Nigeria’s super-emitter flares

an evaluation of trends and causes of natural gas wastage: reducing emissions and improving human health

A regional analysis of onshore global super-emitter flares in the Niger Delta region

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Table of Contents

1. Executive Summary

Emissions from unnecessary flaring and venting contribute significantly to climate change, to health impacts from air quality, to soil contamination by Volatile Organic Compounds (VOCs), and to regional changes in water cycles induced by aerosols. The global volume of gas flared and vented is large, estimated to be circa 300 billion cubic meters (Bcm) annually, which is approximately 7.5 per cent of global gas production. If all natural gas flared and vented globally is captured and brought to market, it could supply annually more than the total South and Central America gas consumption, plus all of Africa's power needs.

This in-depth assessment of the main trends in emissions from oil and gas flaring shows Nigeria as one of the most successful countries to reduce flaring: from 21.4 billion cubic meters in 2005 to 7.2 billion cubic meters in 2020. However, in spite of this early success, Nigeria from 2017-2020 contributed significantly to overall global flaring, particularly from its 19 "super-emitters". In the northern Niger Delta, east of Warri, flaring from 2017 to 2020 increased by 24%, from 51 flares wasting 188 MMscf/d gas, to 62 flares wasting 234 MMscf/d gas. To assess the magnitude of the potential opportunity, we estimated the value of these 62 gas flares in 2020 at USD 730 million per year, based on Q4 2021 LNG prices. Performance analysis of the most substantial emitters show large potential for natural gas savings from individual flares. In 2020, 4 super-emitters in the East Warri region (Kwale gas plant, Kwale flow station, Ebendo flow station, and Obiafu-Obrikom gas plant) flared more than 65 MMscf/d gas; a value of more than USD 200 million per year against Q4 2021 LNG prices.

1.1. Key findings from analysing four Niger Delta super-emitter flares

Flaring appears to fluctuate among flare sources in distinct patterns. Flares are connected to the same production areas and oil and gas assets are linked by infrastructure. Hence, the flare assessment focussed not solely on individual super-emitters, but included all flares in the region of interest in the northern Niger Delta.

Three of the four super-emitters investigated are from marginal oil fields. For these super-emitters, the value of gas wasted can be as high as 35 to 39 per cent of the value of oil produced. Comparison of Ebendo super-emitter flare with its closest globally ranked super-emitter, ADNOC LNG, shows how disproportionately large flaring is from the Ebendo in terms of plant size, throughput and complexity. Ebendo's flaring performance is indicative of non-associated gas also being produced and stripped to recover the natural gas liquids, while the gas is flared as waste.

Flaring is occurring at such large scale and is pervasive through the region, even though multiple options exist to treat and utilise the produced associated gas. For example, for Kwale gas plant such options include: gas reinjection (as was done in the past), use at Kwale-Okpai Independent Power Plant (IPP), export to Obiafu-Obrikom (Ob-Ob) gas plant and beyond, and local OML 60 use.

Detailed flare evaluation shows that the gas volume flared by the three flares nearest to the Kwale-Okpai IPP plant closely match the shortfall in gas demand from the Okpai IPP. This implies that the shortfall in Okpai IPP gas demand is flared, rather than exported to the Ob-Ob plant.

The Okpai IPP plant was designed to reduce gas flaring and increase energy access, given that 43 percent of the population in Nigeria has no access to grid electricity. The Okpai IPP, justified as a Clean Development Mechanism project, failed to deliver on its project expectations for delivering power to the local region and to reduce gas flaring significantly.

The persistent volume of Niger Delta gas flared despite the availability of gas evacuation infrastructure suggests that the associated gas is insufficiently prioritised for use by gas demand centres such as NLNG.

Much more focus is needed to address the various obstacles that prevent efficient utilisation of existing domestic gas monetisation infrastructure, and to improve tie-ins of gas flaring assets to nearby gas infrastructure.

A combination of VNF satellite data from flares with Google Earth satellite images show that communities are often located within only a short distance of large gas flares, sometimes at less than 200 meter distance. Sometimes, community services are exposed to nearby flaring, such as the Kwale village local hospital near Kwale flow station, and the Onyiukwu primary school nearby Kwale Gas plant. Agriculture fields often extend to flares at the boundaries of oil and gas assets, with health risks due to soil contaminations by VOCs and other chemicals. Examples are Midwestern Oil and Gas facility of Ogbe village near Kwale, Ebendo flow station near Obodougva village, Ob-Ob gas plant.

The analysis assessed high variability in flare rates of Kwale and Obiafu-Obrikom gas plants, which can be indicative of poor flaring quality and high emissions of methane, VOCs and other toxic chemicals. Furthermore, flare temperatures similarly can highlight months with poor flare quality operations. All four super-emitters show excessive routine flaring as part of normal oil and gas operations.

VIIRS Nightfire (VNF) satellites as a regulatory diagnostic tool to measure and assess flares

Flare data from satellites provide complementary benefits to other flare assessment solutions, such as gas-flow meters and (hand-held) devices that can be brought to the emitting flare sources for detailed local evaluation and measurement. Each flare assessment tool has its own merits and limitations. In combination, most of these limitations can be avoided. Benefits of satellite measurements are specifically:

1. Flare detection accuracy (spatial and rate) by VNF satellites is high, and flare rates spanning four orders of magnitude can be measured.
2. Gas flare rates are measured on average twice-daily, lack of cloud cover permitting. Flaring point sources are easily identifiable, particularly in combination with open source Landsat / Copernicus / Maxar images. This information is particularly useful for remote and off-shore locations, helping regulators to prioritise production site visits.

3. In the absence of flare gas metering, VNF satellite data are a reliable source for determining flare rates. When gas meters are present, satellite flare data can validate that gas meters are operating correctly, and indicate issues such as 'drift' that would require recalibration of a gas meter.
4. The results from independent VNF flare metering outputs are readily available to regulators, which may not be the case with metering outputs from operators.
5. Regularity in VNF measurements over prolonged time periods creates comprehensive datasets for flare sources, with thousands of flare rate measurements per flare source. This allows flare trends to be continuously assessed throughout the asset lifecycle.
6. VNF datasets can identify those flares that are the most likely candidates for gas development opportunities and those with the largest potential impact in terms of Social Cost of Atmospheric Release (SCAR) reduction. This is particularly promising in Nigeria with its large number of large flares. Combining analysis of small-scale gas monetization options with indicative unit costs of each technology and VNF data, identifies priority options to utilise natural gas, including for local community use.
7. VNF data analysis can distinguish routine flaring from system upsets which are likely to correlate with methane emissions. Policymakers need to be increasingly cognisant of these inter-relationships.
8. VNF data complemented with other sources of information can establish whether additional infrastructure capacity is actually needed, when there are already multiple gas utilisation options which are not being used (fully) to reduce flaring to date.
9. Regional and country wide VNF data assist development of regulations and fiscal measures (including methane). Satellite measurements allows all gas flares to be measured and penalised regardless of their permitting status.

Consequently, it is important for the Nigerian regulators to assess the advantages of satellite data and how these can be more greatly used to complement other means of metering and performance assessment.

