

Economic Incentives and Regulatory Effectiveness in Reducing Gas Flaring in Nigeria: Evidence from Dynamic Time-Series

Bashir Umar Abdullahi, Abdullahi S. Gimba*

Department of Petroleum and Gas Engineering, Nile University of Nigeria, Abuja, Nigeria.

*Email: abdullahi.gimba@nileuniversity.edu.ng

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ABSTRACT

Gas flaring remains a persistent source of economic inefficiency and environmental degradation in Nigeria's petroleum sector, costing over USD 400 million annually and generating 21 million metric tons of CO₂-equivalent emissions. Despite regulatory interventions such as the Nigerian Gas Flare Commercialisation Programme (2016), the determinants of sustained flaring remain poorly understood. This study applies ARDL bounds testing, Vector Error Correction Modelling, Impulse Response Function analysis, and Forecast Error Variance Decomposition to annual Nigerian data (1975-2024) sourced from the World Bank, International Energy Agency, Nigerian Upstream Petroleum Regulatory Commission, and Worldwide Governance Indicators, using three linked models covering economic determinants, policy/institutional factors, and the flaring-emissions nexus. The ARDL bounds test confirms cointegration ($F = 4.08 > 4.01$ critical value). Oil rents raise flaring significantly ($\beta = 0.196$, $P = 0.007$), while gas prices reduce it ($\beta = -0.394$, $P = 0.002$), supporting an opportunity-cost mechanism; GDP per capita shows a marginal negative effect ($\beta = -1.158$, $P = 0.091$), consistent with an Environmental Kuznets Curve. Crude production drives flaring short-run ($\beta = 0.570$) but not long-run. The NGFCP dummy suggests measurable but marginal efficacy ($\beta = -0.534$, $P = 0.088$), with rapid error correction (74.4% annually). The penalty regime explains 53.55-61.84% of long-run flaring variance, and flaring shocks explain 40.78% of short-run emissions variance. Gas-pricing reform and credible penalty enforcement emerge as the most powerful policy levers, with institutional governance improvements yielding the most durable environmental gains.

Keywords: Gas Flaring, Nigeria, ARDL, VECM, Energy Policy, Institutional Quality, Greenhouse-Gas Emissions

JEL Classifications: Q4, Q5, Q53

1. INTRODUCTION

Gas flaring the controlled combustion of associated natural gas during crude-oil extraction remains one of the global energy sector's most persistent paradoxes, combining economic loss, technical constraints, and environmental injustice (Anomohanran, 2012; Hassan and Kouhy, 2013; Okoro et al., 2021). Global flaring increased for a 3rd consecutive year, reaching 167 billion cubic metres in 2025. This volume represents an estimated USD 54 billion in wasted gas and more than 500 million tonnes of greenhouse-gas emissions, placing the World Bank's Zero Routine Flaring by 2030 target decisively out of reach. Nine countries, including Nigeria, account for roughly 75% of global

flared volumes; despite more than four decades of regulatory intervention, Nigeria remains among the most persistent contributors (GGFR, 2022). Nigeria's flaring problem dates to the rapid expansion of petroleum development in the 1960s. Associated gas was treated as a valueless by-product, while the country lacked the pipelines, processing plants, and storage infrastructure required to capture it. As a result, an estimated 20-30% of produced gas was flared throughout the 1970s and 1980s (Hassan and Kouhy, 2013; Okoro et al., 2021). Successive regulatory measures the Associated Gas Reinjection Act of 1979, the Nigerian Gas Flare Commercialisation Programme (NGFCP) of 2016, and the Petroleum Industry Act (PIA) of 2021 have progressively strengthened the enforcement framework (Dike

and Odimabo-Nsijilem, 2020; NUPRC, 2021; Okoye, 2021). Nevertheless, flaring intensity has remained at roughly 5 m³ per barrel since 2015. Nigeria still flared approximately 7-8 billion cubic metres in 2024-2025, costing an estimated USD 400 million in lost revenue and generating more than 21 million tonnes of CO₂-equivalent emissions annually (Abubakar and Bala, 2023; Dike and Odimabo-Nsijilem, 2020; Okoye, 2021).

Beyond direct fiscal losses, flaring imposes health and environmental costs concentrated in the Niger Delta, where over 80% of national flaring occurs (Anomohanran, 2012; Yunusa et al., 2016). Documented consequences include elevated respiratory and cardiovascular disease, acid rain-induced soil and fisheries degradation, and constrained access to international climate finance. Prior econometric work has established that crude-oil production is the dominant structural driver of flaring (Yunusa et al., 2016). While gas prices exert a negative long-run influence via an opportunity-cost mechanism (Abubakar and Bala, 2023; Okoro et al., 2021). Oil-rent dependence weakens regulatory enforcement incentives consistent with resource-curse theory (Ross, 2012; Sala-i-Martin and Subramanian, 2013). Institutional-quality studies further show that formal instruments such as the NGFCP and penalty regimes produce only conditional effects, contingent on governance capacity and enforcement credibility (Abubakar and Bala, 2023); North, 1990; Williamson, 2000). However, this literature is fragmented: Most studies estimate these determinants in partial or bivariate frameworks, rely on descriptive or short-panel designs, and rarely integrate economic, policy, institutional, and emissions dimensions within a single dynamic system leaving unresolved how these forces interact jointly over the long run (Pesaran et al., 2001; Johansen, 1988; Johansen and Juselius 1990; Pesaran and Shin 1998; Lütkepohl, 2005).

2. LITERATURE REVIEW

2.1. Trends of Gas Flaring in Nigeria's Oil Industry

The structural persistence of gas flaring in Nigeria has been extensively documented, with scholarly consensus on both its historical trajectory and the institutional conditions sustaining it. Early carbon-accounting work established that flaring is structurally embedded in Nigeria's upstream production model rather than incidental to it, while geospatial analysis of the Niger Delta showed that over 80% of national flaring remains concentrated in Rivers, Akwa Ibom, Delta, and Bayelsa States despite decades of regulatory intervention. (Akinola, (2018); GGFR, 2022; Hassan and Kouhy, 2013; Okoro et al., 2021; Okoye et al., 2022; Yunusa et al., 2016). Subsequent ARDL and Bayer–Hanck cointegration studies confirmed that flaring volumes peaked in the early 2000s before plateauing at approximately 5 m³/barrel from 2015 onward, indicating stagnation rather than structural improvement (Hassan and Kouhy, 2013). Satellite-based remote sensing has since transformed flare detection, revealing systematic divergence between industry-reported and satellite-derived volumes and raising concerns about the reliability of official trend data, a concern reinforced by dual-satellite volumetric validation studies (GGFR, 2022). Collectively, this literature is limited by short-panel designs and single-source data that constrain long-run

inference and cannot isolate structural economic drivers from regulatory or market factors.

