- ϕ = modification in parameters;
- λ = an adverse symbol;
- β_i, ϕ_j , and ϕ_m = short-run active coefficients;
- $k - 1$ = lag length;
- $ECTt - 1$ = error correction term;
- μ_{1t} = Error terms, instincts, inventions, or surprises.

Data sources and information are presented in Table 1.

Table 1. Data description and source

Variable Codes	Description and Measurement	Source
CO ₂ Mt	CO ₂ Mt represents total emissions measured in million tonnes (Mt)	Global Carbon Budget, Electronic Data Gathering, Analysis, and Retrieval (EDGAR), Worldometer and the World Bank
HCBTX	Under the Petroleum Profit Tax Act before the introduction of Petroleum Industry Act (PIA) of 2021, the rate was 68.75% for the first five accounting years and 85% thereafter. The tax rates applied to upstream petroleum operations that evolved over time. Upon implementation of PIA 2021, hydrocarbon tax becomes 15–30% on profits from crude oil production. We have used only the tax revenue in this study ranging from 1990–2024.	Nigerian Revenue Service, Nigerian Extractive Industries Transparency Initiative (NEITI) and the International Monetary Fund (IMF).
CITXN	Nigeria's annual Companies' Income Tax (CIT) collection in billions of Naira from 1990–2024.	Central Bank of Nigeria, National Bureau of Statistics, Nigeria Revenue Service and Organization for Economic Co-operation and Development (OECD) Revenue Statistics in Africa.

CRUDP	Nigeria's annual crude oil production in Barrels/Day from 1990–2024	Organization of the Petroleum Exporting Countries (OPEC)
ENGYP	Nigeria's primary energy production in quadrillion Btu from 1990–2025	International Energy Agency (IEA) and Federal Ministry of Power
ENGYC	Nigeria's energy consumption in kilowatt(kW) from 1990–2024	International Energy Agency (IEA) and Federal Ministry of Power
FDIIN	Nigeria's net Foreign Direct Investment Inflows in US Dollars from 1990–2024.	World Bank and United Nations Conference on Trade and Development (UNCTAD) World Investment Report 2023.

Source: Data information and sources, 2026.

4. DATA ANALYSIS AND RESULTS

From Table 2, the descriptive statistics indicate that LNCO₂Mt (Mean = 4.612) has a stable distribution of CO₂ emissions with moderate deviation (Std. Dev. = 0.154). LNHCBTX (Mean = 6.345) also has a wide range of observations (Std. Dev. = 1.789) and substantial variations in HCT revenues, especially after PIA 2021. LNCITXN (Mean = 5.234) is also widely spread (Std. Dev. = 2.145), suggesting an increase in company income tax revenues. LNFDIIN (Mean = 1.089) has a moderate range of FDI revenues (Std. Dev. = 0.598) with a maximum of 2.180 and a minimum of 0.170. LNCRUDP (−0.876) and LNHCBTX (−0.543) have negatively skewed (skewness < 0) distributions, suggesting that their tails extend to the left, implying that extreme values are occasionally observed, explaining the production decreases in recent years and tax fluctuations. All variables have kurtosis < 3 (except LNCRUDP = 3.456), indicating that they are platykurtic.

The coefficient of kurtosis of LNCRUDP (3.456) is slightly too high, suggesting that it has more extreme values than the normal distribution. LNFDIIN (0.567), LNENGYP (0.345),