1.2. Key observations from this study that might suggest further policy change

1. **Nigeria's extensive regulatory and fiscal framework for gas flaring and associated petroleum gas use should be implemented**. Natural gas flaring has been banned in Nigeria since 1984. Continuous monitoring is needed of company plans and actions that avoid wastage of associated gas.
2. **VNF flare rate measurements are increasingly used by policymakers and global institutions, such as the World Bank and International Energy Agency (IEA).** Scientific publications and practical studies of gas flaring using VNF data (such as this study) demonstrate the usefulness and reliability of satellite-based flare measurements.
3. **VNF data measurements can provide a readily implementable basis for allocating flare penalties on a 'deemed' basis.** This gives oil and gas operators the opportunity to claim potential rebates on penalties, if they can demonstrate on a case-by-case basis that their gas meter readings provide improved records of gas flare rates that are reliable, accurate, accessible, and that are certified by independent third parties. Such an approach aligns with IMF proposals for (methane) penalties are based on 'deemed' emissions, with rebates for operators that can prove that they emitted less.
4. **Evaluation of flare performance trends should include a regional analysis of all flares.** Remarkable synchronicity in individual flare performance shows the interconnectivity of oil and gas infrastructure with flare volumes shifting to different

flares in the same area. Interconnectivity enables gas utilisation for domestic energy supply or exports. Regional flare analysis can highlight deficiencies in infrastructure access or utilisation.

5. **Interconnectivity of Niger Delta flaring assets with NLNG plant facilitates LNG exports at a time when Europe – a key Nigeria export market, is seeking replacement gas supplies.** NLNG is operating at less than 70 percent capacity. The amount flared in the northern Niger Delta during 2020, equalled 43 percent of one LNG train gas intake, equivalent to 1.5 million tonnes per annum of LNG output.
6. **Oil development approvals and regulatory performance reviews should include measures to ensure that associated gas is insufficiently prioritised and not wasted**.
7. Market based climate measures being discussed under Article 6 of the Paris Agreement can learn from CDM project experience. **Proposals that are justified on the basis of flare rate reductions need to be conditional on monitoring of regional flare rates as a performance metric.**
8. **Findings underscore the large potential of further natural gas savings** if these flare volumes were reduced significantly, with multiple benefits to local communities.
9. Penalties for gas flaring should apply equally. **The assumption that marginal oil producers flare less and therefore should attract lower penalties does not hold.** Applying penalties uniformly at realistic levels increases the commercial incentive for associated gas producers to accept reasonable terms for local gas utilisation or third-party infrastructure access.
10. **Mechanisms for access or sale of third party associated gas into gas infrastructure are a high priority.** A combination of uniformly applied and sufficiently high flare penalties, combined with netback gas prices for third-party gas that reward infrastructure owners appropriately for utilisation cost - yet also offer a profit-sharing percentage to associated gas producers, would provide a win-win-win for associated gas producers, infrastructure owners and government.

2. Introduction

This study was conducted for Oxford Policy Management Nigeria Limited (OPM) as part of the Facility for Oil Sector Transparency and Reform (FOSTER) programme. The objectives of the study were to investigate Nigeria's natural gas flare performance to:

1. Carry out a Nigeria country assessment on how flaring has changed over time compared to its oil production trend (and what that means for flare intensity).
2. Identify the flares in Nigeria that rank within the global top 300 super emitters.
3. Link this to detailed observations for four Nigerian super emitters identified in the Niger Delta region, to show how flare performance (as shown by satellite data) and operational performance are interrelated. Such detailed flare analysis can identify events indicative of much increased methane emissions. Assess the local context of these flares and evaluate the potential impact on local communities.
4. Relate this analysis to improve understanding of the background trends and opportunities for further flare reductions of these 4 super-emitters and a further 58 flares in a 130 x 140 km area of interest east of Warri in the Niger Delta region.
5. Assess the key lessons from the evaluation and suggest how these can be used as a diagnostic tool to monitor whether development promises and production quality standards for individual assets are being met.
6. Provide advice on next steps to use the satellite methodology to assess and compare the operational effectiveness of key Nigerian production assets, such as deep water Floating Production Storage and Offloading vessels (FPSOs).

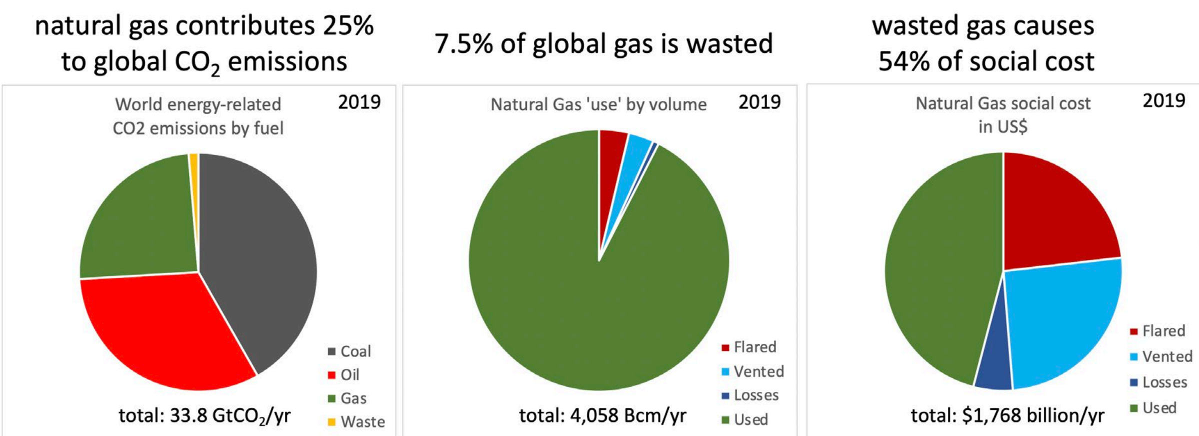
A list of abbreviations and units is included in this paper in Appendix B

EnergyCC and Oxford Policy Management sent a copy of this report in draft to the Operators of four onshore super-emitters in the Niger Delta and to Nigeria LNG with the request to review the draft and correct any factual errors. The request was sent to the company representatives provided by NOSDRA, the Nigeria Regulator. It asked for comments in a four-week period and indicated that feedback received would be incorporated into the draft report before publication. Comments were received from Public Affairs Department of ENI Nigeria and are reproduced in Section 13 of this report. ENI's comments refer to three inconsistencies on flaring measurement, gas production capacity and injection, and oil spills; EnergyCC's response to these comments are also included. ENI also sets out four actions to be implemented by the end of 2023 to improve its flaring and methane emissions, after which further solutions will be defined to strengthen and improve its emissions framework. A second follow up request was sent to Energia Ltd, with another four-week period for comment. No further comments were received.

3. Background

The volume of gas routinely flared and vented is large, estimated to be circa 300 billion cubic meters (Bcm) annually, which is approximately 7.5 per cent of global gas production (Figure 1). Efforts since 2000 to reduce global flaring has reduced its share in natural gas volumes wasted from 58 to 48 per cent, but an estimated increase in the of volume of methane vented has caused the total volume of gas wasted to increase by 7 per cent. However, due to the larger impact of methane on global warming, CO2-equivalent emissions from natural gas flared and vented increased from 2000 to 2019 by 27 per cent, i.e. from 5,500 to 7,000 million tonnes per annum (mtpa), based on a Global Warming Potential (GWP) for methane of 20 years. If all natural gas flared and vented globally is captured and brought to market, it could supply annually more than the total South and Central America gas consumption, plus all of Africa's power needs. [1]

Figure 1: Natural gas flaring and venting has a disproportionally large impact on the social cost of the use of carbon energy.



Source: authors' construction

The objective of this analysis is to better understand the background, trends, and opportunities for further flare rate reductions in Nigeria using satellite data. It sets out an approach for how satellite data can be used to assess the operational effectiveness of oil and gas production assets and processing plants, and identify events that are indicative of methane and other harmful chemical emissions.

