Energy Policy 153 (2021) 112260

Contents lists available at ScienceDirect

Energy Policy

journal homepage: http://www.elsevier.com/locate/enpol

Research Article

Gas flaring, ineffective utilization of energy resource and associated economic impact in Nigeria: Evidence from ARDL and Bayer-Hanck cointegration techniques

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ARTICLE INFO

Keywords:
Gas flaring
Gas utilization
Economic growth
Gas prices
Fossil fuel
Autoregressive distributed lag
Cointegration

ABSTRACT

This study aligns with Sustainable Development Goal 7 which aims at *"ensuring access to affordable, clean energy, reliable, sustainable and modern energy for all"*. The Gazetted Flare Gas Regulations 2018 provides a legal framework to support the policy objectives of the Federal Government for the reduction of Green House Gas emissions through the flaring and venting of natural gas. The Regulations provide the legal basis for the implementation of the Nigerian Gas Flare Commercialization Programme. This study investigates the factors contributing to gas flaring activities in Nigeria from 1970 to 2019. Using the autoregressive distributed lag error correction representation and cointegration techniques, findings reveal, among others, that in the long-run: (1) gas flaring activities is persistent; (2) economic growth induces flaring activities; (3) gas prices exert asymmetric impact; (4) gas utilization and fossil fuel are negative predictors. The result shows that gas price contemporaneously exerts positive and statistically significant impact at the 1% level. Gas price contributes 0.187 percent increase to gas flaring while its first lag induces significant reduction in gas flaring by 0.293 percent at 1 percent level of significance. This study also provides sufficient evidence on the persistency of gas flaring activities in Nigeria.

1. Introduction

It is estimated that over 4.6 trillion cubic feet of associated gas was flared globally in 2019 (World Bank, 2020). Using the UK National Petroleum Board and US Henry Hub gas prices, this amounts to about $19 billion and $9.5 billion, respectively, of wasted revenue. Associated gas flaring is one example of ineffective use of energy resources, and characteristic of most oil producing nations, with obvious implications for macroeconomic performance and environmental sustainability. Globally, this practice is highly criticized as it confers no economic or welfare benefits either to the citizens or the national economy (Tahouni et al., 2016). Nigeria is rated among the top ten world's largest gas flaring nations, and data from Nigerian Gas Flare Tracker (2019) showed that over 425.9 billion standard cubic feet of associated gas was flared in 2019. This is at the peak of government enforcement of policies, regulations, commercialization and increased utilization of gas for power generation (Okoro et al., 2017). The estimated value of associated gas flared in Nigeria for the year 2019 is put at approximately $1.1 billion (PWC, 2019). This indeed is an aberration in a period of scarcity of funds to finance the annual budget.

To achieve Goal No. 7 of the Sustainable Development Goals (SDGs) which aims at "*ensuring access to affordable, clean energy, reliable, sustainable and modern energy for all*", there is need to implement a policy of energy conservation through reduction or outright elimination of wasteful and destructive consumptive practices like associated gas flaring. Fawole et al. (2016) emphasized the resultant air pollution from associated gas flaring. The study focussed on the black carbon emission from gas flaring and its impact on the environment and its inhabitants. Giwa et al. (2019) recommended the implementation of sustainable development goals that is aimed at reducing gas flaring to enhance the well-being of the people and the environment. Ojijiagwo et al. (2016) showed that an annual net profit of $ 2.68 billion can be recovered from

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https://doi.org/10.1016/j.enpol.2021.112260
Received 5 September 2020; Received in revised form 2 February 2021; Accepted 17 March 2021

utilization of associated gas rather than resort to flaring. The study considers gas flaring as a waste of natural resource with huge economic impact. The work of Hajizadeh et al. (2018) which conducted an economic evaluation of three technical approaches for recovery and utilization of flared gas revealed that liquefaction and liquefied petroleum gas (LPG) production shows a high rate of return on investment for different scenarios.

The actual rather than ideal reason for continued prevalence of associated gas flaring is unique for each emitting country. Some of the actual reasons include, but not limited to: location of these gas fields in-country, ease of availability, market structure, infrastructures, institutional capacity, governance and policies. The exact economic, geographical, and institutional reasons that reinforce associated gas flaring are relatively diverse. Willyard (2019) highlighted the political-legal developments that offer legitimacy for oil and gas companies to flare natural gas. These platforms include but are not limited to Texas Statewide Rule 32 that shifted from shutting down violators to issuing cash-penalty; and also the legal opportunities and economic incentives supporting the practice since the shale oil boom. The study proposed an incentive for companies to invest in the technology and infrastructure necessary to collect, store and use natural gas as a way to minimize the waste. The study of Beltrán-Jiménez et al. (2018) which focused on southern cone countries in Latin America, observed that when infrastructure is limited or there exists low domestic demand for associated gas, flaring becomes the least-cost solution for the oil and gas companies.

The possible remedy highlighted by Hajilary et al. (2020) is the need for significant changes in the current government policies and practices in oil and gas production and processing with awareness of the environmental impact and the ratification of the Kyoto protocol. The World Bank identified erratic data and under-estimation of actual volume of gas flared by governments and companies as key factors that complicates the global effort to track progress on flaring reduction (World Bank, 2020).