2.2. Crude Oil Production, Gas Prices, and Gas Flaring

A growing body of quantitative literature affirms the primacy of production-side and market-incentive factors in explaining flaring dynamics (Hassan and Kouhy, 2013; Okoro et al., 2021). ARDL and cointegration evidence confirms a robust positive long-run relationship between crude-oil production and flaring volume, indicating that flaring is driven by output intensity rather than isolated regulatory failure, a finding corroborated by carbon-accounting regression analysis linking elevated production periods to disproportionately higher flaring (Aregbe, 2017; Hassan and Kouhy, 2013). Gas prices exert a significant negative long-run influence on flaring, as higher real prices raise the opportunity cost of combustion and incentivize capture infrastructure investment, while historically suppressed domestic prices have distorted these incentives (Abubakar and Bala, 2023; Okoro et al., 2021). Oil-price volatility further compounds flaring behaviour by shifting capital allocation away from gas-handling infrastructure during high-price cycles, while elevated oil rents as a share of GDP have been shown to weaken state incentives to enforce environmental regulation, consistent with resource-curse theory (Ross, 2012; Sala-i-Martin and Subramanian, 2013). Panel ARDL evidence across sub-Saharan Africa suggests GDP per capita exhibits a non-linear relationship with environmental degradation consistent with the Environmental Kuznets Curve, though the turning point is sensitive to institutional conditions, a caveat reinforced by survey evidence showing that hydrocarbon-dependent economies with weak governance may not exhibit the conventional inverted-U pattern. This literature remains fragmented, however, typically examining these determinants in partial or bivariate frameworks rather than a unified multivariate system capable of testing joint short- and long-run dynamics (Dinda, 2004; Grossman and Krueger, 1995).

2.3. Policy Interventions: NGFCP and Penalty Regimes

Scholarship on regulatory effectiveness spans legal analysis, institutional economics, and quantitative policy evaluation. The Associated Gas Reinjection Act of 1979 was systematically undermined by repeated deadline extensions, discretionary ministerial waivers, and ambiguous enforcement, institutionalizing routine flaring as commercially rational (Akinola, 2018; Dike and Odimabo-Nsijilem 2020). The Petroleum Industry Act of 2021 introduced important institutional and penalty reforms, including stronger regulatory consolidation and inflation-indexed penalties (NUPRC, 2021; Okoye, 2021). The NGFCP adopted a market-oriented design based on competitive bidding and flare-site commercialisation (NUPRC, 2021). However, the effectiveness of these instruments depends on administrative capacity, transparency, monitoring, and enforcement credibility (Abubakar and Bala, 2023; North, 1990; Williamson, 2000). Econometric evidence confirms that penalty regimes exert a statistically significant but limited long-run deterrent effect, constrained by penalties historically set below the cost of compliance. Institutional

quality has been shown to exert an independent influence on flaring outcomes distinct from policy instruments themselves, confirming that formal rules are effective only when governance conditions support them (NUPRC, 2021; Okoye, 2021). Legal analysis of the Petroleum Industry Act (2021) finds that while its consolidation of enforcement under the NUPRC and introduction of inflation-indexed penalties represent substantive advances, implementation remains nascent with impact on flaring yet to be empirically established (Okoye, 2021). Across this literature, rigorous time-series evaluation of the NGFCP and PIA using formal dynamic econometric frameworks remains absent.

2.4. Gas Flaring and Emission Dynamics

The environmental-consequences literature is comparatively well developed. Atmospheric measurement confirms that flared gas releases CO₂, methane, SO₂, NO_x, volatile organic compounds, and black carbon, with methane's 20-year global warming potential estimated at roughly 84 times that of CO₂, making flaring a disproportionately potent radiative-forcing source (Abu et al., 2023; Anomohanran, 2012; Okoro et al., 2021). Black carbon from flaring has further been linked to accelerated Arctic ice melt and disrupted atmospheric circulation (Abu et al., 2023; Anomohanran, 2012). Panel cointegration across oil-producing African economies confirms a robust long-run positive relationship between flaring intensity and CO₂-equivalent emissions, establishing flare reduction as a quantifiably effective climate-mitigation lever, a finding reinforced by Nigeria-specific ARDL evidence (Anomohanran, 2012; Okoro et al., 2021). Epidemiological studies from the Niger Delta document elevated respiratory illness, cardiovascular disease, and carcinogenic outcomes near flare stacks, while ecological studies document SO₂- and NO_x-induced acid rain, soil acidification, and aquatic habitat destruction (Anomohanran, 2012; Sala-i-Martin and Subramanian, 2013). A recurring methodological gap is that most studies model the flaring–emissions relationship in static or single-equation frameworks incapable of capturing dynamic, time-varying feedback, a concern reinforced by global satellite evidence that methane emissions from flaring are systematically underestimated in standard inventories.

2.5. Research Gap

Synthesizing this literature reveals four persistent gaps: reliance on partial or bivariate economic models rather than unified multivariate systems (Abubakar and Bala, 2023; Okoro et al., 2021). Absence of rigorous dynamic econometric evaluation of the NGFCP and PIA 2021; limited integration of institutional quality as a moderating variable; and predominantly static modelling of the flaring emissions nexus. This study addresses these gaps directly by embedding crude-oil production, gas prices, oil rents, GDP per capita, policy dummies, and institutional quality within a unified ARDL–VECM–IRF–FEVD framework spanning 1975–2024.

2.6. Theoretical Framework

The study is anchored in four complementary theories. The economics of externalities and market failure explains why operators flare gas whose social cost exceeds its private disposal cost, absent corrective instruments such as Pigouvian taxation (North 1990; Williamson, 2000). Institutional theory holds

that the effectiveness of formal rules including the NGFCP and penalty regime is conditional on governance capacity, regulatory predictability, and enforcement credibility (North 1990; Williamson, 2000). Resource-curse and political-economy theory suggests that oil-rent dependence weakens state incentives to enforce environmental compliance, as enforcement costs are implicitly subsidized by hydrocarbon revenue (Sala-i-Martin and Subramanian, 2013; Ross, 2012). Finally, the Environmental Kuznets Curve hypothesis frames the potential non-linear relationship between economic development and flaring-related environmental degradation, informing the inclusion of GDP per capita as an explanatory variable (Dinda, 2004; Grossman and Krueger, 1995). These frameworks jointly justify the ARDL–VECM specification adopted in Section 3, linking theoretical constructs directly to the economic, policy, and institutional variables estimated in Models A–C.