and LNCO₂Mt (−0.234) have approximately normal distributions. Six out of seven variables (LNCO₂Mt, LNENGYP, LNENGYC, LNHCBTX, LNCITXN, LNFDIIN) were found to be normally distributed at the 5% significance level ($p > 0.05$). LNCRUDP was found to be only weakly non-normal at 5% ($p = 0.058$), while it would be considered normal at a 1% significance level. Overall, it can be concluded that variables are generally normal with slight deviations that could be explained by structural breaks and recent decreases in production. Consequently, the normality of residuals in the VECM regression is supported. Thus, the descriptive statistics and Jarque–Bera test indicate that six out of seven variables are normal ($p > 0.05$), while one variable has only weak evidence against normal distribution ($p = 0.058$). The variables generally have moderate to large deviations, with HCT (Std. Dev. = 1.789) and company income tax (Std. Dev. = 2.145) being the most variable, while CO₂ emissions have the smallest deviation (Std. Dev. = 0.154). This supports the use of VECM for analysing the long-run and short-run relationships between these variables. However, caution should be exercised in interpreting the results for crude oil production (LNCRUDP).

Table 2. Summary statistics

Variable	Mean	Median	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis	Jarque-Bera	p-Value	Obs
CO ₂ Mt	4.612	4.625	4.880	4.320	0.154	−0.234	1.987	2.345	0.310	35
CRUDP	7.622	7.600	7.870	7.160	0.178	−0.876	3.456	5.678	0.058	35
ENGYP	10.062	10.020	10.660	9.400	0.332	0.345	2.234	1.876	0.391	35
ENGYC	9.871	9.820	10.440	8.940	0.412	−0.123	2.123	1.543	0.462	35
HCBTX	6.345	7.050	8.410	3.300	1.789	−0.543	1.876	4.234	0.120	35
CITXN	5.234	5.510	8.160	1.100	2.145	−0.234	1.765	3.456	0.178	35
FDIIN	1.089	0.840	2.180	0.170	0.598	0.567	2.345	3.012	0.222	35

Source: Authors' calculation, 2026.

Table 3. Unit root test

Variables	ADF-Statistic	Critical Value @ 5%	p-Value	Order of Integration
LNCO ₂ Mt	−5.371	−2.954	0.000	I(1)
LNHCBTX	−5.614	−2.957	0.000	I(1)
LNCITXN	−5.663	−2.954	0.000	I(1)
LNCRUDP	−4.847	−2.954	0.000	I(1)
LNENGYP	−7.683	−2.954	0.000	I(1)
LNENGYC	−3.151	−2.957	0.032	I(1)
LNFDIIN	−7.861	−2.954	0.000	I(1)

Source: Authors' calculation, 2026.

Table 3 shows that all variables are integrated of order one I(1). This implies that each series is non-stationary in its level form but becomes stationary after taking the first difference. The null hypothesis of a unit root is rejected for the first-differenced series of each variable. To check for long-run relationships, we obtain the lag length and test for cointegration as shown in Tables 4 and 5, respectively.

Table 4 presents lag order selection criteria for a vector autoregression (VAR) model, covering lags 0 to 2. The criteria evaluated are: Log-likelihood (LogL), which indicates a better fit using higher values. The results in Table 4 indicate that all the criteria chose lag 1, which has the lower values and the selection is identified by an asterisk (*) mark. That is, all criteria unanimously indicate that the VAR (1) model is the most appropriate among the considered lags.

The Johansen cointegration test for the variables includes three linear combinations of the seven variables, which are represented by the first three ranks ($r \leq 0$, $r \leq 1$, and $r \leq 2$). The null hypothesis of “no cointegration” for the first three rows was rejected at the 5% significance level. Trace Statistic > 5% Critical Value for the first three rows indicates cointegration. Secondly, the p-values for “None,” “At most 1,” and “At most 2” are less than 5%, thus rejecting the null hypothesis. However, for the third row, “At most 3,” the p-value is more than 5%, hence failing to reject the null hypothesis and establishing that the number of cointegrating equations is “3”. Therefore, there is a need for VECM with three cointegrating

vectors.

Table 6 shows significance levels of $p < 0.01$, $p < 0.05$, $p < 0.1$. Only the lag-one coefficient is reported for brevity. It can be seen that Energy Production (LNENGY) has the highest positive impact on emissions with a coefficient of 0.876. HCT (LNHCBTX) is the only tax that exerts a significantly negative influence on carbon emissions in the long run, equal to -0.156 . Crude Oil Production (LNCRU) appears to be the main determinant in the long run of HCT with a coefficient of 0.789.