Orji (2014) studied the legal and policy regimes in Nigeria designed to reduce gas flaring and enhance gas utilization and re-injection of unwanted associated gas. One of the major obstacles identified in the study was the absence of attractive incentives that will encourage oil producing companies to invest in gas re-injection or utilization facilities. Balsalobre-Lorente et al. (2019a,b) in their empirical analysis suggested that natural gas consumption and utilization exerts a significant positive impact on economic output in Iran. Thus, there is a one-way causality from gas utilization to economic output.

Elvidge et al. (2018) after analysing the three categories of flaring (downstream, upstream and transportation facilities), proposed the utilization of associated gas as a key approach to reducing gas flaring in other to meet greenhouse gas mitigation targets. Zolfaghari et al. (2017) study results on economic evaluation and recovery of flare gas showed that gas utilization is one of the most economical solution for gas flaring. Willyard (2020) analyzed the venting and flaring practice of most oil and gas production facilities in Texas using a two-way hurdle regression model. The study findings showed that flaring practices are consistently associated with huge oil production. This outcome aligned with observed trend in Nigerian data between 1970 and 2010 (see Fig. 1) as well as the gas flare study conducted by Fisher and Wooster (2019). The study of Fisher and Wooster (2019) further reveals a decreasing trend in the number of flaring sites for most nations, with exception of the United States.

Nigeria has demonstrated marked reduction in gas flaring between 1970 and 2000, nearly a 50 percent reduction, but still remains among the top ten countries in the world that flares large volumes of associated gas, worth about $1.1 billion in 2019 alone, an amount that may have considerably improved the country's massive infrastructure deficit. Though gas flaring has been outlawed in Nigeria since 1984, implementation has been grossly ineffective, with deadlines consistently unmet (Thurber et al., 2012; Reed, 2018). The current deadline is 2020. One observed gap in the Associated Gas Re-Injection Act is the lack of clarity on who bears responsibility for gas re-injection costs. Inadequacy of sanctions against non-compliance further works against effective implementation of the Act. For instance, the monetary penalty for continued flaring of gas by oil companies under the Act is grossly inadequate and is preferred by the oil companies as opposed to complying with the phase-out of gas flaring (Udok and Akpan, 2017).

Strategies in many countries are often linked and dependent on available resources such as mineral deposits, and hydrocarbons. In spite of the estimated gas potentials of Nigeria, both anecdotal and empirical evidences suggest that the potentials from the level of resource endowment have not been maximally exploited. Failure to maximize potential gas reserves and identify the economic impact of waste/underutilization have encouraged huge volume of gas flaring in most developing economies with high level of resource endowment. There are no doubts about the environmental, health and economic consequences of gas flaring. There is a business case for proper harnessing and adequate utilization of natural gas, as it can be a huge source of foreign exchange (Diugwu et al., 2013). When compared with other oil producing countries such as Norway, Nigeria lags far behind in terms of associated gas conservation and utilization.

This loss can be attributed to lack of economic value of the resources,

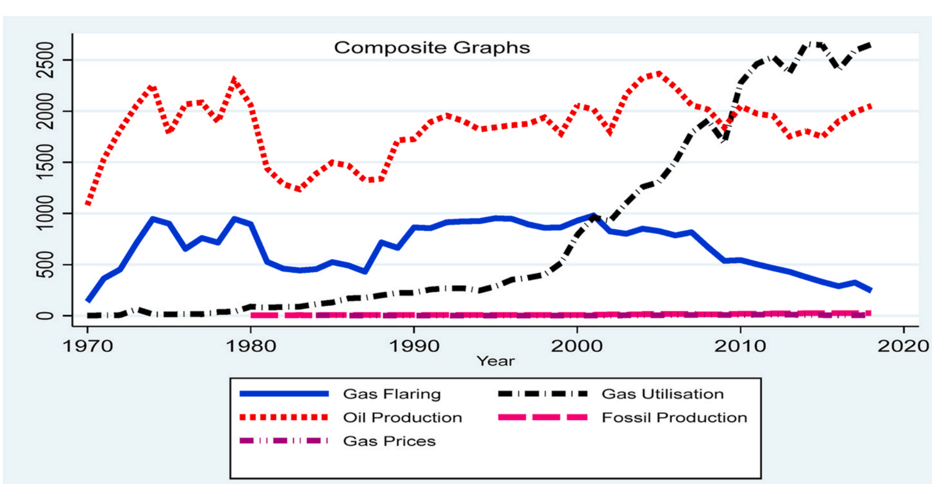

Fig. 1. Comparison of Associated Gas Flaring with some contributing Variables.
Source: Authors' from OPEC and BP Statistical Review of World Energy.

inadequate gas extraction technologies, processing and transportation infrastructure. Literature shows that for over fourteen years (2001–2014), the volume of gas flared surpasses the domestic sales and this is an anomaly because there is a demand-supply gap in the domestic and international gas market (Gas Flare Tracker, PwC analysis). Flaring leads to significant potential revenue loss and this has a direct economic effect on the country's economy. In addition, apart from the revenue value from gas derivatives, there are other economic benefits if gas processing activities are carried out, and this include but not limited to more job creation and opportunities, infrastructure development and so on. There is need for monetary economic value addition from this resource waste approach.