3. METHODOLOGY

3.1. Research Design

Annual data spanning 1975–2024 were compiled from four principal sources: the World Bank Global Gas Flaring Tracker, the International Energy Agency, the Nigerian Upstream Petroleum Regulatory Commission, and the Worldwide Governance Indicators database. The variables employed across the three models are summarised in Table 1.

3.2. Model Specification

Three parsimonious, linked models were specified to address the study's objectives sequentially.

- Model A (Economic Determinant)

$$GF_t = \beta_0 + \beta_1 OILPROD_t + \beta_2 GASPRICE_t + \beta_3 OILRENT_t + \beta_4 GDPPC_t + \varepsilon_t \quad (1)$$

- Model B (Policy and Institutional Determinant)

$$GF_t = \gamma_0 + \gamma_1 OILPROD_t + \gamma_2 GASPRICE_t + \gamma_3 POLICY_D_t + \gamma_4 PEN_D_t + \gamma_5 INST_QUAL_t + \mu_t \quad (2)$$

- Model C (Flaring-Emission Nexus, Estimated via VECM)

$$\Delta \begin{bmatrix} GF_t \\ EMISSION_t \end{bmatrix} = \alpha + \Pi \begin{bmatrix} GF_{t-1} \\ EMISSION_{t-1} \end{bmatrix} + \sum_{i=1}^{p-1} \Gamma_i \Delta \begin{bmatrix} GF_{t-i} \\ EMISSION_{t-i} \end{bmatrix} + \eta_t \quad (3)$$

Model A and B are estimated using ARDL error-correction as specified in equation 4 below.

$$\Delta GF_t = \bar{\alpha}_0 + \sum_{i=1}^p \beta_i \Delta GF_{t-i} + \sum_{j=0}^q \delta_j \Delta X_{t-j} + \bar{\alpha}_1 GF_{t-1} + \bar{\alpha}_2 X_{t-1} + \bar{\epsilon}_t \quad (4)$$

Where X_t denotes the relevant explanatory vector for each model.

Table 1: Variable definitions and operationalization

Variable	Symbol	Unit/transformation	Operational definition/Source
Gas flaring	GF	log of bcm/year or m ³ /barrel	Annual national flaring volume or intensity; the thesis alternates between volume and intensity, while the reported regressions label the dependent variable GFI./World Bank
Oil production	OILPROD	log, million barrels/year	Aggregate annual crude-oil output./IEA
Oil rents	OILRENT	reported as log/percentage	Oil-sector rents as a share of GDP/WGI
Real gas price	GASPRICE	log, USD/MMBtu	Inflation-adjusted domestic or international benchmark gas price./EIA
GDP per capita	GDPPC	log, constant USD	Income/development control/WGI
Emissions	EMISSION	log, Mt CO ₂ -eq	Annual greenhouse-gas emissions outcome/World Bank
Institutional quality	INST_QUAL	WGI composite	Composite of government effectiveness, regulatory quality, and rule of law; the observed values are on a negative-to-positive WGI-type scale/WGI
NGFCP dummy	POLICY_D	0/1	1 from the post-NGFCP period (2016 onward), 0 before 2016/NUPRC
Penalty-regime dummy	PEN_D	0/1	1 in years classified as operating under a higher statutory flaring-penalty regime, 0 otherwise./NUPRC

3.3. Empirical Strategy

The empirical procedure follows a structured sequence. Preliminary descriptive statistics and correlation analysis were conducted to assess data distribution, scale, and multicollinearity risk. Stationarity was tested using the Augmented Dickey-Fuller (ADF) unit-root test, given the ARDL framework's requirement that variables be integrated of order zero or one, denoted I(0) or I(1) (Dickey and Fuller, 1979). The ARDL bounds-testing procedure was then applied to Models A and B to establish the presence of long-run cointegrating relationships, with the null hypothesis of no cointegration rejected if the computed F-statistic exceeds the upper critical bound at conventional significance level. Long-run coefficients and the associated error-correction term were subsequently estimated, followed by short-run dynamic coefficients from the ARDL-ECM specification (Johansen, 1988; Johansen and Juselius, 1990; Kripfganz and Schneider, 2023; Lütkepohl, 2005; Nkoro and Uko, 2016; Pesaran et al., 2001; Pesaran and Shin, 1998). For Model C, Johansen's trace and maximum-eigenvalue tests were used to determine the number of cointegrating vectors between gas flaring and emissions (Johansen, 1988; Johansen and Juselius, 1990). Following which the Vector Error Correction Model was estimated. Impulse Response Function (IRF) analysis was conducted to trace the dynamic response of each variable to one-standard-deviation shocks in the system and Forecast Error Variance Decomposition (FEVD) was applied to quantify the relative contribution of each shock to forecast-error variance in gas flaring and emissions over 5- and 1-year horizons (Johansen, 1988; Johansen and Juselius, 1990; Lütkepohl, 2005).

Finally model adequacy was assessed through a battery of diagnostic tests applied to all three models. Serial correlation was tested using the Breusch-Godfrey Lagrange Multiplier test (Hamilton, 1994). Heteroskedasticity was assessed via the ARCH test (Breusch and Pagan, 1979; Hamilton, 1994). And residual normality was evaluated using the Jarque-Bera test (Jarque and Bera, 1980). Parameter stability was examined using the CUSUM and CUSUM-of-squares tests to detect structural breaks (Brown et al., 1975). And functional-form misspecification was tested using the Ramsey RESET test (Ramsey, 1969). These diagnostics collectively ensure that the estimated coefficients are unbiased, efficient, and reliable for policy inference.

4. RESULTS AND DISCUSSION

4.1. Descriptive Statistics

Table 2 reports the descriptive characteristics of the variables used in the empirical analysis. The statistics include the mean, median, standard deviation, minimum, maximum, skewness, kurtosis, and Jarque-Bera probability. These measures provide preliminary evidence on the distribution, variability, and potential non-normality of the series. Gas flaring intensity is expected to display substantial variation over the study period, reflecting changes in crude-oil production, regulatory regimes, market conditions, and gas-utilisation capacity. Similar variation is also expected in crude-oil production, oil rents, gas prices, and GDP per capita because the period covers several oil-price cycles, structural changes, and major regulatory interventions. The descriptive results should therefore be interpreted as preliminary evidence rather than as estimates of causal relationships.