Why is the quantity of gas flared by super-emitters important? The top two percent of all flares burn more than 35 percent of all gas wasted from the world's 10,390 flares globally. Routine flaring is a significant waste of a valuable energy resource. Understanding the quantity of gas flared over time assists not only in reducing unnecessary waste, but also in

[1] Romsom and McPhail (2021a), 'Capturing economic and social value from hydrocarbon gas flaring: evaluation of the issues', WIDER Working Paper 2021/5, Helsinki: UNU-WIDER; https://doi.org/10.35188/UNU-WIDER/2021/939-6

identifying the greatest opportunities to repurpose the wasted gas for use; to benefit energy security;[2] and potentially to raise additional revenues for government.

Reducing flaring from super-emitters and other routine flares can create local benefits. It can provide significant additional revenues for governments, improve human health, and create energy access opportunities for local communities. Satellite data are increasingly important in achieving this. Such data can provide regular information on volumes of gas flared, the exact location of the emission sources, and their distance to market, which then enables an assessment of gas monetisation opportunities. This data can also provide performance trends over the asset lifecycle, and distinguish between routine and non-routine flaring.

Why is the quality of gas flared important? The operational effectiveness of oil production facilities can have a significant impact on the combustion efficacy of flares. If the combustion of a flare is incomplete, the emission of harmful chemicals increases by orders of magnitude. Methane and other harmful emissions from flaring occur because not all the gas entering the flare stack is combusted into carbon dioxide (CO_2) and water.[3] Trends in satellite data can detect operational performance issues, including individual flaring events due to process trips[4] or equipment failure. There is evidence to show that gas destruction efficiency of flares can vary significantly over time, and often dip well below the typical factors used to model (methane) emissions from flares. Companies seldom measure and report emissions, meaning that actual emissions from flaring are often much higher than modelled. [5]

Why is satellite data of gas flaring important for measuring methane emissions? One challenge with estimating methane emissions from the oil and gas industry is that fugitive emissions such as leaks can occur at many locations, are often unplanned, and are less easily detectable with remote sensing by satellites. Conversely, natural gas vents are deliberate emissions when natural gas is being disposed into the atmosphere as part of maintenance activities, or as 'waste' in routine oil and gas production operations. In the absence of methane satellite data, information about these occurrences relies heavily on company self-reporting. However, satellite detection and data processing technologies for methane are maturing rapidly, providing much improved geospatial accuracy and lower detectable limits for methane emission rates.

[2] Romsom and McPhail (2021b), 'Capturing economic and social value from hydrocarbon gas flaring and venting: solutions and actions'. WIDER Working Paper 2021/6. Helsinki :UNU-WIDER. https://doi.org/10.35188/UNU-WIDER/2021/940-2.

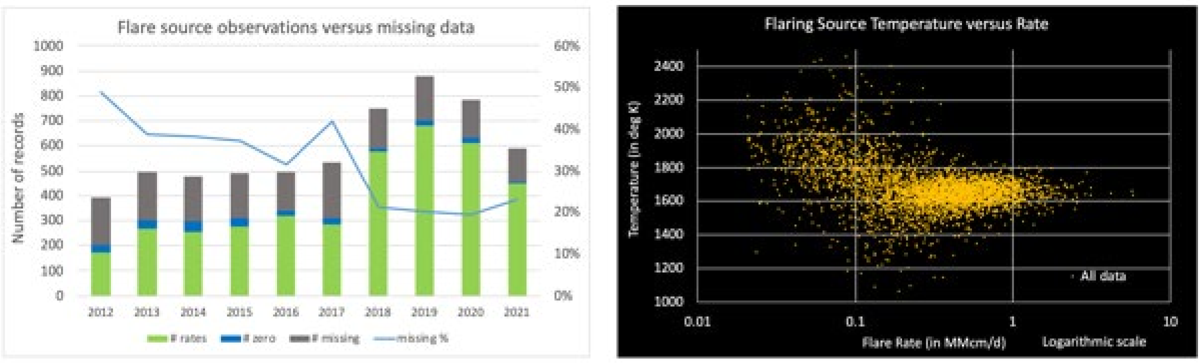
[3] The wider-ranging impacts from this broad spectrum of releases can be captured in a multi-impact economic valuation framework of SCAR that assigns a social cost per ton for each individual atmospheric release (SCAR), including: carbon dioxide (CO_2), methane (CH_4), black carbon (BC), nitrogen and sulphur oxides (NO_X and SO_X), volatile organic compounds (VOCs), organic carbon (OC), carbon monoxide (CO), ammonia (NH_3) and nitrous oxide (N_2O). See also: Shindell, D.T. The social cost of atmospheric release. Climatic Change 130, 313–326 (2015). https://doi.org/10.1007/s10584-015-1343-0.

[4] A process trip refers to an unplanned, uncontrolled, "emergency" shutdown of a machine, process, or piece of equipment. A process trip occurs when safety system sensors detect an abnormal process condition, such as temperature and pressure, and places the process in its safe state by tripping process elements, such as closing an automated valve, stopping a pump, etc. These actions can result in emergency flaring to depressurise equipment and divert flammable gas, thereby reducing the risk of a potentially damaging or destructive event.

[5] See Footnote 1.

Other potential sources of methane emissions, i.e. natural gas flares, are already easily detectable, particularly by VIIRS Nightfire (VNF) satellites[6]. Flare detection accuracy (spatial and rate) by VNF satellites is high due to flaring specific combustion temperatures, fixed location and limited combustion area.[7] Gas flare rates are measured twice-daily, lack of cloud cover permitting. Flaring point sources are easily identifiable, particularly in combination with open source Landsat / Copernicus / Maxar images. This information is particularly useful for remote and off-shore locations, helping regulators to prioritise production site visits. Natural gas flares can of course be major sources of methane emissions if flare quality is less than perfect, as described above. In the absence of flare gas metering, VNF satellite data are a reliable source for determining flare rates. The regularity in VNF measurements over prolonged periods of time also create comprehensive datasets for flare sources (see Figure 2). This allows flaring trends to be established, not only in terms of volumes of gas flared, but also, as this report will reveal, in terms of insights into (quality of) production operations.[8]

Figure 2: regularity, frequency and high volume of flare measurements from 2012 – 2021 allows detailed analyses to be made of individual gas flare sources.



Source: authors' representation, based on analysis of VNF data.
Note: Satellite flare data from Obiafu-Obrikom gas plant, Rivers State. VNF 2012-2021 data include 5900 records, 3896 rates measured, 245 zero rates and 1759 missing observations (due to cloud cover).

How can satellite data complement other existing methods to determine gas flaring? There are multiple ways to determine gas flare rates and each of these have their benefits. Generally, continuous metering of flare gas is preferred as this can provide the highest accuracy, continuity and opportunity to capture irregularities in flare rates over long periods

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[6] C. D. Elvidge, M. Zhizhin, K. Baugh, F. C. Hs and T. Ghosh, "Methods for Global Survey of Natural Gas Flaring from Visible Infrared Imaging Radiometer Suite Data", Energies 2016, 9(1), 14, MDPI; https://doi.org/10.3390/en9010014.