Ultimately, the geographical, economic and institutional factors that underpin flaring are quite diverse and regionally driven. To explore and categorize the selected determinants of gas flaring from empirical evidence, there is need to establish a trade-off between these gas flaring determinants and their economic impact. World Bank (2020) has estimated the volume of gas flared around the world to equivalent to almost one third of the European Union's gas consumption, and this should be an economic concern. With these assertions, this study developed econometric models to investigate the determinants of gas flaring with focus on some identified contributing variables such as gas price, crude oil production, utilization, and GDP growth. The correlation and evidence of gas flaring dependency in long and short run was established, and this approach is unique from other studies. This was achieved using the autoregressive distributed lag (ARDL) approach and cointegration techniques (canonical cointegration technique and Bayer-Hank cointegration tests). Since the traditional regression approach does not imply causation, it becomes imperative to probe causal relations among the variables of interest.

Abdulkareem and Odigure (2009) highlights that the major contributing factor to flaring is unsustainable exploitation practices with the lack of gas utilization infrastructures. Other authors have also identified other factors and categorized them into economic, commercial and technological issues (Ojide et al., 2012). But understanding the sustainability and economic impact of gas utilization will help develop key policy objective for sustainable economic development. The structure of gas flaring in Nigeria in relation to its determinants was examined using some identified variables with the objective of correcting the institutional and policy lapses. Data have shown that against the massive economic loss, natural gas can play vital roles in the Nigerian economy. In addition, the Federal Government of Nigeria had extended the zero flaring deadline, replacing the previous apparent date for ending the flaring of 2008. The World Bank has set 2030 as the year for the cessation of routine natural gas flaring in countries concerned.

Our findings provide policymakers useful and practical insight into the state of natural gas development in Nigeria and its economic impact. The rest of the paper is structured as follows: section 2 engages stylized facts on Nigeria's gas flare; section 3 outlines the data and methodology; section 4 discusses the results; and section 5 the conclusion.

2. Nigeria's gas flaring activities

Given the growing awareness in the likely catastrophic effects of climate change and the close association of climate change with global emission of greenhouse gases, considerable research efforts have been devoted to the analysis of high volume of flared gases and its relationship to sustainable development. The importance of energy consumption to the growth of the economy in the last two or three decades is given a strong recognition not only by the economists but by policymakers, engineers, businessmen, government and energy agencies (Balsalobre-Lorente et al., 2019a,b). Though Fig. 1 shows that associated gas flaring has nearly reduced by half in Nigeria since 1970, it still ranks among the top ten countries in the world with large flare volumes of associated gas, worth about $ 1.1 billion in 2019 alone. This is an amount that may have considerably reduced the country's massive infrastructure deficit. The flaring trend between 1970 and 2000 has been directly proportional to crude oil production. There is also a continuous downward reduction trend since 2000 with a significant increase in gas utilization, mostly for power generation. This observation is supported by the gas flare counts study conducted by Fisher and Wooster (2019), and their results also reveal a general decreasing trend in the number of flaring sites for most nations, with the exception of the United States. Gas flaring is a form of waste of natural resource and it carries along huge economic impacts (Ojijiagwo et al., 2016). Yunusa et al. (2016) in their study observe that gas flaring in Nigeria has a negative impact on crude oil revenue and it is statistically significant.

In practice, bans on gas flaring have been ineffective, because flaring has been illegal in Nigeria since 1984 and repeated deadlines for ending gas flaring practices have remained unmet. The current deadline is 2020. (Thurber et al., 2012; Reed, 2018). Nigeria's Associated Gas Re-Injection Act has failed to effectively define the party or parties who ought to bear responsibility for gas re-injection costs. Unfortunately, the monetary penalties for continued flaring of gas by oil companies under the Act is grossly inadequate and is preferred by the oil companies as opposed to complying with the phase-out of gas flaring (Udok and Akpan, 2017). The World Bank in a response to the natural gas flaring challenge set the year 2030 as the deadline for the cessation of natural gas flaring in countries concerned (World Bank, 2015).

Empirical study has identified natural gas flaring penalty, crude oil production, natural gas price, natural gas marketization and lack of natural gas infrastructure as fundamental determinants of natural gas flaring. In addition, Nigeria is a signatory to several United Nations Protocols on the environment and climate change and the United Nations Framework Convention on Climate Change (UNFCCC) whose major goal is to stabilize greenhouse gas emissions at a level that would prevent dangerous anthropogenic interference to climate change (Aghalino, 2009). The current rate of natural gas flaring in Nigeria contravenes these Protocols. The pursuitof economic growth can help mitigate natural gas flaring, because flaring goes against the goals of sustainable development hypothesis. Policy makers would prefer an inverse relationship between natural gas price and natural gas flared. The economic intuition is that natural gas marketization is more profitable with a competitive natural gas price because competitive natural gas price creates the desired economic incentive to invest in the natural gas sector.