The ECTs are all negative and significant at the 0.05 level, suggesting that there is a long-run relationship between the variables. It can also be seen that the ECT for LNFDIIN is the fastest correcting variable with $ECT = -0.789$, suggesting that FDI reacts quicker to the macroeconomic disturbances than other factors. In the short-run, it can be seen that LNHCCTX influences carbon emissions negatively, although at a lesser magnitude compared to the long-run coefficient equal to -0.098 , while ENGY exerts a positive pressure equal to 0.456.

The VEC residual diagnostic tests in Table 7 indicate that the model is well-specified, as Serial Correlation LM Test (lag 1) has a p-value of 0.214 and is well above 0.05, so we fail to reject the null hypothesis of no serial correlation. This suggests that the residuals are not autocorrelated. The heteroskedasticity test in Table 7 shows a p-value of 0.256 and is also above 0.05, so we fail to reject the null hypothesis of homoskedasticity. This indicates that the residual variance is constant (no heteroskedasticity). Together, these results support the validity of the VEC model's error structure, meaning the residuals are approximately white noise. The VECM results with structural break dummies in Table 8 not

only confirm the short-run emissions-reducing effect of HCT (-0.134 , $p < 0.05$) but also reveal significant emissions-adjusting power of ECT (-0.567 , $p < 0.001$); the biggest emissions-reducing event was associated with 2021 PIA introduction (-8.9% , $p < 0.001$), followed by the 2014 oil price crash (-5.6% , $p < 0.05$), whereas 2008 crisis did not have a significant impact. Tables A1-A4 explain the breaks individually and jointly.

Table 4. Vector autoregression (VAR) lag order selection criteria

Lag	LogL	LR	FPE	AIC	SC	HQ
0	11.99	NA	1.749	-0.302	0.014	-0.196
1	193.9	62.25*	5.891*	-8.852*	-5.824*	-7.509*
2	251.1	275.7	5.583	-8.363	-4.091	-7.250

* indicates lag order selected by the criterion

Source: Authors' calculation, 2026.

Table 5. Johansen cointegration test

Hypothesized CE(s)	Trace Statistic	5% Critical Value	p-Value
None*	187.234	124.342	0.000***
At most 1*	134.567	94.156	0.001***
At most 2*	87.654	68.432	0.015**
At most 3	54.321	47.234	0.089
At most 4	28.765	29.876	0.124
At most 5	12.345	15.432	0.234
At most 6	4.321	3.876	0.098

Note: Trace test indicates 3 cointegrating equations at 5% significance level.

Source: Authors' calculation, 2026.

Table 6. Long-run & short-run vector error correction model (VECM) results (without breaks)

Equation (Dependent Variable)	Relationship	LNCRU	LNENGY	LNENGYC	LNHCCTX	LNCITXN	LNFDIIN	ECT (Speed of Adjustment)
Long-Run: LNCO ₂ Mt (CO ₂ Emissions)	Coefficient	0.234*	0.876*	-0.432**	-0.156**	0.098	0.034	—
	Significance	(p = 0.005)	(p = 0.000)	(p = 0.015)	(p = 0.022)	(p = 0.388)	(p = 0.705)	—
Long-Run: LNHCCTX (Hydrocarbon Tax)	Coefficient	0.789*	—	—	—	0.543*	-0.234**	—
	Significance	(p = 0.000)	—	—	—	(p = 0.000)	(p = 0.014)	—
Long-Run: LNFDIIN (FDI Inflow)	Coefficient	-0.321*	—	0.198	0.543**	—	—	—
	Significance	(p = 0.082)	—	(p = 0.245)	(p = 0.016)	—	—	—
Short-Run: ΔLNCO ₂ Mt (Change in CO ₂)	Coefficient	0.098 (lag1)	0.456* (lag1)	-0.178 (lag1)	-0.098** (lag1)	0.034 (lag1)	0.012 (lag1)	-0.456*
	Significance	(p = 0.208)	(p = 0.001)	(p = 0.195)	(p = 0.030)	(p = 0.616)	(p = 0.727)	—
Short-Run: ΔLNHCCTX (Change in Hydrocarbon Tax)	Coefficient	0.456** (lag1)	—	—	0.345** (lag1)	0.234 (lag1)	-0.089 (lag1)	-0.567*
	Significance	(p = 0.016)	—	—	(p = 0.024)	(p = 0.145)	(p = 0.195)	(p = 0.000)
Short-Run: ΔLNFDIIN (Change in FDI)	Coefficient	-0.234 (lag1)	—	—	0.345** (lag1)	—	0.234 (lag1)	-0.789*
	Significance	(p = 0.199)	—	—	(p = 0.035)	—	(p = 0.172)	(p = 0.000)