[7] The spectral characteristics of natural gas flares are distinct from city lights or wildfires and therefore light sources that are not natural gas flares can be filtered out. See C. D. Elvidge, M. Zhizhin, F. C. Hsu and K. Baugh, "What is so great about nighttime VIIRS data for the detection and characterization of combustion sources?", Proceedings of the Asia-Pacific Advanced Network 2013 v. 35, p. 33-48. ISSN 2227-3026; http://dx.doi.org/10.7125/APAN.35.5

[8] Although flares are being measured twice a day (cloud cover permitting), analysis showed that upscaling the data to monthly averages was most beneficial to establish long term trends. At highest resolution, individual flare measurements can also identify specific production events, such as trips, equipment failures and emergency shutdowns.

of time. However, being carried out by companies, the results from metering outputs may not be (readily) available to regulators. Metering inaccuracies can also occur if flare gas carries significant liquids (water and/or oil) or if the flow regime is high irregular (e.g. slugging well performance).[9] Gas flow meters also can be affected by poor calibration and drift.[10] When gas meters are present, satellite flare data can validate that gas meters are operating correctly, and indicate issues such as drift that would require recalibration of a gas meter. Another method to assess flare rates is by temporary devices (some are handheld) that can be brought to the emitting flare sources for detailed local evaluation and measurement. The advantage of such a local intervention is the interaction with the operator that can result in on the spot clarifications and recommendations to reduce the volume of gas flared and/or improve the flare quality.

Satellite measurements provide complementary benefits to these above-mentioned flare assessment solutions. For example, where flare meters are installed, the combination of metered data and satellite inferred flare rates can be indicative of the need to recalibrate flare gas meters. Satellite data can also assist in prioritising which assets are most important to visit for individual performance inspection. This is particularly helpful in remote or offshore areas. Satellite measurements are taken in a highly consistent manner that facilitates comparison of flare performances between different flares. Since 2012, NASA's EarthData publishes open annual data on global flare site surveys[11] derived from the VIIRS Nightfire satellites. As Figure 1 shows there was a significant improvement in flare source observations starting in 2018. NASA sees this transparent dataset as 'valuable for measuring the current status of global gas flaring, which can have significant environmental impacts.'. It provides a high degree of transparency and decision-useful information to regulators, local communities and other interested parties. Satellite data are used by international organisations, such as World Bank GGFR to aggregate and trend flare data of individual countries.

Nevertheless, satellite data do have their limitations that are related to the satellites' orbits that determine the moments of measurement; potential cloud cover may obscure the flare source and cause missing observations (see Figure 2); and flare measurements are restricted to night time. Satellite data updates are available daily, but not quite in real time. Satellite data provide a daily snapshot and this may result in some highly variable flare rates being missed. **Consequently, it is important for the Nigerian regulators to assess the advantages of satellite data and how these can be more extensively used to complement other means of metering and performance assessment**.

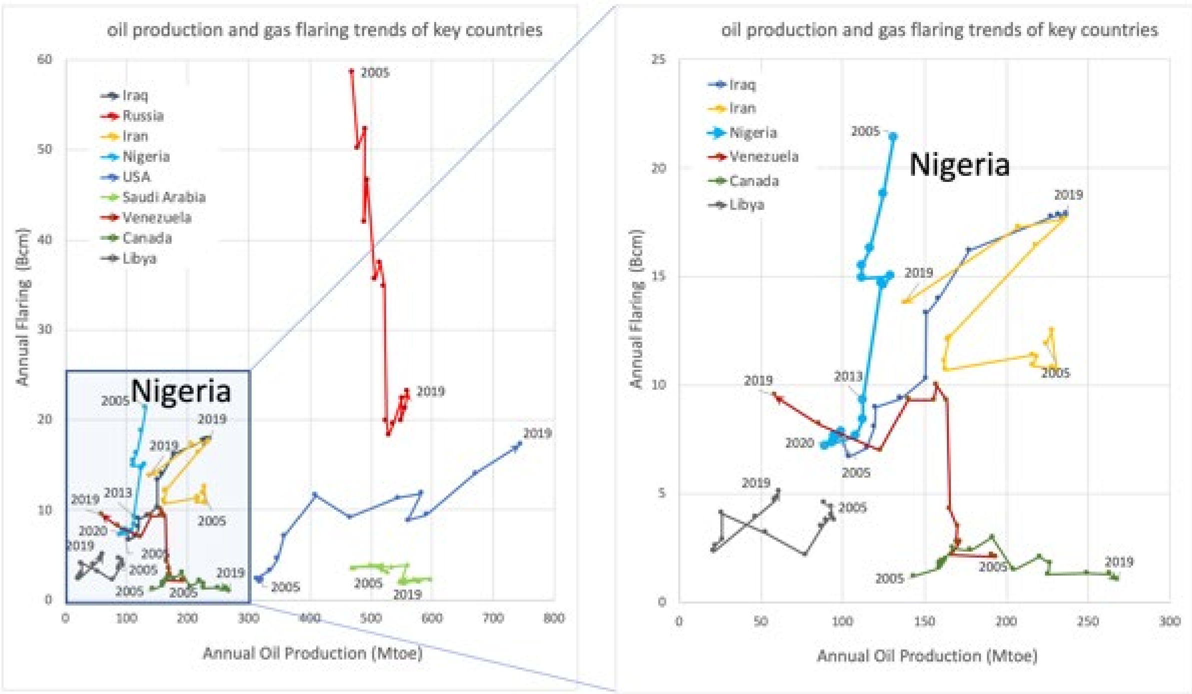
[9] Slug flow is a multiphase-fluid flow regime characterized by a series of liquid slugs separated by a relatively large gas pockets that occupy almost the entire cross-sectional area of the flow-carrying pipe. The resulting flow alternates between high-liquid and high-gas composition and can cause liquid carry-over in the (flare) gas if not separated out by a slug-catcher. Liquid content in flare gas can cause incomplete combustion and high emissions.
[10] Drift is a measurement error caused by the gradual shift in a gauge's measured values over time. Although incorrect handling can accelerate it, nearly all measuring instruments will experience drift during their lifetime. If left unchecked, this shift can cause extensive measuring errors, safety hazards, and quality issues, see also: https://premierscales.com/what-is-measurement-drift/ .
[11] ORNL DAAC, "Global Gas Flare Survey, 2012-2019", 9 January 2021; https://daac-news.ornl.gov/content/global-gas-flare-survey-2012-2019.

4. Nigeria Country Assessment

4.1. Nigeria's flaring record to date

According to BP [12], Nigeria is Africa's largest oil producer - 1.6 million barrels per day (bopd) in 2021 - and it is the world's 6th largest Liquefied Natural Gas (LNG) exporter - with 17.9 million metric tons (MMt) in 2021.[13] It is also **one of the most successful countries to reduce flaring: in 2020, Nigeria ranked as 7th highest flaring country globally, down from 2nd in 2005**; and gas flaring reduced by 66 percent between 2005 and 2015 (see Figure 3 below).

Figure 3: After Russia, Nigeria has been most successful in reducing natural gas flaring,



Source: authors' representation, based on VNF data, Worldbank (GGFR) and oil rates by BP Statistical Review.

Nigeria has demonstrated a remarkable decline in gas flaring from 21.4 Billion cubic meter (Bcm) in 2005 to 7.2 Bcm in 2020. Many elements and efforts have contributed to this success, including regulatory policies, fiscal policies (Nigeria imposes financial penalties on gas flared), development of infrastructure, innovative use of technologies and transparency measures: elements that are set out together in the Diamond Model in Figure 4 below.

Nigeria is already pioneering the application of satellite technologies to measure natural gas flaring.[14] The Gas Flare Tracker, created by Stakeholder Democracy Network, supported by

[12] BP, "Statistical Review of World Energy", 2022; https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html.