This study, therefore, attempts to relate the contributing variable of associated gas flaring and GDP growth in a bid to highlight their intrinsic relationship such that government may embark on initiatives to restructure the gas sector. There is correlation between crude oil production and natural gas flaring in Nigeria (Howden, 2010). The direct relationship between crude oil and natural gas production in Nigeria contradicts the practice in Norway where crude oil production is 50% larger than Nigeria but Norway flares only 3% of its total natural gas production. Weak institutional framework in the natural flaring dynamics ranges from weak enforcement of environmental laws to low compliance by industry operators (Kuncic, 2013).

3. Data and method

3.1. Data and priors

This study uses annual time series data on six (6) variables – gas flaring is the dependent variable and the explanatory variables are: gas prices, crude oil production, gas utilization, fossil fuel and gross domestic product (GDP) growth. The data span is from 1970 to 2018. Gas, fossil and crude oil data are obtained from OPEC and BP Statistical Review of World Energy, while data on GDP growth is sourced from World Development Indicators of World Bank (2020).

3.2. Empirical model and estimation techniques

To investigate the determinants of gas flaring in Nigeria, this study modifies the methodological construct of Balsalobre-Lorente et al. (2019) and Solarin and Ozturk (2016). The variables with the exception of GDP growth are transformed into natural logarithms specifically to control for outliers, reduce "noise" in the model, and to establish elasticity relationships. Also, given the strong collinearity between gas utilization and fossil fuel (see Table 1), two models are constructed to show the distinct marginal impact of each variable on gas flaring. This approach allows the use of all the regressors while circumventing the problem of multicollinearity that may bias our results. Controlling for gas prices, crude oil production, and GDP growth, the implicit model that shows the relation between gas flaring and utilization is expressed as:

$$\ln FLARE_t = f(GR_t, \ln PR_t, \ln OIL_t, \ln UTIL_t) \quad (1)$$

And gas flaring and fossil relation is stated as:

$$\ln FLARE_t = f(GR_t, \ln PR_t, \ln OIL_t, \ln FOS_t) \quad (2)$$

Where, *FLARE* is gas flaring, *GR* is GDP growth, *PR* is gas prices, *OIL* is crude oil production, *UTIL*is gas utilization, *FOS* is fossil fuel and ln is natural logarithm.

3.2.1. Autoregressive distributed lag (ARDL) model

To empirically engage the impact of gas utilization and fossil fuel on gas flaring, equation (1) and [2] are estimated using the autoregressive distributed lag (ARDL) approach. The ARDL technique as developed by Pesaran and Shin (1998) is a single-equation model that has several advantages. It allows for robust estimations when the sample size is small, it does not require that all the variables under investigation be integrated of the same order and can be applied when the underlying variables are integrated of order one, order zero or mixed. Also, by applying the ARDL technique the long-run unbiased estimates of the model are obtained (Adeleye et al., 2018; Adeleye et al., 2020). Thus, following Balsalobre-Lorente et al. (2019a,b), the generalised ARDL $(p, q, \ldots, q)$ model is specified as:

$$Y_t = \phi_{0i} + \sum_{i=1}^{p} \delta_i Y_{t-i} + \sum_{i=0}^{q} \beta'_i \boldsymbol{X}_{t-i} + \sum_{i=0}^{q} d'_i \boldsymbol{Z}_{t-i} + \varepsilon_t \quad (3)$$

Where: Y_t represents the natural logarithm of gas flaring; X contains the baseline regressors (GR_t, $\ln PR_t$, $\ln OIL_t$), Z contains $\ln UTIL_t$, and $\ln FOS_t$ used sequentially, the variables in $(X_t')'$ and $(Z_t')'$ are allowed to be purely $I(0)$ or $I(1)$ or co-integrated; δ, β, and d are coefficients; ϕ is the constant; p, q are optimal lag orders; ε_t is a vector of the error terms – unobservable zero mean white noise vector process (serially uncorrelated or independent).

3.2.2. Cointegration techniques

To ascertain if a long-run association exists, the presence of cointegration is tested using two approaches. The first is the Pesaran et al. (2001) bounds test for cointegration which is mainly based on the joint *F*-statistic whose asymptotic distribution is non-standard under the null hypothesis of no cointegration (i.e. $\beta_i = d_i = 0$) against the alternative hypothesis of a cointegrating relationship (i.e. $\beta_i \neq d_i \neq 0$). Under the bounds test, it is assumed that the model comprises both $I(0)$ and $I(1)$ variables and two levels of critical values are obtained. The null hypothesis of no cointegration is rejected if the *F*-statistic is higher than the critical value of both the $I(0)$ and $I(1)$ regressors, and not rejected if otherwise (Adeleye et al., 2020). Given that previous tests have varying conclusions about the null hypothesis of no cointegration, Bayer and Hanck (2013) recently advanced cointegration test provides more robust results by using the Fisher formulae to amalgamate the different individual test statistics premised on the Engle and Granger (1987), Johansen (1991), Boswijk (1995), and Banerjee et al. (1998) tests. The null hypothesis of no cointegration is rejected if the $EG-JOH-BO-BDM$ test statistic is higher than the critical value at the chosen level of statistical significance.[1] Both the bounds and Bayer-Hanck cointegration tests are deployed to ensure robustness of the outcomes.