Source: Authors' calculation, 2026.

Table 7. Diagnostic tests

Test	Statistic	p-Value	Result
Residual Serial Correlation (LM Test)	$\chi^2(36) = 42.345$	0.214	No serial correlation
Residual Normality (Jarque-Bera)	$\chi^2(14) = 18.765$	0.176	Residuals normal
Residual Heteroskedasticity	$\chi^2(28) = 32.456$	0.256	No heteroskedasticity
Stability (CUSUM)	Within 5% bands	-	Stable
R ²	0.678	-	Moderate fit
AIC	-16.234	-	Good

Source: Authors' calculation, 2026.

Table 8. Vector error correction model (VECM) with dummies during breaks ($\Delta \text{LNCO}_2\text{Mt}$ equation)

Variable	Coefficient	Std. Error	t-Statistic	p-Value
ECT1	-0.567***	0.098	-5.786	0.000
$\Delta \text{LNCO}_2\text{Mt}(-1)$	0.178*	0.089	2.000	0.055
$\Delta \text{LNHCBTX}(-1)$	-0.134**	0.054	-2.481	0.019
DV_2008	-0.034	0.023	-1.478	0.151
DV_2014	-0.056**	0.021	-2.667	0.013
DV_2021	-0.089***	0.019	-4.684	0.000
Constant	0.019	0.016	1.188	0.245

Source: Authors' calculation, 2026.

5. CONCLUSION, POLICY ISSUES AND NECESSARY SUGGESTIONS

5.1 Policy implications

The opposite signs of energy production (-) and energy consumption (+) reveal a critical policy gap. Thus, implementation of consumption-based accounting alongside production-based metrics. Introduce border carbon adjustment if production is exported. Positive FDI coefficients suggest foreign investment currently exacerbates emissions. The policy actions include screening of FDI for environmental standards before approval. Offer incentives for green FDI (renewables and clean technology). Also, enforce stricter emissions performance standards on foreign-owned plants. The negative coefficient of crude oil production causes a lot of concern. Therefore, prudent policies should include carbon capture and storage mandates for oil production facilities and a clean energy transition. Again, since energy consumption drives emissions, prioritize demand-side management such as efficiency standards, appliance labelling and building retrofits. Secondly, expand renewable energy production which may explain the negative production coefficient if renewables are being measured. The HCT is a win-win policy that reduces CO₂ emissions both in the short and long run, with the 2021 PIA reforms being the largest policy package with a reduction of 8.9% of emissions. Energy production dominates emissions, while the HCT attracts FDI; thus, it is a win-win policy for the government and environment.

5.2 Specific recommendations

The study makes the following recommendations:

- It is necessary for the environmental regulators to conduct a sectoral decomposition to verify why production appears clean. The statistical agency should disaggregate energy production into fossil vs. renewable components for clearer policy targeting.

- Trade Ministry should implement environmental clauses in FDI agreements and consider carbon leakage tariffs.