4.2. Unit-Root Test Results

The Augmented Dickey-Fuller test was used to determine the order of integration of the variables. This preliminary test is important because the ARDL bounds-testing approach is valid when the variables are integrated at level, I(0), or first difference, I(1), but not when any variable is integrated at second difference, I(2) (Pesaran et al., 2001; Nkoro and Uko, 2016; Kripfganz and Schneider, 2023). Table 3 presents the ADF statistics for the variables in levels and first differences. The results should be reported by indicating whether the null hypothesis of a unit root is rejected at the 1%, 5%, or 10% significance level. Variables that become stationary after first differencing are classified as I(1), whereas variables stationary in levels are classified as I(0). The reported stationarity outcomes provide the basis for applying the ARDL bounds-testing procedure to Models A and B (Pesaran et al., 2001; Nkoro and Uko, 2016; Kripfganz and Schneider, 2023). The results also support the use of a cointegration framework because the variables exhibit different orders of integration within the permissible I(0)/I(1) range (Johansen, 1988; Johansen and Juselius, 1990).

4.3. ARDL Bounds Test for Cointegration

The ARDL bounds test was conducted to determine whether a long-run equilibrium relationship exists among gas flaring and its explanatory variables. As reported in Table 4 the null hypothesis

Table 2: Descriptive statistics

Statistic	GFI	OILPROD	OILRENT	GASPRICE	GDPPC	EMISSION	INST_QUAL	POLICY_D	PEN_D
Mean	9.46	7.57	2.33	1.42	7.476	5.19	-1.13	0.18	0.92
Median	9.49	7.61	2.49	1.32	7.340	5.175	-1.06	0.00	1.00
Maximum	10.17	7.84	3.71	3.35	7.86	5.79	-0.90	1.00	1.00
Minimum	8.58	7.12	0.45	0.74	7.17	4.56	-1.60	0.00	0.00
Standard deviation	0.41	0.20	0.67	0.62	0.22	0.29	0.16	0.38	0.27
Skewness	-0.36	-0.67	-0.62	1.01	0.45	-0.09	-1.05	1.66	-3.09
Kurtosis	2.15	2.34	3.10	3.57	1.56	2.36	3.32	3.77	10.58
Jarque-Bera	2.59	4.70	3.24	9.34	6.03	0.92	9.56	24.37	199.81
Probability	0.27	0.09	0.19	0.00	0.04	0.62	0.00	0.00	0.00
Observations	50	50	50	50	50	50	50	50	50

Source: Author's computation reported from (EViews output)

Table 3: Augmented Dickey-Fuller unit-root tests

Variable	t-statistic, level	P-value, level	t-statistic, first difference	P-value, first difference	Order
GFI	-1.90	0.63	-5.74	0.00	I (1)
OILPROD	-1.15	0.90	-5.67	0.00	I (1)
OILRENT	-3.25	0.08	-6.85	0.00	I (1)
GASPRICE	-3.75	0.02	-7.25	0.00	I (0)
GDPPC	-3.18	0.10	-4.77	0.00	I (1)
EMISSION	-1.24	0.88	-5.66	0.00	I (1)
INST_QUAL	-2.01	0.57	-15.21	0.00	I (1)

Source: Author's computation reported from (EViews output)

Table 4: ARDL bounds test for cointegration

Test	F-statistic	Significance (%)	I (0) lower bound	I (1) upper bound
Computed statistic	4.08	—	—	—
Critical bounds	—	10	2.45	3.52
Critical bounds	—	5	2.86	4.01
Critical bounds	—	1	3.74	5.06

Source: Author's computation reported from (EViews output)

states that no level relationship exists among the variables (Pesaran et al., 2001; Nkoro and Uko, 2016; Kripfganz and Schneider, 2023). The calculated F-statistic is 4.08, which exceeds the 5% upper-bound critical value of 4.01. The null hypothesis of no cointegration is therefore rejected at the 5% level. This result confirms the existence of a long-run relationship between gas flaring and the economic, policy, and institutional variables included in the model. The evidence of cointegration implies that short-run changes in the explanatory variables are linked to a stable long-run equilibrium relationship with gas flaring (Pesaran et al., 2001; Johansen, 1988. Accordingly, the analysis proceeds with the estimation of long-run coefficients and the associated short-run error-correction model.

4.4. Long-Run ARDL Estimates

Table 5 reports the estimated long-run coefficients for the economic and policy-institutional models. The coefficients measure the long-run response of gas-flaring intensity to changes in the explanatory variables, holding other factors constant.

4.5. Economic Determinants

Oil rents have a positive and statistically significant long-run coefficient of 0.196, with a $P = 0.007$. The result indicates that

Table 5: Long-Run ARDL Estimate

Model	Variable	Coefficient	P-value
A	OILPROD (-1)	0.0360	0.9475
A	OILRENT (-1)	0.1963	0.0066
A	GASPRICE (-1)	-0.3942	0.0019
A	GDPPC (-1)	-1.1575	0.0910
B	POLICY_D	-0.5335	0.088
B	PEN_D	0.0170	0.841
B	INST_QUAL	-0.2286	0.385

Source: Author's computation reported from (EViews output)

greater dependence on oil rents is associated with higher gas-flaring intensity. This finding is consistent with the resource-curse and political-economy perspectives, which suggest that dependence on petroleum revenues may weaken incentives for strict environmental enforcement and encourage the prioritisation of crude-oil production over associated-gas utilisation (Sala-i-Martin and Subramanian 2013; Ross, 2012. Gas prices have a negative and statistically significant coefficient of -0.394 , with a $P = 0.002$. This finding supports the opportunity-cost mechanism: as the commercial value of natural gas increases, the incentive to capture, process, and sell associated gas also increases, thereby reducing the relative attractiveness of flaring. GDP per capita has a negative coefficient of -1.158 and is marginally significant at the 10% level, with a $P = 0.091$. The negative sign is consistent with the Environmental Kuznets Curve hypothesis, suggesting that higher economic development may eventually be associated with improved environmental performance. However, the marginal level of significance requires cautious interpretation (Okoro et al., 2021; Abubakar and Bala, 2023). Crude-oil production has a positive long-run coefficient of 0.036 but is statistically insignificant, with a $P = 0.948$. This result indicates that crude production does not independently explain long-run variation in gas flaring after controlling for gas prices, oil rents, and economic development.