3.2.3. Error correction model (ECM)

In the event of cointegration, we proceed to analyse the long-run relationships and short-run dynamics using the autoregressive distributed lag (ARDL) error correction representation approach generalised as:

$$\Delta \ln Y_t = \alpha_0 - \gamma(\ln Y_{t-1} - \theta \boldsymbol{X}_t - \xi \boldsymbol{Z}_t) + \sum_{i=1}^{p-1} \omega_{\ln Yi} \Delta \ln Y_{t-1} + \sum_{i=0}^{q-1} \omega_{Xi} \Delta \boldsymbol{X}_{t-i} + \sum_{i=0}^{q-1} \omega_{Zi} \Delta \boldsymbol{Z}_{t-i} + \boldsymbol{v}_t \quad (4)$$

where Δ is the difference operator; $\gamma = 1 - \sum_{j=1}^{p} \delta_i$ is the speed of adjustment coefficient; $\theta = \frac{\sum_{j=0}^{q} \beta_j}{\alpha}$ and $\xi = \frac{\sum_{j=0}^{q} \xi_j}{\alpha}$represent long-run coefficients, ω_i are the short-run coefficients, $\boldsymbol{v}_t$ is a vector of the error terms – unobservable zero mean white noise vector process (serially uncorrelated or independent) and others are as previously defined in Equation (3). Equation (4) states that $\Delta \ln Y$ depends on its lag, the differenced explanatory variables and also on the equilibrium error term. If the latter is nonzero, then the model is out of equilibrium. Since γ is expected to be negative, its absolute value decides how quickly equilibrium is restored.

3.2.4. Causal analysis

Since the traditional regression does not imply causation, it becomes imperative to probe causal relations between the variables. For instance, when a variable *K* Granger causes *S*, it implies that variable *K* and its past realizations are good predictors of variable *S*. This additional examination is necessary for policymakers and stakeholders take informed decisions about the gas industry. To achieve this, the study employs the Granger causality technique as the means of detecting the predictability power that exists among the variables and the generalised specification for bivariate (K, S) Granger test is expressed as:

$$K_t = a_0 + a_1 K_{t-i} + a_2 S_{t-i} + e_t \quad (5)$$

$$S_t = b_0 + b_1 S_{t-i} + b_2 K_{t-i} + m_t \quad (6)$$

From equation (5), the null hypothesis that *K* does not Granger cause *S* is tested against the alternate hypothesis that *K* Granger causes S. The strength of causality is thus inferred: unidirectional (meaning from *K* to *S* or vice versa), bidirectional (implying feedback relationship from both ends) and neutrality (implying no casual interaction between the variables). Analogous for equation (6).

4. Results and discussions

4.1. Correlation test and summary statistics

Table 1 shows the correlation matrix (upper panel) and summary statistics of each variable (lower panel). The upper panel of the matrix shows non-significant negative association between GDP growth (GR) and gas flaring (FLARE). Similar trend was observed by Ramanathan (2006) when GDP and carbon dioxide emission was studied simultaneously using Data Envelopment Analysis. This study observed that there is an inverse association between the two variables. The panel also shows strong negative correlation between gas price (PR) and gas

[1] Interested reader is referred to Bayer-Hanck (2013).

Table 1
Pairwise correlation analysis and summary statistics.

	ln*FLARE*	*GR*	ln*PR*	ln*OIL*	ln*UTIL*	ln*FOS*
ln*FLARE*	1.000					
GR	−0.109	1.000				
ln*PR*	−0.533***	0.276	1.000			
ln*OIL*	0.526***	0.145	0.336**	1.000		
ln*UTIL*	0.039	−0.074	0.791***	0.379***	1.000	
ln*FOS*	−0.489***	0.357**	0.779***	0.510***	0.950***	1.000
	Mean	*SD*	*Minimum*	*Maximum*		
FLARE	667.97	233.16	138.94	980.66		
GR	3.98	6.42	−13.13	25.01		
PR	5.07	2.98	1.86	11.60		
OIL	1843.79	297.05	1083.00	2365.90		
UTIL	828.77	951.22	1.76	2654.80		
FOS	12.62	6.60	4.10	25.00		

Note: ***, ** indicate statistical significance at the 1% and 5% level, respectively.
Source: Authors' Computations.

flaring, which suggests that high gas price is a disincentive to gas flaring. With regard to the nexus among crude oil production (OIL), gas utilization (UTIL) and gas flaring, the matrix indicates that crude oil production has robust positive association with gas utilization, but gas utilization did not correlate significantly with gas flaring. A statistically significant negative association is also observed between fossil fuel (FOS) and gas flaring. The correlation matrix also shows robust positive correlation between crude oil production (OIL) and gas price. Also, there is evidence that gas utilization has strong positive connection with gas price and crude oil production. Finally, the matrix shows that fossil fuel correlates positively with GDP growth, gas price, crude oil production and gas utilization. However, there is evidence of near perfect positive correlation between fossil energy and gas utilization. Since this condition may lead to spurious regression estimates with biased outcomes, both variables are captured in different models.

On the properties of each variable, basic statistical features of the variables (see lower panel) reveal that minimum and maximum volumes of gas flared between 1970 and 2018 are 138.94 and 980.66 respectively while GDP growth rate ranged between −13.13 and 25.01 percent over the same period. In addition, crude oil production ranged between 1083 and 2365.9 while gas utilization hovers between 1.76 and 2654.8 during the period. Fossil fuel (FOS) has its lowest value as 4.10 and highest value as 25.00 over the period of the study.