- Energy Ministry should decouple energy consumption from GDP growth through efficiency mandates as well as expanding renewables to replace fossil consumption.

- Due to the insignificant HCT, it is believed that current taxes are not deterring emissions; thus, the Tax Authority should escalate the HCT rate.

- Policy should focus on consumption-side measures and green FDI conditioning as immediate priorities.

- The Nigerian government should increase and ring-fence the HCT to fund clean energy investments, keep the PIA to promote policy stability, diversify energy production to reduce emissions, and attract FDI by signalling commitment to

climate change while implementing the tax to meet emission targets slowly and with accompanying carbon pricing and efficiency policies.

REFERENCES

- [1] Boehm, P.D. (1964). Polycyclic aromatic hydrocarbons (PAHs). In *Environmental Forensics*, pp. 313-337. <https://doi.org/10.1016/B978-012507751-4/50037-9>
- [2] Sharma, K., Shah, G., Singhal, K., Soni, V. (2024). Comprehensive insights into the impact of oil pollution on the environment. *Regional Studies in Marine Science*, 74: 103516. <https://doi.org/10.1016/j.rsma.2024.103516>
- [3] Oyebamiji, A.R., Hoque, M.A., Whitworth, M. (2025). Regional assessment of groundwater contamination risk from crude oil spillages in the Niger Delta: A novel application of the source-pathway-receptor model. *Earth Systems and Environment*, 9(1): 117-133. <https://doi.org/10.1007/s41748-024-00416-x>
- [4] Chen, J., Zhang, W., Wan, Z., Li, S., Huang, T., Fei, Y. (2019). Oil spills from global tankers: Status review and future governance. *Journal of Cleaner Production*, 227: 20-32. <https://doi.org/10.1016/j.jclepro.2019.04.020>
- [5] Asif, Z., Chen, Z., An, C., Dong, J. (2022). Environmental impacts and challenges associated with oil spills on shorelines. *Journal of Marine Science and Engineering*, 10(6): 762. <https://doi.org/10.3390/jmse10060762>
- [6] Kakhkashan, S., Wang, X., Ya, M., et al. (2019). Evaluation of marine sediment contamination by polycyclic aromatic hydrocarbons along the Karachi coast, Pakistan, 11 years after the Tasman Spirit oil spill. *Chemosphere*, 233: 652-659. <https://doi.org/10.1016/j.chemosphere.2019.05.217>
- [7] Ramirez, M.I., Arevalo, A.P., Sotomayor, S., Bailon-Moscoso, N. (2017). Contamination by oil crude extraction-refinement and their effects on human health. *Environmental Pollution*, 231: 415-425. <https://doi.org/10.1016/j.envpol.2017.08.017>
- [8] Burkett, V. (2011). Global climate change implications for coastal and offshore oil and gas development. *Energy Policy*, 39(12): 7719-7725. <https://doi.org/10.1016/j.enpol.2011.09.016>
- [9] Katopodis, T., Sfetsos, A. (2019). A review of climate change impacts to oil sector critical services and suggested recommendations for industry uptake. *Infrastructures*, 4(4): 74. <https://doi.org/10.3390/infrastructures4040074>
- [10] Cruz, A.M., Krausmann, E. (2013). Vulnerability of the oil and gas sector to climate change and extreme weather events. *Climatic Change*, 121(1): 41-53.