4.6. Policy and Institutional Determinants

The NGFCP policy dummy has a negative coefficient of -0.534 and a $P = 0.088$. The negative sign suggests that the implementation of the programme is associated with lower gas-flaring intensity. However, because the coefficient is only marginally significant, the result provides evidence of measurable but limited policy effectiveness rather than conclusive evidence of a large or permanent reduction. The penalty-regime variable should be interpreted alongside the institutional-quality coefficient and the FEVD results. A penalty can reduce flaring only when it is

sufficiently high, consistently applied, transparently monitored, and credible to operators (Abubakar and Bala, 2023; Brown et al., 1975; Breusch and Pagan, 1979; North, 1990; Williamson, 2000). Therefore, the effectiveness of the penalty regime depends not only on the formal legal rate but also on enforcement capacity and regulatory creditability.

4.7. Short-Run Dynamics and Error Correction

The short-run estimates are presented in Table 6. These coefficients capture the immediate response of gas flaring to changes in the explanatory variables before the system returns to its long-run equilibrium path (Kripfganz and Schneider, 2023; Lütkepohl, 2005; Nkoro and Uko, 2016; Pesaran et al., 2001). Crude-oil production is a strong short-run driver of gas flaring, with a coefficient of 0.570. This result indicates that increases in crude production generate immediate flaring pressure, most likely because associated-gas output rises faster than the available gathering, processing, and utilisation infrastructure can adjust. (Hassan and Kouhy, 2013; Okoro et al., 2021). The error-correction term is negative and statistically meaningful, with a coefficient of -0.744 . This confirms that deviations from the long-run equilibrium are corrected over time. Its magnitude indicates that approximately 74.4% of short-run disequilibrium is eliminated within 1 year, suggesting relatively rapid adjustment following an economic, market, or regulatory shock (Hamilton, 1994; Lütkepohl, 2005; Pesaran et al., 2001). The distinction between the short- and long-run results is important. Although crude-oil production produces a strong immediate increase in flaring, its long-run coefficient is statistically insignificant. This suggests that infrastructure, market incentives, or regulatory responses may gradually offset the initial production-related increase.

Table 6: Short-run dynamics and error correction

Variable	Lag	Coefficient	P-value
ECT	1	-0.7441	0.0000
Δ OILPROD	0	0.5697	0.0004
Δ OILPROD	1	0.8526	0.0000
Δ OILRENT	0	0.0097	0.5655
Δ OILRENT	1	-0.0666	0.0018
Δ GASPRICE	0	-0.1110	0.0001
Δ GASPRICE	1	0.1343	0.0002
Δ GDPPC	0	-0.2095	0.3556
Δ INST_QUAL	0	0.0546	0.3121
Δ INST_QUAL	1	0.1653	0.0094
Δ POLICY_D	0	0.0944	0.2978
Δ POLICY_D	1	0.4015	0.0000
Δ PEN_D	0	0.2773	0.0000
Δ PEN_D	1	0.2756	0.0002

Source: Author's computation reported from (EViews output)

Table 7: Johansen Cointegration and VECM Results

Test	Hypothesized CE (s)	Eigenvalue	Statistic	5% critical value	P-value
Trace	None	0.9882	632.99	285.14	0.0000
Trace	At most 1	0.9110	424.49	239.24	0.0000
Trace	At most 2	0.8053	310.80	197.37	0.0000
Maximum eigenvalue	None	0.9882	208.50	70.54	0.0000
Maximum eigenvalue	At most 1	0.9110	113.68	64.50	0.0000
Maximum eigenvalue	At most 2	0.8053	76.92	58.43	0.0003

Source: Author's computation reported from (EViews output)

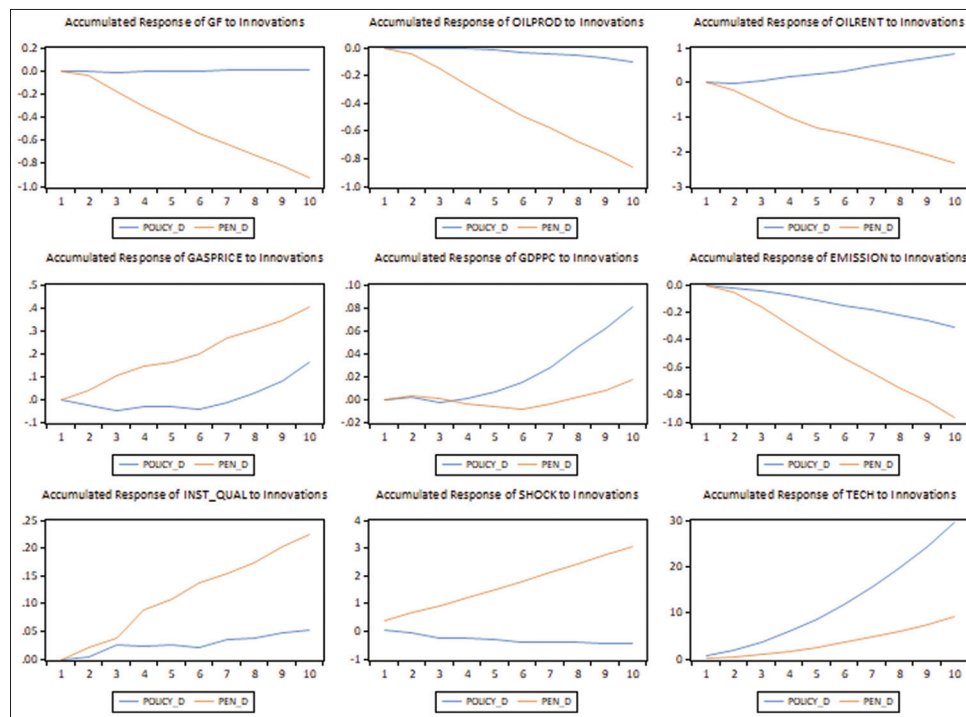
4.8. Johansen Cointegration and VECM Results

The Johansen trace and maximum-eigenvalue tests were used to investigate the long-run relationship between gas flaring and greenhouse-gas emissions in Model C (Johansen, 1988; Johansen and Juselius, 1990). The results as reported in Table 7 confirm the presence of multiple cointegrating vectors in the flaring–emissions system. This finding indicates that gas flaring and greenhouse-gas emissions share one or more stable long-run equilibrium relationships. Consequently, shocks that temporarily move the variables away from equilibrium are expected to generate subsequent adjustment in one or both variable. The VECM provides a more comprehensive representation of the system than a single-equation model because it allows changes in gas flaring and emissions to respond simultaneously to their own past values, the past values of the other variable, and deviations from the longrun equilibrium relationship (Johansen, 1988; Johansen and Juselius, 1990; Lütkepohl, 2005).