4.2. Cointegration tests

'The cointegration result presented in Table 2 shows strong evidence that the variables have no tendency to drift apart over the long-run. A close examination of the utilization and fossil models shows that the observed *F*-statistic from the ARDL Bounds Test (6.407 and 6.221) is greater than the Pesaran et al. (2001) upper bound critical values at 1 percent level of significance (5.06). In addition, the Bayer-Hanck (2013) statistic produced from the combination of Engle-Granger, Johansen maximum eigenvalue, Banerjee and Boswijk tests for both models (70.44 and 110.849) exceed the critical value at 1 percent. Evidence of cointegration demonstrated above justifies the examination of long- and short-run analysis using the ARDL/ECM procedure.

Table 2
Cointegration test results.

Cointegration Hypotheses	Utilization Model	Fossil Model
Bounds Test (F-stat)	6.407***	6.221***
Bayer-Hanck Test (EG-J-Ba-Bo-)	70.44***	110.849***

Note: *** indicates statistical significance at the 1% level; Pesaran et al. (2001) upper bound critical value at 1% = 5.06; Bayer-Hanck (2009) 1% critical value = 30.774; EG = Engle-Granger; J = Johansen; Ba = Banerjee; Bo = Boswijk.
Source: Authors' Computations.

4.3. Long-run and short-run estimations

The long-run result for the utilization model shows strong evidence of gas flaring dependence or lag effect of gas flaring. The first and second lags of gas flaring is positive and statistically significant at the 1 percent level which suggests that past gas flaring strongly predicts current flaring in Nigeria. These outcomes provide sufficient evidence on the persistency of gas flaring activities in Nigeria. An increase of between 0.38 and 0.46 percent is expected on current flaring activities from a percentage change in past gas flaring activities. Similarly, economic growth makes positive contribution to gas flaring at the 10 percent level marginally by 0.008 percent, on average, *ceteris paribus*. Furthermore, gas prices contemporaneously exert a positive and statistically significant impact at the 1% level. It contributes 0.187 percent increase to gas flaring while the past lag induces significant reduction in gas flaring by 0.293 percent at the 1 percent level, from a percentage in gas prices, on average, *ceteris paribus* (Table 3). Correspondingly, gas utilization is a statistically significant negative predictor of gas flaring in Nigeria. The result indicates that a percentage change in the level of gas utilization reduces gas flaring by 0.084 percent. Though, crude oil production has a positive coefficient its impact on gas flaring is not statistically significant.

In the short-run, the first lag of gas flaring and gas prices have

Table 3
ARDL and ECM results.

Variable	Utilization Model		Fossil Model	
	Coefficient	*t*-Statistic	Coefficient	*t*-Statistic
Constant	0.902	0.891	1.106	0.997
Long-run:				
Gas Flaring_1, log	0.379***	4.612	0.374***	5.636
GDP growth	0.008*	1.794	0.007	1.403
Gas Price, log	0.187***	3.716	0.137**	2.309
Gas Price_1, log	−0.293***	−4.325	−0.248**	−2.481
Crude oil production	0.108	0.704	0.124	0.611
Gas utilization	−0.084***	−3.229		
Fossil production			−0.203**	−2.219
Adjustment	−0.164***	−6.080	−0.220	−5.991
Short-run:				
ΔGas Flaring_1, log	−0.456***	−3.393	−0.407***	−3.052
ΔGas Price, log	0.187**	2.337	0.137	1.708
Observations	34		34	
R-squared	0.946		0.945	
F-statistic	64.91***		63.80***	
Selected ARDL Model	(2, 0, 1, 0, 0)		(2, 0, 1, 0, 0)	

Note: ***, **, * represent statistical significance at the 1%, 5%, and 10% levels, respectively; *t*-statistics from HAC standard errors & covariance (Pre-whitening with lags = 1, Bartlett kernel, Newey-West fixed bandwidth = 4.0000).
Source: Authors' Estimations.

asymmetric impact on gas flaring at 1% and 5% levels, respectively. The results indicate that gas flaring drops by 0.456 percent in response to a change in the previous year's gas flaring while it rises by 0.187 percent when a percentage change in gas prices occurs. The error correction or adjustment mechanism shows that deviation from long-run equilibrium is corrected at an adjustment speed of 16.4 percent. This indicates reversion to long-run stable state.

On a similar note, the long-run result for the fossil model shows substantial evidence that the current state of gas flaring depends on its previous conditions. It reveals that the both past lags of gas flaring have positive and statistically significant impact at the 1% level, which suggests that past gas flaring strongly predicts current flaring in Nigeria at 0.374 and 0.407 percent, respectively. Additionally, the result shows that the contemporaneous level of gas prices positively contributes to 0.137 percent increase gas flaring at the 5% level while its past lag reduces gas flaring by 0.248 percent at 5% level of significance. Also, fossil fuel production is a statistically significant negative predictor of gas flaring in Nigeria. It indicates that a percentage change in fossil production reduces gas flaring by 0.203 percent, on average, *ceteris paribus*. It is however observed that GDP growth and crude oil production do not significantly increase gas flaring. The short-run result indicates that the first lag of gas flaring has a negative impact on gas flaring at the 1% level. It is also observed that though gas price exhibits positive influence on gas flaring, its effect is not significant. The adjustment mechanism shows that deviation from long-run equilibrium is corrected at an adjustment speed of 22.0 percent. This indicates reversion to a long-run long-run equilibrium condition. The observed values of the R-squared and F-stat show that the goodness-of-fit of both models is satisfactory.