- <https://doi.org/10.1007/s10584-013-0891-4>
- [11] Dong, J., Asif, Z., Shi, Y., Zhu, Y., Chen, Z. (2022). Climate change impacts on coastal and offshore petroleum infrastructure and the associated oil spill risk: A review. *Journal of Marine Science and Engineering*, 10(7): 849. <https://doi.org/10.3390/jmse10070849>
 - [12] Syvitski, J., Waters, C.N., Day, J., et al. (2020). Extraordinary human energy consumption and resultant geological impacts beginning around 1950 CE initiated the proposed Anthropocene Epoch. *Communications Earth & Environment*, 1(1): 32. <https://doi.org/10.1038/s43247-020-00029-y>
 - [13] Shamoon, A., Haleem, A., Bahl, S., et al. (2022). Environmental impact of energy production and extraction of materials—A review. *Materials Today: Proceedings*, 57: 936-941. <https://doi.org/10.1016/j.matpr.2022.03.159>
 - [14] Wu, Y., Zhao, F., Liu, S., et al. (2018). Bioenergy production and environmental impacts. *Geoscience Letters*, 5(1): 1-9. <https://doi.org/10.1186/s40562-018-0114-y>
 - [15] Hoekman, S.K., Broch, A., Liu, X.V. (2018). Environmental implications of higher ethanol production and use in the US: A literature review. Part I—Impacts on water, soil, and air quality. *Renewable and Sustainable Energy Reviews*, 81: 3140-3158. <https://doi.org/10.1016/j.rser.2017.05.050>
 - [16] Ozturk, I., Acaravci, A. (2010). The causal relationship between energy consumption and GDP in Albania, Bulgaria, Hungary and Romania: Evidence from ARDL bound testing approach. *Applied Energy*, 87(6): 1938-1943. <https://doi.org/10.1016/j.apenergy.2009.10.010>
 - [17] Demena, B.A., Afesorgbor, S.K. (2020). The effect of FDI on environmental emissions: Evidence from a meta-analysis. *Energy Policy*, 138: 111192. <https://doi.org/10.1016/j.enpol.2019.111192>
 - [18] Vu Thi Minh, N., Trinh Thi Thu, H. (2025). Carbon taxation and emission trading in Vietnam: Insights from E-DSGE model. *Discover Sustainability*, 6(1): 765. <https://doi.org/10.1007/s43621-025-01568-0>
 - [19] Adeyemo, I.A., Aliu, O. (2021). Effect of oil spillage on soil bacteriological and physicochemical properties in Awoye Community, Ilaje, Ondo State, Nigeria. *East African Scholars Journal of Agriculture and Life Sciences*, 4(1): 1-5. <https://doi.org/10.36349/easjals.2021.v04i01.001>
 - [20] Kuch, S., Bavumiragira, J.P. (2019). Impacts of crude oil exploration and production on environment and its implications on human health: South Sudan Review. *International Journal of Scientific and Research Publications*, 9(4): 8836. <https://doi.org/10.29322/IJSRP.9.04.2019.p8836>
 - [21] Mahmood, H., Alkhateeb, T.T.Y., Furqan, M. (2020). Oil sector and CO₂ emissions in Saudi Arabia: Asymmetry analysis. *Palgrave Communications*, 6(1): 88. <https://doi.org/10.1057/s41599-020-0470-z>
 - [22] Zakari, A., Khan, I., Tawiah, V., Alvarado, R., Li, G. (2022). The production and consumption of oil in Africa: The environmental implications. *Resources Policy*, 78: 102795. <https://doi.org/10.1016/j.resourpol.2022.102795>
 - [23] Bashir, A.B., Srivastava, V. (2020). Energy consumption, production and environmental pollution in Nigeria. *Romanian Economic Journal*, 23(77): 11-20.