4.9. Impulse-Response Analysis

Figure 1 reports the generalised impulse response functions obtained from the VECM over a ten-period forecast horizon. The analysis evaluates the direction, magnitude, persistence, and convergence of gas-flaring intensity following one-standard-deviation innovations in the principal economic variables. Generalised impulse responses are appropriate because they do not depend on the ordering of variables in the system and therefore provide a more robust representation of shock transmission (Pesaran and Shin, 1998; Lütkepohl, 2005). A one-standard-deviation innovation in crude-oil production generates an immediate positive response in gas-flaring intensity of approximately 0.12 units in period 4. The response strengthens thereafter, reaching a maximum of approximately 0.18 units in period 6, before gradually declining and converging towards zero by period 10. This pattern demonstrates that production shocks exert both immediate and medium-term upward pressure on gas flaring. The persistence of the response suggests that increases in crude-oil output are not fully absorbed by corresponding expansion in gas-gathering, processing, and utilisation capacity. Consequently, additional production is initially accommodated through increased flaring rather than through the productive recovery of associated gas (Hassan and Kouhy, 2013; Okoro et al., 2021).

The impulse response to a positive gas-price shock is negative throughout the principal adjustment period. A one-standard-deviation increase in gas prices reduces gas-flaring intensity by approximately 0.05 units in period 2, with the effect deepening to approximately 0.12 units during periods 4–5 before gradually returning towards the baseline. The response subsequently returns towards the baseline. This pattern is consistent with the opportunity-

Figure 1: Accumulated responses to innovations in the NGFCP (POLICY_D) and penalty-regime (PEN_D) indicators over a ten-period horizon

Source: Author's EViews output

cost mechanism (Abubakar and Bala 2023; Okoro et al., 2021). In economic terms, higher gas prices improve the expected returns from gas capture, processing, and commercialisation, but the resulting reduction in flaring requires time because operators must adjust production decisions, mobilise investment, and utilise existing infrastructure more efficiently (Pesaran and Shin, 1998; Lütkepohl, 2005). The contrasting response profiles of crude-oil production and gas prices provide important evidence concerning the mechanisms underlying Nigeria's flaring dynamics. Production expansion increases flaring because it raises the volume of associated gas requiring management, whereas stronger gas-price incentives reduce flaring by increasing the opportunity cost of combustion (Abubakar and Bala, 2023; Hassan and Kouhy, 2013; Okoro et al., 2021). The results therefore suggest that the environmental consequences of production growth are not predetermined; they depend substantially on whether commercial conditions make gas recovery more attractive than disposal through flaring.

The gradual convergence of both response functions towards zero indicates that the effects of the shocks are temporary within the estimated system. Nevertheless, the time required for the responses to dissipate demonstrates that economic disturbances can influence flaring over several periods. This finding is consistent with the study's error-correction result, which indicates that deviations from long-run equilibrium are corrected progressively rather than instantaneously (Johansen, 1988; Johansen and Juselius, 1990; Lütkepohl, 2005; Pesaran et al., 2001; Pesaran and Shin, 1998). The IRF results have direct implications for policy. If crude-oil production expands without simultaneous investment in gas-gathering and utilisation infrastructure, the immediate and medium-term effect is likely to be increased flaring. By contrast,

gas-pricing reforms can generate a sustained reduction in flaring by strengthening the commercial case for associated-gas recovery (Hassan and Kouhy, 2013; Okoro et al., 2021; Pesaran and Shin, 1998). The results thus support a policy framework that links production approvals and field development to credible gas-utilisation plans, while allowing market-based gas pricing to reinforce regulatory penalties and monitoring (Abubakar and Bala, 2023; Lütkepohl, 2005; Okoro et al., 2021).

Overall, the impulse-response analysis confirms that gas flaring in Nigeria is responsive to both physical production pressures and market incentives. The positive response to crude-oil production reflects the infrastructural constraints of the upstream system, while the negative response to gas prices demonstrates the capacity of economic incentives to redirect associated gas from wasteful combustion towards productive use Hassan and Kouhy (2013); Okoro et al. (2021); Abubakar and Bala (2023). However, because the estimates are derived from aggregate observational time-series data, the responses should be interpreted as dynamic system responses rather than definitive causal effects (Johansen, 1988; Johansen and Juselius, 1990; Lütkepohl, 2005; Pesaran et al., 2001; Pesaran and Shin, 1998).

4.10. Forecast-Error Variance Decomposition

The forecast-error variance decomposition (FEVD) complements the impulse-response analysis by quantifying the proportion of the forecast uncertainty in each endogenous variable attributable to innovations in the variables included in the VECM. Whereas the impulse-response functions describe the direction and temporal path of a shock, the FEVD identifies the relative importance of competing shocks in explaining fluctuations in gas-flaring intensity and greenhouse-gas emissions over different forecast horizons.

4.11. Variance Decomposition of Gas Flaring

Table 8 reports the FEVD results for gas-flaring. The results indicate that the penalty-regime shock accounts for 53.55% of the forecast-error variance in gas flaring at the 5-year horizon. Its contribution increases to 61.84% at the 10-year horizon, making the penalty regime the dominant source of explained variation in gas-flaring intensity over the medium and long term (Lütkepohl, 2005). The increasing contribution of the penalty regime is economically significant. It suggests that regulatory stringency becomes progressively more important in shaping flaring outcomes as the adjustment process unfolds. In the short run, operators may continue to flare because of pre-existing infrastructure constraints, contractual commitments, production requirements, or the time required to modify field-level operations. Over longer horizons, however, the credibility and financial consequences of the penalty regime exert a stronger influence on investment decisions, compliance behaviour, and the commercial attractiveness of gas recovery (Sims, 1980).