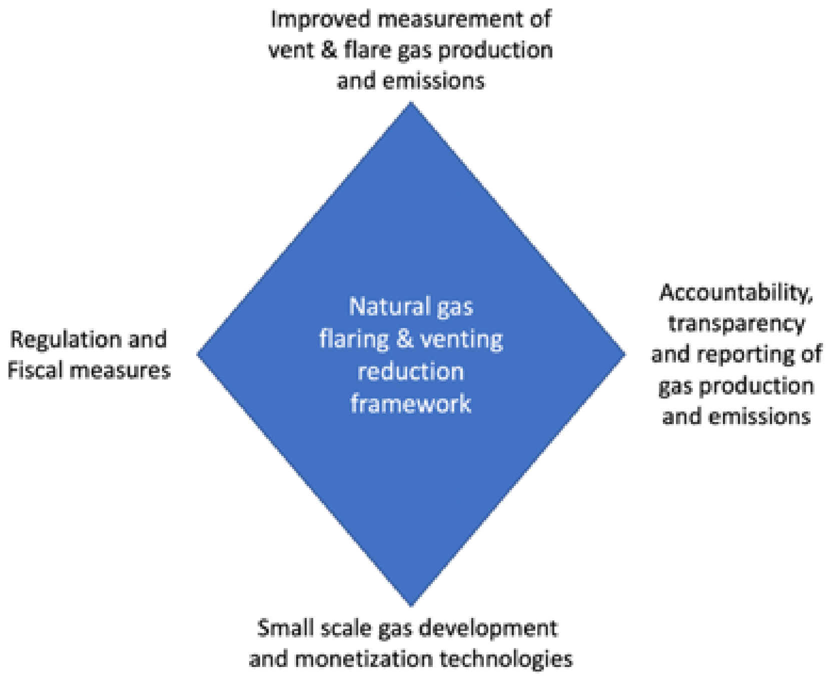
[13] S&P Global (IHSMarkit), "United States Poised to be World's Largest LNG Exporter in 2022 as China Becomes Top LNG Importer", 5 January 2022; https://news.ihsmarkit.com/prviewer/release_only/slug/bizwire-2022-1-5-united-states-poised-to-be-worlds-largest-lng-exporter-in-2022-as-china-becomes-top-lng-importer .

[14] The UN High-Level Global Roundtable on Extractive Industries, Chaired by UN Secretary General (UNSG) António Gutierres, prioritizes technologies and innovation to reduce emissions. The Policy Brief specifically cites Nigeria's success: "the use of remote sensing via satellites to provide data on successful attempts to reduce wasteful gas flaring in Nigeria resulted in reduced emissions and raised significant fiscal revenues".

FOSTER and the Department for International Development (DFID) / Foreign, Commonwealth and Development Office (FCDO), was commissioned by the Nigeria Ministry of Environment in 2014,[15] and is managed by the National Oil Spill Detection and Response Agency (NOSDRA).

The regulator continues to use self-reported figures provided by the companies as a basis for levying penalties. As mentioned in Section 3, with robust and peer reviewed satellite datasets published annually by NASA, this could be complimented by the IMF's innovative proposals set out in Section 7 to create additional revenues for government. Satellite data can further complement Nigeria's ongoing efforts to reduce emissions at source. Satellite observations provide opportunity to calibrate reported flare rates with independent measurements. This information can be particularly useful in identifying unreported flares and therefore support obtaining substantial additional revenues (estimated fines related for flaring amounted USD 270 million in 2020).[16]

Figure 4: Diamond model: an Integrated framework to end routine flaring and venting,



Source: authors' representation (Romsom and McPhail (2021b)

Integration of satellite data can further be applied to identify and prioritise gas utilisation projects. Recent World Bank analysis concludes that since Nigeria has 'steadily reduced its flaring volumes by some 70 percent over the past 15 years, it is now dealing with the challenge of bringing small flares to the market.'[17]

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[15] GasFlareTracker.ng, "Nigerian Gas Flare Tracker Briefing Document", October 2014; https://www.stakeholderdemocracy.org/wp-content/uploads/2015/05/2-Nigerian-Gas-Flare-Tracker-briefing-document-.pdf

[16] Energy Capital & Power, "Nigeria Takes Aim Against Gas Flaring in 2020", 4 September 2020; https://energycapitalpower.com/nigeria-takes-aim-against-gas-flaring-in-2020/ .

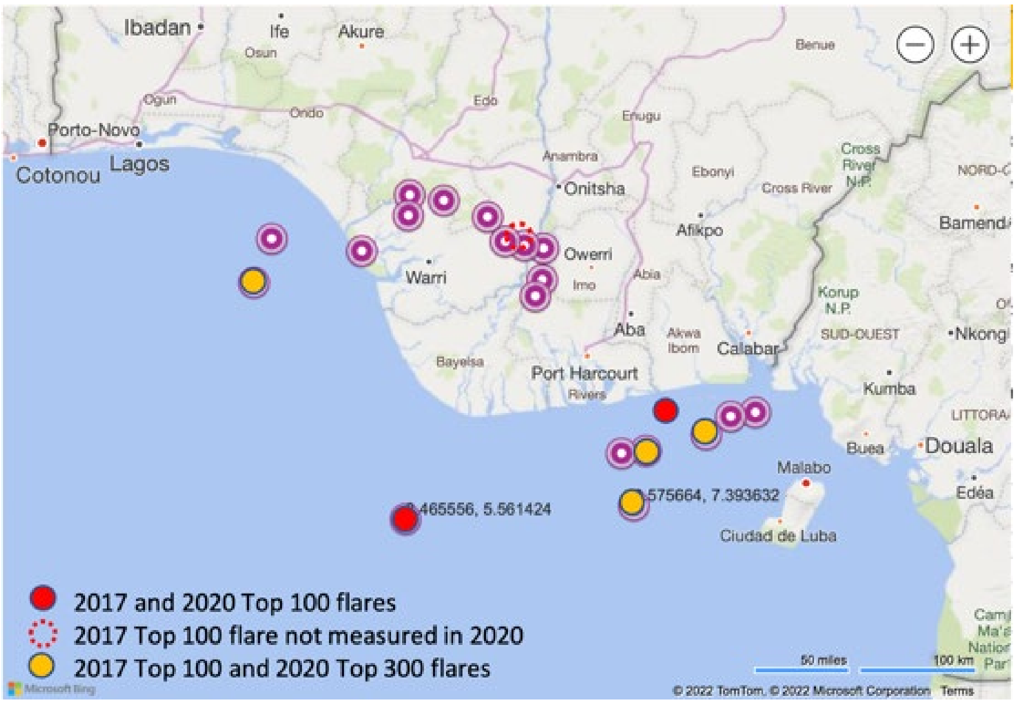
[17] Lorenzato, G.; Tordo, S.; van den Berg, B.; Howells, H. M.; Sarmiento-Saher, S. "Financing solutions to reduce natural gas flaring and methane emissions". International Development in Focus, World Bank Washington, DC, 2022, © World Bank; https://openknowledge.worldbank.org/handle/10986/37177 . License: CC BY 3.0 IGO.