4.4. Robustness checks

To check for the robustness of our results, we use per capita GDP to control for per capita income of the nationals (Table 4). The results mirror those of the main analysis.

4.5. Granger causality tests

All the regressors with the exception of GDP growth Granger cause gas flaring at the 1% and 10% significance levels are tabulated in Table 5. Gas utilization Granger causes GDP growth at the 5% level, crude oil production, gas utilization and fossil fuel Granger cause gas prices at the 5% significance level and gas utilization Granger causes and fossil fuel at the 5% significance level. There is however no evidence of feedback causality among the variables. Contrary to expectation, there is no evidence that GDP growth Granger causes gas flaring in Nigeria.

Table 4
ARDL and ECM results (robustness).

Variable	*Utilization Model*		*Fossil Model*	
	Coefficient	t-Statistic	Coefficient	t-Statistic
Constant	0.453	0.267	0.939	0.610
Long-run:				
Gas Flaring_1, log	0.414***	5.951	0.388***	5.927
GDP per capita	0.123	1.289	0.077	0.745
Gas Price, log	0.172*	1.893	0.135	1.410
Gas Price_1, log	−0.365***	−3.882	−0.296**	−2.437
Crude oil production	0.004	0.019	0.042	0.201
Gas utilization	−0.101***	−3.267		
Fossil production			−0.228***	−2.952
Adjustment	−0.062***	−5.840	−0.154***	−5.764
Short-run:				
ΔGas Flaring_1, log	−0.523***	−3.687	−0.457***	−3.294
ΔGas Price, log	0.172**	2.118	0.135	1.649
Observations	34		34	
R-squared	0.943		0.943	
F-statistic	61.98***		61.07***	
Selected ARDL Model	(2, 0, 1, 0, 0)		(2, 0, 1, 0, 0)	

Note: ***, **, * represent statistical significance at the 1%, 5%, and 10% levels, respectively; *t*-statistics from HAC standard errors & covariance (Pre-whitening with lags = 1, Bartlett kernel, Newey-West fixed bandwidth = 4.0000).
Source: Authors' Estimations.

Table 5
Granger causality test (Abridged*[1]).

Null Hypothesis	F-Statistics	Probability	Outcome
GR does not Granger Cause LNFLARE	0.09938	0.9056	Neutrality
LNFLARE does not Granger Cause GR	0.35165	0.7056	
LNGPRICE does not Granger Cause LNFLARE	**9.54545**	**0.0007**	Unidirectional
LNFLARE does not Granger Cause LNGPRICE	0.39992	0.6741	
LNCOIL does not Granger Cause LNFLARE	**6.4029**	**0.0037**	Unidirectional
LNFLARE does not Granger Cause LNCOIL	0.80297	0.4548	
LNUTIL does not Granger Cause LNFLARE	**2.92027**	**0.0649**	Unidirectional
LNFLARE does not Granger Cause LNUTIL	0.58932	0.5592	
LNFOSSIL does not Granger Cause LNFLARE	**3.17813**	**0.0551**	Unidirectional
LNFLARE does not Granger Cause LNFOSSIL	0.00511	0.9949	

Source: Authors' computation. Note: *, **, *** 1%, 5%, 10% significance level.
*[1]Table 5 is limited to the interaction between the dependent and independent variables. The full result of dynamic interaction among the variables in the model is available on request.

4.6. Diagnostic tests

Table 6 presents the diagnostics from both models. We find no evidence of higher order autocorrelation and heteroscedasticity in the model. With *p*-values above 0.05, the Jarque-Bera test shows that the data satisfies the requirement of normal distribution. The cumulative sum of squared residuals (CUSUMQ) shown in Figs. 2 and 3 indicates that the models are structurally stable.

5. Conclusion and policy implications

It may be an understatement to say that the Nigerian economy depends heavily on revenue from oil and gas field development. However, it is troubling to note that potential economic benefits derivable from gas field development are largely lost to flaring. The reasons for non-utilization of associated gas are complex and interrelated, and they include but are not limited to technological, commercial and institutional barriers. While many existing oil fields are located in remote areas far from existing infrastructure or technological solutions for associated gas utilization, new oil fields are planned in even more remote areas without access to gas transmission systems. The optimal utilization of associated gas in Nigeria with the current policies will only be possible within the framework of a long-term structural reform in the oil sector. There is urgent need for a reform that changes the gas pricing system in-

Table 6
Diagnostic tests results.