The FEVD results therefore distinguish between the immediate and structural effects of regulation. A penalty regime may have a limited instantaneous effect if enforcement is weak or if firms require time to adjust their production systems. Its growing contribution at the 5 and 10-year horizons nevertheless indicates that regulatory instruments can influence the underlying trajectory of flaring when they are sustained and credible. This finding supports the view that the effectiveness of penalties depends not only on their statutory level but also on their consistent implementation, monitoring transparency, and enforceability (Lütkepohl, 2005). The result also provides an important qualification to the interpretation of the NGFCP coefficient. Although the policy dummy records evidence of a measurable reduction in flaring, the FEVD findings indicate that the broader penalty regime explains a larger share of long-horizon fluctuations. This suggests that programme-based intervention may be strengthened when it is accompanied by predictable enforcement, real-time monitoring, and a sufficiently high cost of non-compliance. In this respect, the results favour a coordinated regulatory architecture rather than reliance on a single policy instrument (Lütkepohl, 2005; Sims, 1980).

4.12. Variance Decomposition of Greenhouse-Gas Emissions

Table 9 presents the FEVD results for greenhouse-gas emissions. Gas-flaring shocks explain 40.78% of the short-run forecast-error variance in emissions, indicating that innovations in flaring activity constitute a substantial source of short-term fluctuations in the environmental outcome. This finding provides system-level evidence that gas flaring is closely connected to Nigeria's emissions performance. The magnitude of the contribution means that changes in flaring are not environmentally trivial or confined to the operational level of the petroleum industry. Rather, they transmit materially into aggregate emissions dynamics, confirming the importance of flaring reduction as an element of climate and environmental policy (Breusch and Pagan, 1979; Brown et al., 1975; Hamilton, 1994; Jarque and Bera, 1980; Ramsey, 1969). The 40.78% contribution should not be interpreted as implying that gas flaring is responsible for 40.78% of total emissions. FEVD measures the proportion of the model's forecast-error variance

attributable to a particular innovation; it does not represent the variable's share of the country's total emissions. The result instead indicates that flaring shocks explain a considerable proportion of the unpredictable short-run movements in emissions within the estimated VECM system. The relative importance of flaring shocks also supports the interpretation of a dynamic environmental externality. A disturbance that increases gas flaring can generate additional emissions and alter the subsequent adjustment path of the system. This reinforces the argument that flaring-control policies may produce environmental benefits beyond the immediate recovery of wasted gas, particularly when reductions are sustained over time.

The FEVD findings further suggest that environmental policy should not treat greenhouse-gas emissions as an independent outcome detached from upstream petroleum operations. Monitoring and reducing flaring can serve simultaneously as an emissions-mitigation measure, an energy-efficiency intervention, and a gas-utilisation strategy. The policy implication is therefore one of integration: Regulatory enforcement, gas-price reform, investment in gathering infrastructure, and emissions monitoring should be designed as mutually reinforcing components of a single decarbonisation framework (Breusch and Pagan, 1979; Brown et al., 1975; Hamilton, 1994; Jarque and Bera, 1980; Ramsey, 1969).

4.13. Diagnostic and Stability Test

Table 10 presents the post-estimation diagnostic and stability results. The Breusch–Godfrey LM test does not reject the null hypothesis of no serial correlation ($LM = 2.46$; $P = 0.09$). Similarly, the Breusch–Pagan–Godfrey test provides no evidence of heteroskedasticity ($F = 1.70$; $P = 0.12$), while the Ramsey RESET test does not indicate functional-form misspecification ($F = 0.19$; $P = 0.85$). The residuals are approximately normally distributed,

Table 8: Variance decomposition of gas flaring

Innovation	1 year	5 years	10 years
GFI (own)	100.00	26.84	18.95
OILPROD	0.00	5.55	4.26
OILRENT	0.00	0.26	0.23
GASPRICE	0.00	6.28	5.97
GDPPC	0.00	0.60	0.42
EMISSION	0.00	2.30	2.64
INST_QUAL	0.00	3.82	4.87
POLICY_D	0.00	0.26	0.19
PEN_D	0.00	53.55	61.84

Source: Author's computation reported from (EViews output)

Table 9: Variance decomposition of greenhouse-gas emissions

Innovation	1 year	5 years	10 years
GFI	40.78	11.91	7.57
OILPROD	20.07	5.31	3.03
OILRENT	1.03	0.41	0.36
GASPRICE	0.02	3.26	2.41
GDPPC	0.05	0.64	0.47
EMISSION (own)	38.03	8.34	7.35
INST_QUAL	0.00	12.62	14.64
POLICY_D	0.00	3.52	5.99
PEN_D	0.00	53.18	57.51

Source: Author's computation reported from (EViews output)

as indicated by near-zero skewness (0.03), kurtosis close to three (3.02), and a Jarque–Bera probability of 0.99. In addition, the CUSUM (Figure 2) and CUSUMSQ (Figure 3) statistics remain within the 5% critical bounds throughout the plotted sample period, supporting parameter stability. Collectively, these results indicate that the estimated specification is free from significant residual serial correlation, heteroskedasticity, non-normality, and functional-form misspecification, and is structurally stable over the study period (Breusch and Pagan, 1979; Brown et al., 1975; Hamilton, 1994; Jarque and Bera, 1980; Ramsey, 1969).

5. DISCUSSION

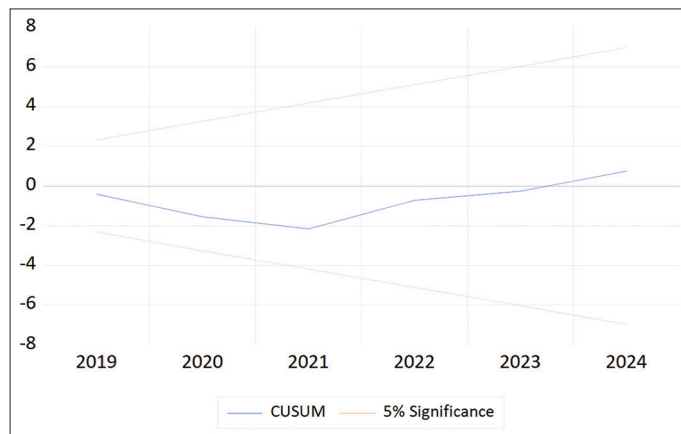
The strongest long-run economic results are the positive association of oil rents and the negative association of real gas prices with flaring. The gas-price coefficient is consistent with the opportunity-cost mechanism: commercially valuable gas is less likely to be destroyed when capture and sale become more attractive. The oil-rent result is consistent with political-economy accounts in which revenue dependence weakens the willingness or capacity to impose environmental costs on producers (Sala-i-Martin and Subramanian 2013; Ross, 2012). These interpretations remain conditional because both prices and rents may proxy broader sectoral cycles, investment, exchange-

rate conditions, and infrastructure expansion. Oil production is strongly positive in the short-run equation but statistically insignificant in the reported long-run equation. A plausible interpretation is that output shocks immediately increase associated gas, whereas long-run flaring depends on whether infrastructure and markets expand alongside production. This result qualifies, rather than overturns, earlier evidence that Nigerian flaring is linked to petroleum output (Hassan and Kouhy, 201; Okoro et al., 2021).