4.2. Identifying global top 300 super-emitter flares in Nigeria

Our own evaluation shows that in 2020, there were 197 flares observed in Nigeria. Of this population, 124 flares each burn on average more than 1 million standard cubic feet per day (MMscf/d) and 19 burn more than 10 MMscf/d. Among these most prolific flares are those that are considered to be among the global Top 300 super-emitters based on their persistent high rate flaring of at least 10 MMscf/d during 2017 to 2020. Nigeria has 31 such global super emitters that each exceeded 10 MMsf/d average annual flare rate during one or more years in the period from 2017 to 2020. [18]

The top 300 super emitter flares (ranked by volume of gas flared annually) account for 42.5 percent of all gas fared globally. Over the combined four-year period 2017-2020, **Nigeria had 19 of the largest 300 flares in the world and it ranks 6th among the 29 countries** that have Top 300 super emitter flares.[19] Super emitters tend to account for a large proportion of the gas flared in the countries in which they are located, as well as globally. Gas flares can vary over time and among countries, with individual flares moving in and out of the top lists of super-emitters year on year (see Figure 5).

Figure 5: Nigeria's 20 super-emitter flares in global top 300 during the year 2020



Source: authors' analysis and representation

So although Nigeria's progress so far has been impressive, there are significant further opportunities to extend this, as the next sections of this paper demonstrate. This paper evaluates four super-emitter flares located in the onshore Niger Delta region in detail to assess their flare performance over time. This analysis aims to increase understanding of the background, trends, opportunities and benefits for further flare rate reductions of super-emitters and other large flares.

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[18] Note that the annual number of Nigerian super emitters in the global Top 300 can very year on year.

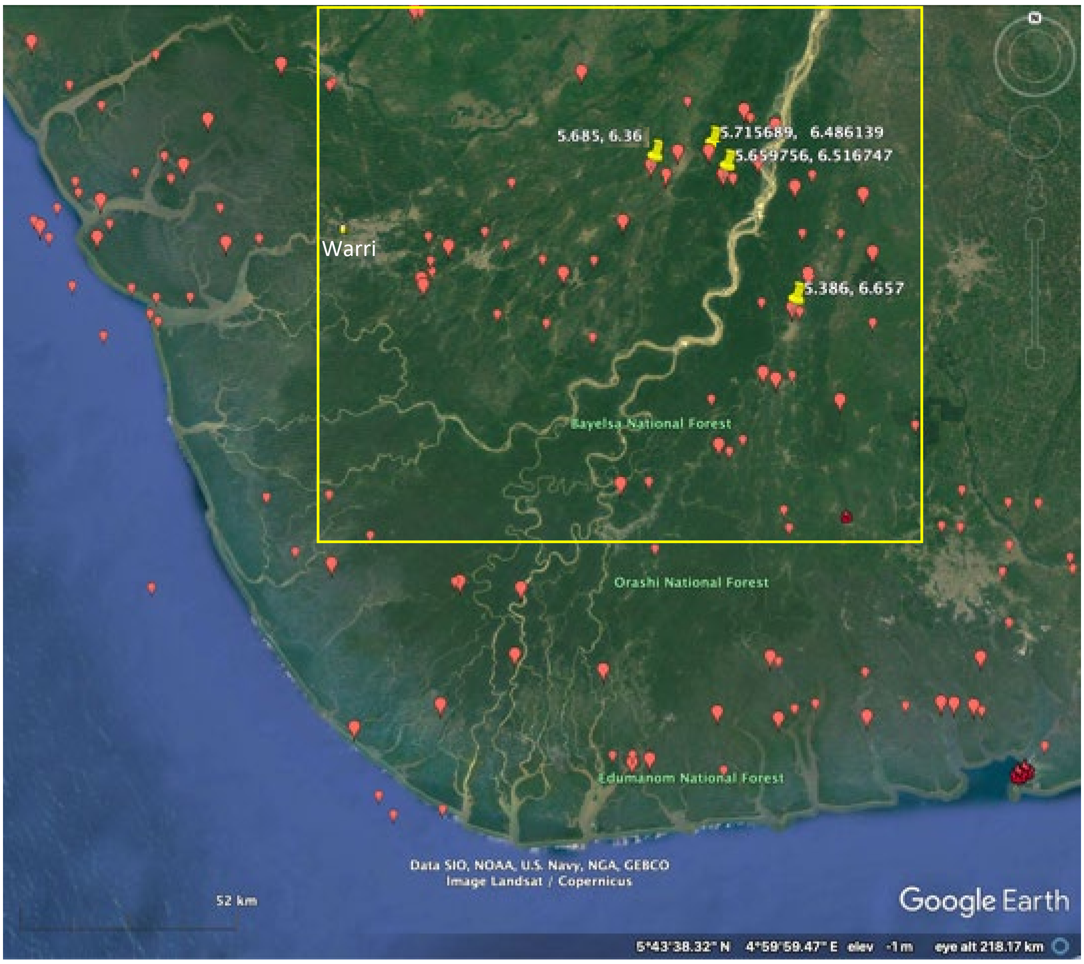
[19] EnergyCC confidential study

5. Regional flare evaluation and analysis in northern Niger Delta

Four closely clustered flares, some 80 km east of Warri in the northern Niger delta, are ranked in the global top 200 flares (see Figure 6). These super emitters are: Kwale flow station, Kwale gas plant (both in OML 60), Ebendo flow station (OML 56) and the Obiafu-Obrikom (Ob-Ob) gas plant. See Appendix A for more details of these four super-emitters.

The first three of these four flares are within 17 km distance from each other, near the town of Umusadage and Kwale. The fourth, most eastern super-emitter is situated at Obrikom village, north of Omoku town, and 46 km from the most western super-emitter at the Ebendo flow station. Kwale flow station (Lat=5.716, Lon=6.486 deg.), which is nearest to Kwale town, saw a remarkable drop in flare rate from 22.1 MMscf/d in 2017 to 9.2 MMscf/d in 2020. Thus, it declined significantly in the global ranking of super-emitter flares from 86th in 2017 to 309th in 2020. However, in the same period, Kwale gas plant (also in OML 60 license area, at Lat=5.660, Lon=6.517 deg.) increased its flare rate from 14.6 to 19.3 MMscf/d and moved up in the global flare ranking from 161st to 108th. **Because of the variation in flare rates, this assessment included not only reviews of specific individual flares but also addressed whether flaring in the wider area improved and how local communities were affected**.

Figure 6*: Four global top 200 flares (indicated by yellow pins) are located in the northern Niger delta*



Source: *authors' illustration based on a combination of Google Earth images with VIIRS data*
Note: *individual flares are shown by orange balloons; the 130 x 140 km area of interest is shown as a yellow box*

The flare performance in the wider 130 x 140 km area east of Warri was compared for the years 2017 and 2020 and is shown in Figure 7ab. In 2017, 51 flares were measured in the selected area. These wasted 188 MMscf/d of natural gas. In 2020 the number of such flares had increased to 62 (+21%), flaring at an increased combined rate of 234 MMscf/d (+24%).