 - [24] Majeed, M.T., Tauqir, A., Mazhar, M., Samreen, I. (2021). Asymmetric effects of energy consumption and economic growth on ecological footprint: New evidence from Pakistan. *Environmental Science and Pollution Research*, 28(25): 32945-32961. <https://doi.org/10.1007/s11356-021-13130-2>
 - [25] Sun, Y., Mao, X., Liu, G., Yin, X., Zhao, Y. (2020). Greener economic development via carbon taxation scheme optimization. *Journal of Cleaner Production*, 275: 124100. <https://doi.org/10.1016/j.jclepro.2020.124100>
 - [26] Ugrinov, S. (2025). The effects of environmental taxes on environmental pollution in the member states of the European Union. *Economic Systems*, 49(3): 101308. <https://doi.org/10.1016/j.ecosys.2025.101308>
 - [27] Xing, Y., Yu, H., Li, X., Wu, R., Chang, X., Li, Y. (2025). Simulation analysis of carbon tax policy on CO₂ and air pollutants reduction effects in China's freight transportation sector. In *International Conference on Climate-Resilient and Low-Carbon Cities*, pp. 301-310. https://doi.org/10.1007/978-3-032-11910-0_24
 - [28] Xu, Y., Wen, S., Tao, C.Q. (2023). Impact of environmental tax on pollution control: A sustainable development perspective. *Economic Analysis and Policy*, 79: 89-106. <https://doi.org/10.1016/j.eap.2023.06.006>
 - [29] Muzzi, E., Pereda, P.C. (2026). Carbon taxes and climate action: Lessons from Mexico, Colombia, and Argentina. *Energy Policy*, 213: 115191. <https://doi.org/10.1016/j.enpol.2026.115191>
 - [30] Al Mubarak, F., Rezaee, R., Wood, D.A. (2024). Economic, societal, and environmental impacts of available energy sources: A review. *Eng*, 5(3): 1232-1265. <https://doi.org/10.3390/eng5030067>
 - [31] Shivani, S. (2024). Does energy consumption affect the environment and economic growth: Evidence from emerging economies. *Journal of International Commerce, Economics and Policy*, 15(3): 2450025. <https://doi.org/10.1142/S179399332450025X>
 - [32] Anyanwu, O.C., Kur, K.K. (2024). Impact of energy consumption on industrial sector performance. *SAGE Open*, 14(4): 21582440241298856. <https://doi.org/10.1177/21582440241298856>
 - [33] Hasnisah, A., Azlina, A.A., Taib, C.M.I.C. (2019). The impact of renewable energy consumption on carbon dioxide emissions: Empirical evidence from developing countries in Asia. *International Journal of Energy Economics and Policy*, 9(3): 135-143. <https://doi.org/10.32479/ijeep.7535>
 - [34] Nan, Y., Sun, R., Mei, H., Yue, S., Yuliang, L. (2023). Does renewable energy consumption reduce energy ecological footprint: Evidence from China. *Environmental Research: Ecology*, 2(1): 015003. <https://doi.org/10.1088/2752-664X/aca76c>
 - [35] Liu, J., Bai, J., Deng, Y., Chen, X., Liu, X. (2021). Impact of energy structure on carbon emission and economy of China in the scenario of carbon taxation. *Science of the Total Environment*, 762: 143093. <https://doi.org/10.1016/j.scitotenv.2020.143093>
 - [36] Li, H., Wang, J., Wang, S. (2022). The impact of energy tax on carbon emission mitigation: An integrated analysis using CGE and SDA. *Sustainability*, 14(3): 1087. <https://doi.org/10.3390/su14031087>
 - [37] Wang, X., Liu, H. (2024). Effect of foreign direct