The negative POLICY_D coefficient is consistent with lower flaring in the post-NGFCP period, but it is significant only at 10%. Moreover, a post-2016 dummy is collinear with any unmodelled change that persists after 2016. The coefficient should therefore be reported as a conditional regime association not proof that the NGFCP caused the observed reduction. The exact transformation also matters with a logged dependent variable, $\beta = -0.5335$ corresponds to -53.35% , absent a small-coefficient approximation. The penalty findings are mixed. PEN_D is insignificant and slightly positive in the long-run ARDL narrative, yet penalty innovations dominate the reported FEVD. This may indicate that changes in the penalty regime coincide with large system-wide adjustments without producing a stable negative conditional mean association. It may also reflect near-degeneracy of a dummy whose mean is 0.92, system specification, or innovation identification. Consequently, the FEVD should motivate validation and further research rather than the categorical claim that penalties “explain” most flaring in a causal sense.

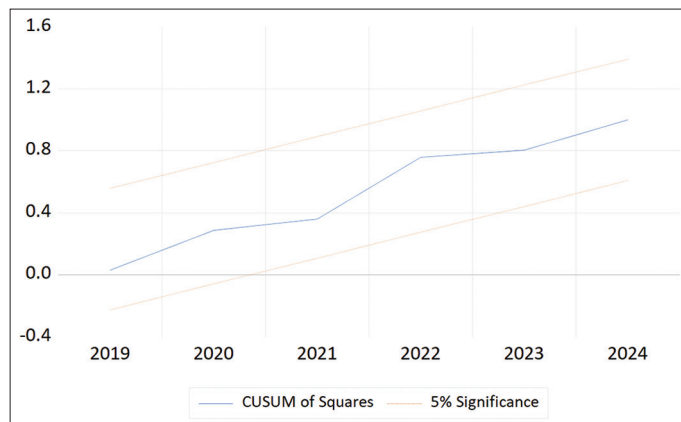
The negative but insignificant long-run INST_QUAL coefficient is directionally compatible with institutional theory. Its growing FEVD share for emissions at longer horizons suggests that governance innovations may be dynamically relevant, but this conclusion also depends on the disputed system specification. In substantive terms, monitoring, public disclosure, collection of penalties, licensing conditions, and judicial enforceability are the channels through which governance can alter operator behaviour (North, 1990; Williamson, 2000). The environmental results indicate a close dynamic association between flaring and emissions: GF innovations account for 40.78% of the 1-year emissions FEVD. This result is consistent with the direct

Figure 2: CUSUM parameter-stability test



Source: Author's EViews output

Figure 3: CUSUMSQ parameter-stability test



Source: Author's EViews output

Table 10: Diagnostic and stability test

Test	Statistic	P-value/ result	Decision at 5%
Breusch–Godfrey	2.46	0.09	Do not reject no serial correlation
LM serial correlation			
Breusch–Pagan–Godfrey	1.70	0.12	Do not reject homoskedasticity
heteroskedasticity			
Ramsey RESET	0.19	0.85	Do not reject stated functional form
Residual skewness	0.03	—	Near zero
Residual kurtosis	3.02	—	Near three
Jarque–Bera	NR	0.99	Do not reject normality
CUSUM	—	Within 5% bounds	Stable over plotted window
CUSUMSQ	—	Within 5% bounds	Stable over plotted window

Source: Author's computation reported from (EViews output)

combustion pathway documented in the Nigerian literature (Anomohanran, 2012).

6. CONCLUSION AND POLICY IMPLICATIONS

Using annual Nigerian observations for 1975-2024, the reported ARDL results identify oil rents and real gas prices as the clearest long-run correlates of gas-flaring intensity. Short-run oil-production changes are positively associated with flaring, and the negative, significant error-correction coefficient indicates rapid reversion toward the estimated equilibrium. The post-NGFCP indicator is negatively associated with flaring at the 10% level, but the observational design does not identify a causal programme effect. The penalty and institutional results differ across the single-equation and system outputs, highlighting the distinction between conditional coefficients and variance attribution. The study's policy message is therefore measured: stronger gas-market incentives, credible enforcement, better monitoring, and utilisation infrastructure are jointly required. The empirical outputs also expose important reporting gaps. Standard errors, t-statistics, confidence intervals, complete lag orders, dummy coding, and a reconciled VECM specification are not available in the thesis. These items should be recovered from the original dataset and EViews workfile before the manuscript is submitted or its system results are treated as definitive.

Policy implications for the study are as follow:

1. First, Nigeria should improve the commercial value of associated gas through predictable, cost-reflective pricing, bankable offtake arrangements, and access to processing and transmission capacity. The negative long-run GASPRICE coefficient supports market incentives, but its magnitude should not be converted mechanically into a policy forecast without scenario analysis.
2. Second, the NGFCP should be evaluated with transparent project-level milestones: flare-site awards, financial close, construction, commissioning, captured volumes, and verified emissions. A binary post-2016 indicator cannot distinguish programme intensity from general time effects. Public release of site-level data would enable stronger interrupted-time-series, synthetic-control, or panel designs.
3. Third, penalties should be indexed to the economic value of gas and environmental damage, measured independently, collected consistently, and disclosed by operator and site. The contrast between an insignificant average ARDL coefficient and a large FEVD share implies that nominal policy changes alone are insufficient; credibility and enforcement determine deterrence.
4. Fourth, gas-gathering, reinjection, modular processing, gas-to-power, and small-scale LNG/CNG projects should be prioritised where marginal abatement costs are lowest. Production licensing should require verifiable gas-utilisation plans and should link waivers to transparent, time-limited technical criteria.

Finally, flaring reduction should be integrated with Nigeria's greenhouse-gas inventory and nationally determined contribution.

Satellite estimates, operator metering, and regulatory records should be reconciled annually. This would improve both policy accountability and the quality of future econometric evaluation.

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