Figure 7a: *In 2017, 51 flares in Warri area combust 188 MMscf/d gas, while the Kwale global super-emitter (indicated by the yellow pin) flared 22.1 MMscf/d.*

Figure 7b: *In 2020, 62 flares in Warri area combust 234 MMscf/d gas, while the Kwale global super-emitter (indicated by the yellow pin) flared 9.2 MMscf/d.*

Source: authors' illustrations based on a combination of Google Earth images with VIIRS data

5.1. Interconnectivity of flares and gas monetisation infrastructure

To put the volume and value of this much gas flared into perspective, we have compared it to the capacity and value of the Nigeria LNG (NLNG) plant on Bonny Island, one of the largest LNG plants worldwide with 6 LNG trains, a total LNG capacity of 22 mtpa and 3,500 MMscf/d of natural gas intake.[20] During 2020, the **gas flared in the east Warri area of interest** (see Figure 6) equalled 43 percent of one LNG train gas intake, **equivalent to 1.5 mtpa of LNG** output. At Q4 2021 LNG prices, this wasted gas would have a **market value of no less than USD 730 million per year**.[21] In 2020, the **four** super-emitters identified flared more than 65 MMscf/d (28 percent of the east Warri area volume flared), wasting more than USD 200 million per year against Q4 2021 LNG prices. What is remarkable is that many east Warri **assets where flaring occurs are connected to gas infrastructure that leads to the Bonny LNG plant** (Figure 8). Therefore, this gas could relatively easy have been monetised had it not been flared. As this is a wholly avoidable loss, **actions might be prioritised** to eliminate the wastage.

***Figure 8**: Facilities at the gas flares are interconnected to pipelines and other oil and gas plants.*

***Source:** Oando Energy Resources Inc. Investor presentation, September 2014, https://www.oandoplc.com/wp-content/uploads/OER-Investor-Presentation-_-September2014.pdf.*

The facilities at the four super-emitters are linked by oil and gas pipelines and connected to other infrastructure. Ebendo flow station is connected by an oil pipeline to the Kwale flow station. Gas output from the Kwale flow station is connected to the Kwale gas plant, which itself provides gas to the nearby Kwale-Okpai Independent Power Producer (IPP) plant. Excess gas is transported to the Ob-Ob gas plant and from there transported to the NLNG plant at Bonny Island for export. Oil is aggregated and exported from Kwale to Brass River oil terminal at the coast (Figure 8). It is because of this close interconnectivity of oil and gas infrastructure

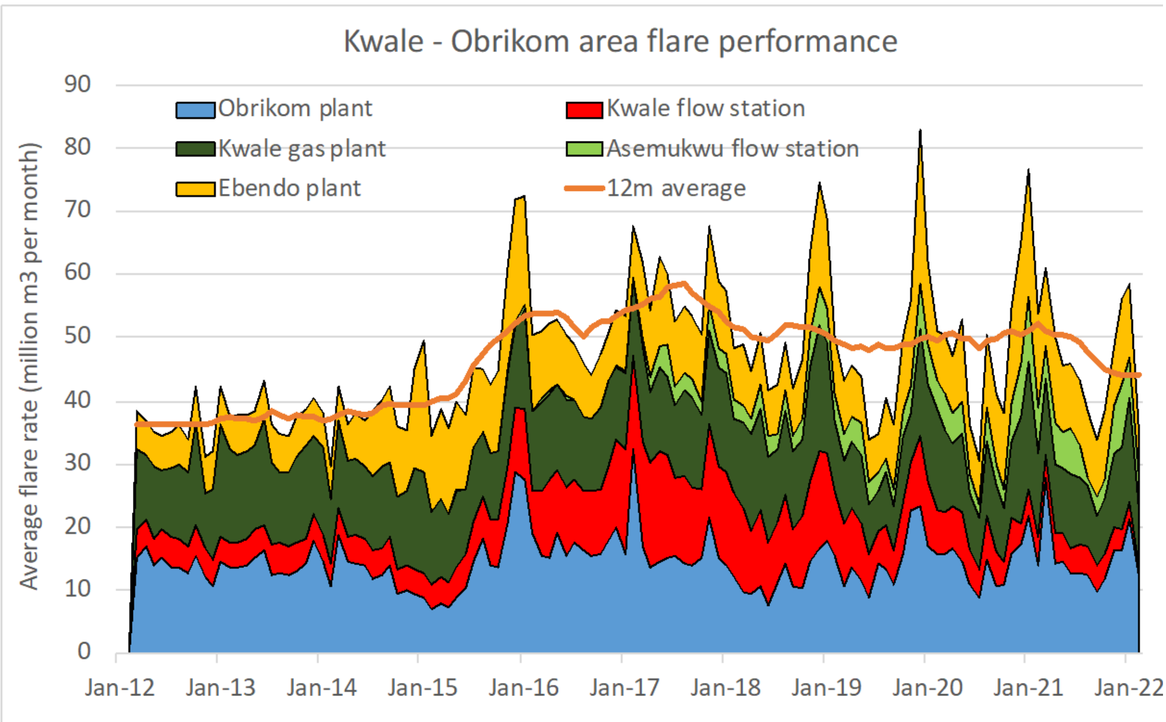
[20] Bonny Island NLNG plant https://www.nigerialng.com/operations-strategies/Pages/The-Plant.aspx.
[21] Q4 2021 US LNG prices were $10 per thousand cubic feet: https://www.eia.gov/dnav/ng/hist/n9133us3m.htm; value excludes liquefaction cost; 1 tonne of LNG contains 48.7 billion cubic feet (Bcf) of gas.

that it is desirable that any flare evaluation going forward should include an explicit regional analysis in addition to the analysis of individual gas flares.

5.2. Synchronicity between flares

The **connectivity of infrastructure is a probable cause of the remarkable degree of synchronicity in individual flare performance**. For example, the increase in Ob-Ob flaring to average 25.6 million m^3 per month during November 2015 to January 2016 period (up from 13.6 million m^3 per month previously) appears to be mirrored by other upstream assets (Kwale gas plant and Kwale and Ebendo flow stations), more than doubling the combined increase in flaring by an average of 23.8 million m^3 per month in this same period (from 44.6 to 68.5 million m^3 per month) . The same trend of interrelated flaring can also be seen in the end-of-year months in each of the years from 2017 to 2021 (see Figure 9). This synchronicity in flaring rates indicates a mutual dependency between assets that can be due to 'bottlenecks' in oil and gas evacuation. For example, if the Ob-Ob plant has a temporary restriction in gas processing, facilities supplying the plant may be forced to divert their gas to their local flare. Also, dependency on the electrical power grid for oil and gas operations may result in synchronised outages (and therefore gas flaring) when the electricity supply is down. In the past, oil was developed from this region under gas-reinjection schemes to preserve natural gas for later development and use. With the availability of local gas utilisation and gas evacuation, **gas reinjection schemes may no longer be maintained and used**. Therefore, when gas infrastructure is unavailable or constrained, **gas is no longer reinjected but flared instead**.

Figure 9*: Facilities at the gas flares are interconnected to pipelines and other oil and gas plants*