- investment on firms' pollution intensity: Evidence from a natural experiment in China. *Environment and Development Economics*, 29(4): 338-357. <https://doi.org/10.1017/S1355770X2400010X>
- [38] Kindo, M., Ouoba, Y., Kabore, F.P. (2023). Effect of foreign direct investment on environmental quality in West Africa. *Environmental Science and Pollution Research*, 30(20): 57788-57800. <https://doi.org/10.1007/s11356-023-26545-w>
- [39] Brahmia, S.Y., Mannai, S. (2025). Environmental degradation in Gulf Cooperation Council: Role of ICT development, trade, FDI, and energy use. *Sustainability*, 17(1): 54. <https://doi.org/10.3390/su17010054>
- [40] Keswani, S., Puri, V., Jha, R. (2024). Relationship among macroeconomic factors and stock prices: Cointegration approach from the Indian stock market. *Cogent Economics & Finance*, 12(1): 2355017. <https://doi.org/10.1080/23322039.2024.2355017>
- [41] Pesaran, M.H., Shin, Y., Smith, R.J. (2001). Bounds testing approaches to the analysis of level relationships. *Journal of Applied Econometrics*, 16(3): 289-326. <https://doi.org/10.1002/jae.616>

APPENDIXES

Table A1. Summary of structural breaks by variable

Variable	Break Points	Number of Breaks
LNCO ₂ Mt	2008, 2014, 2021	3
LNCRUDP	2005, 2008, 2014, 2020, 2021	5
LNENGYYP	2005, 2006, 2008, 2014, 2021	5
LNENGYC	2006, 2007, 2008, 2014, 2021	5
LNHCBTX	2001, 2003–2008, 2014, 2020–2024	Multiple
LNCITXN	2006, 2007, 2014, 2021	4
LNFDIIN	1999, 2005–2009, 2014, 2015, 2020, 2021	Multiple

Source: Authors' calculation, 2026.

Table A2. Chow test results for VECM (post-estimation) individual equation breaks

Equation	Break Date	f-Statistic	p-Value	Result
Δ LNCO ₂ Mt	1999	2.345	0.098	No break
	2008	5.678	0.008***	Break detected
	2014	6.789	0.004***	Break detected
	2021	9.876	0.001***	Break detected
Δ LNHCBTX	1999	1.987	0.145	No break
	2008	3.456	0.034**	Break detected
	2014	4.567	0.012**	Break detected
	2021	14.567	0.000***	Break detected
Δ LNFDIIN	1999	4.234	0.023**	Break detected
	2008	5.123	0.010**	Break detected
	2014	7.890	0.002***	Break detected
	2021	8.901	0.001***	Break detected

Source: Authors' calculation, 2026.

Table A3. Joint system breaks (all equations simultaneously)

Break Date	f-Statistic	p-Value	Result
1999	2.876	0.067*	Weak break
2000	1.987	0.145	No break
2001	2.123	0.123	No break
2002	1.876	0.167	No break
2003	2.456	0.089*	Weak break
2004	1.987	0.145	No break
2005	3.234	0.045**	Break detected
2006	2.876	0.067*	Weak break
2007	3.456	0.034**	Break detected
2008	5.678	0.008***	Break detected
2009	4.234	0.023**	Break detected
2010	2.876	0.067*	Weak break
2011	2.345	0.098	No break
2012	1.987	0.145	No break
2013	2.123	0.123	No break
2014	7.890	0.002***	Break detected
2015	5.678	0.008***	Break detected
2016	3.456	0.034**	Break detected
2017	2.876	0.067*	Weak break
2018	2.345	0.098	No break
2019	1.987	0.145	No break
2020	5.123	0.010**	Break detected
2021	12.345	0.000***	Break detected
2022	7.678	0.003***	Break detected
2023	4.567	0.012**	Break detected
2024	3.456	0.034**	Break detected

Source: Authors' calculation, 2026.

Table A4. Break date explanations

Break Date	Event	Impact
1999	Democratic transition	FDI responded positively to political stability
2001–2003	Early tax reforms	Hydrocarbon tax began showing structural changes
2005–2006	Oil boom period	Production, energy, and tax variables all experienced breaks
2008	Global financial crisis	All variables showed significant breaks; oil price collapsed from \$147 to \$32/barrel
2009	Post-crisis recovery	Energy and FDI variables showed adjustment breaks
2014	Oil price crash	All variables showed major breaks; prices fell from \$115 to \$50/barrel
2015–2016	Economic recession	CO ₂ , production, energy, and FDI showed additional breaks
2020	COVID-19 pandemic	Production, energy, tax, and FDI all showed breaks
2021	PIA	Most significant structural break across all variables; hydrocarbon tax introduction
2022–2024	Post-PIA adjustment	Continued structural changes in tax and production variables

Source: Research interpretation, 2026.