Specification	*Utilization Model*	*Fossil Model*	Conclusion
	p-values	*p*-values	
Breusch-Godfrey (autocorrelation)	0.383	0.72	No higher-order autocorrelation
Breusch-Pagan-Godfrey (Heteroscedasticity)	0.209	0.349	No heteroscedasticity
Jarque-Bera (normality)	0.143	0.478	Evidence of normality
CUSUMSQ (stability)	stable	stable	Evidence of stability

Source: Authors' Computations.

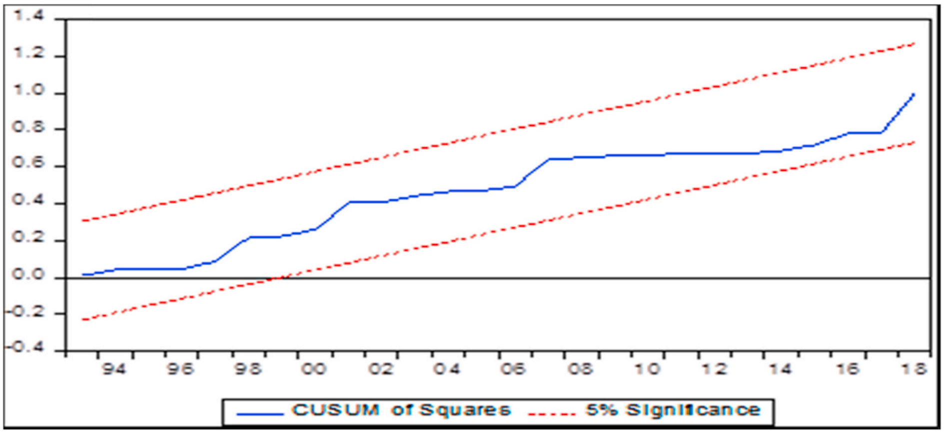

Fig. 2. Plot of CUSUMSQ for Utilization Model. Stability at 5% level of Significance
Source: Authors' Computations.

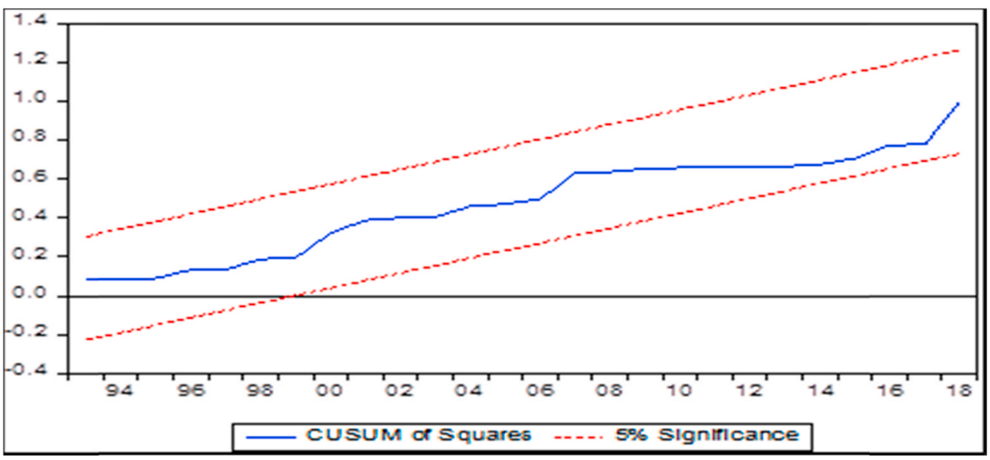

Fig. 3. Plot of CUSUMSQ for Fossil Model. Stability at 5% level of Significance
Source: Authors' Computations.

country and makes gas sales in the domestic market more profitable.

The result shows that gas price contemporaneously exerts positive and statistically significant impact at the 1% level. Gas price contributes 0.187 percent increase to gas flaring while its first lag induces significant reduction in gas flaring by 0.293 percent at 1 percent level of significance. This study also provides sufficient evidence on the persistency of gas flaring activities in Nigeria. An increase of between 0.38 and 0.37 percent is expected on current flaring activities from a percentage change in past gas flaring activities. The result further indicates that a percentage increase in the level of gas utilization reduces gas flaring by 0.084 percent. In addition, the result shows that consumption of more fossil fuel lowers the propensity to flare associated gas.

Based on our observations in this study, we conclude that gas flaring in Nigeria is largely determined by consumption and pricing of gas, as well as past activities of oil and gas companies that sustain the practice. This study therefore proposes that Nigerian government should introduce policies that will address associated gas flaring which is responsible for the loss revenue for many years and thereby avert further loss of revenue. A disaggregated approach to policy formulation and implementation is needed for active engagement of all stakeholders during the introduction and implementation of such policies. The Nigerian government should also do more to increase private sector participation in both the upstream and downstream.

Funding sources

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

CRediT authorship contribution statement

Emmanuel E. Okoro: Conceptualization, Data curation, Methodology, Software, Writing – original draft, Resources, Validation, Writing – review & editing. **Bosede N. Adeleye:** Methodology, Validation, Writing – review & editing. **Lawrence U. Okoye:** Conceptualization, Data curation, Methodology, Software, Writing – original draft, Methodology, Validation, Writing – review & editing. **Maxwell Omeje:** Resources, Validation, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors would like to appreciate the management of Covenant University for providing an enabling environment to carry out this study and assistance in publication.

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