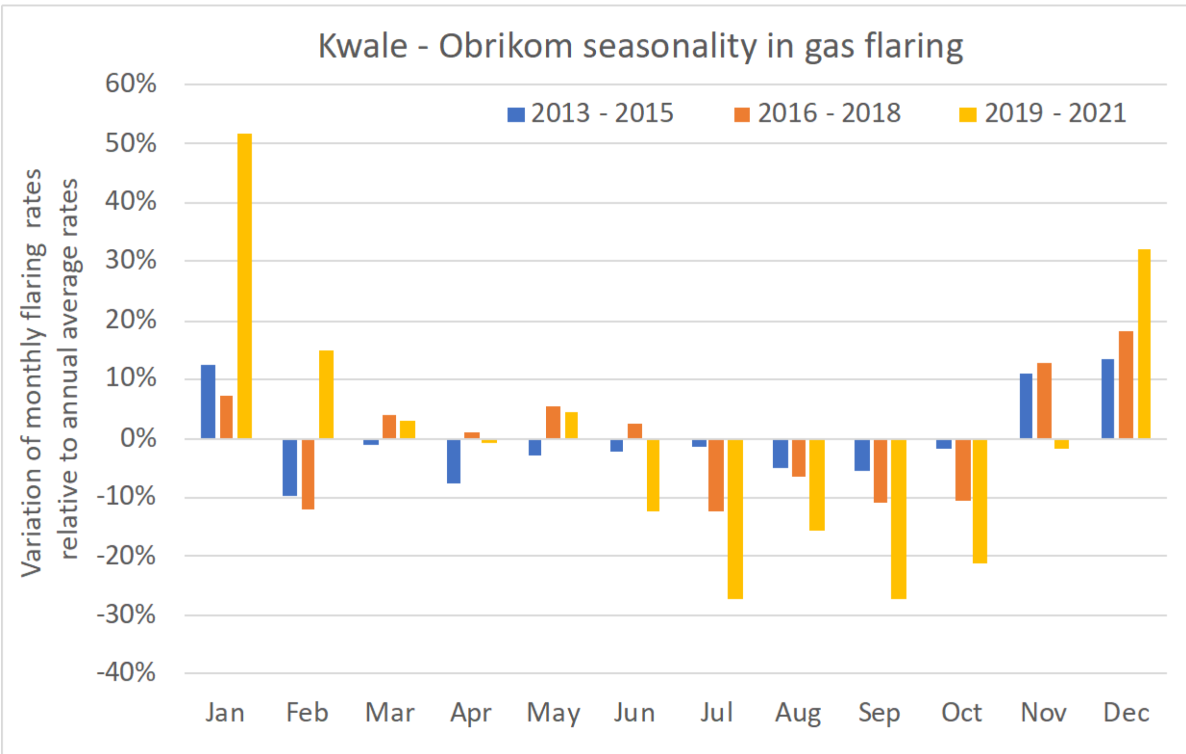
Source: *Source: authors' illustration based on VNF data from Payne institute, Colorado School of Mines* *https://payneinstitute.mines.edu/eog/viirs-nightfire-vnf/.*

The orange line in Figure 9 is the 12-month moving average of the combined flare rates of the 5 plants shown. The combined flare rate is 20 percent higher now (early 2022) than in 2012. In 2015, flaring increased by some 40 percent compared to the prior period. Flaring remained high until mid 2021 when a gradual reduction was observed.

5.3. Seasonality in flaring

In addition to synchronicity in regional gas flares, the apparent seasonality in flaring is also noteworthy. Since 2016, flaring in the December and January periods repeatedly exceeds the annual average flare rates significantly, the increase being a factor two higher compared to the months prior to and after this period. The seasonality in gas flaring appears to have become stronger in recent years, as shown in Figure 10. The Bonny Island LNG plant discussed above provides half of its output to European gas markets, which are desperately trying to find replacement supplies to reduce their dependency on Russian gas. It is remarkable therefore that **so much gas is flared, particularly during winter months, while Bonny LNG utilisation is well below capacity, at below 70 percent.**[22]

***Figure 10**: Seasonality in gas flaring of Ob-Ob and Kwale gas plants and Kwale and Ebendo flow stations*



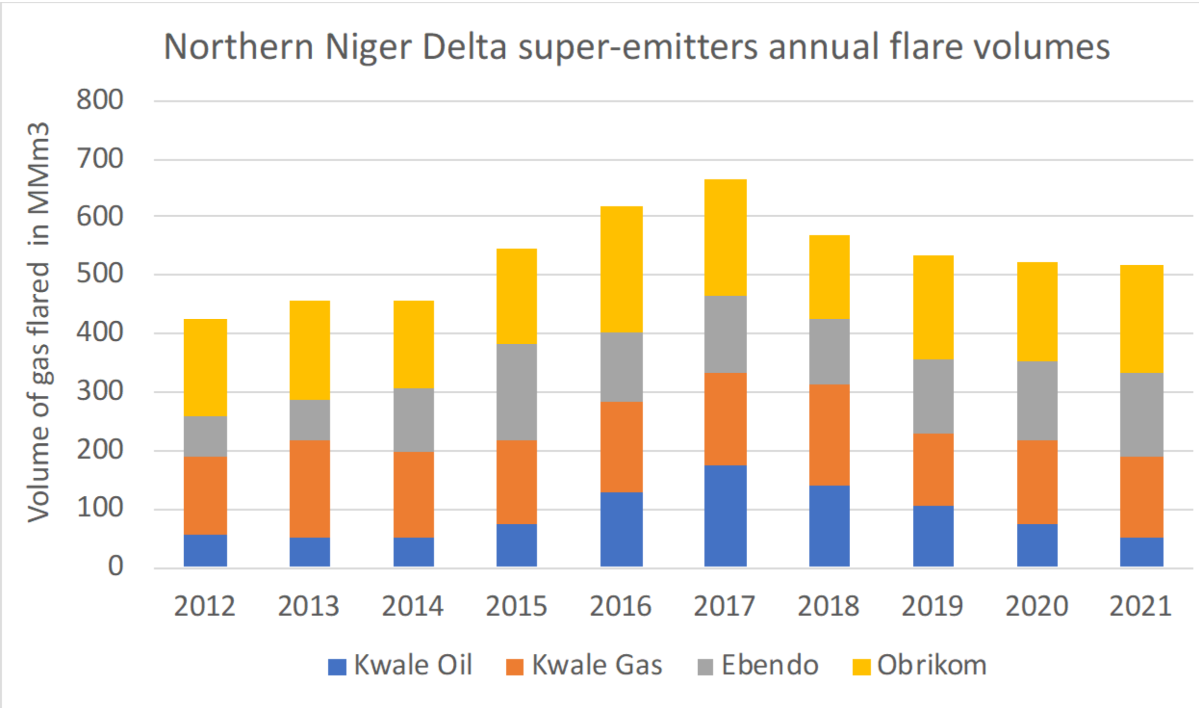
***Source:** Source: authors' illustration based on VNF data from Payne institute, Colorado School of Mines https://payneinstitute.mines.edu/eog/viirs-nightfire-vnf/.*

[22] Business Post, "Why Nigeria can't produce 70% of gas capacity – NLNG", 6 April 2022; https://businesspost.ng/economy/why-nigeria-cant-produce-70-of-gas-capacity-nlng/

5.4. Changes in flare rates over time

Figure 11 shows the variation in annual average flare rates for the four super-emitter flares in the northern Niger Delta region. The graph highlights that although the annual volume flared by these super emitters varies over time, all these flares have been flaring large volumes of gas during the last ten years. **Compared to 2012, these super emitters flared 93 million m^3 (+22 percent) more in 2021**.

Figure 11*: Annual volume of gas flared by the four super emitters in the period 2012 - 2021*



Source: *Source: authors' illustration based on VNF data from Payne institute, Colorado School of Mines* *https://payneinstitute.mines.edu/eog/viirs-nightfire-vnf/.*

When focusing specifically on the area around the Kwale flow station, which is the super-emitter with a remarkable drop in flaring rate from 2017 to 2020, we note that the individual flare sites and flare rates are quite variable as well. In a 15 km radius around the Kwale flow station, there were a total of 8 flares, including three super emitters, combusting 63 MMscf/d of natural gas in 2017 (total volume flared 651 million m^3). In the same area in 2020, the number of flares had increased to 10, combusting 70 MMscf/d (total volume flared 723 million m^3). This implies that although the Kwale oil station super-emitter had reduced flaring in this period, this was more than offset by increased flaring from other flares nearby in this local region. The **interconnectivity of infrastructure also allows gas volumes of high rate flares to be reallocated over a larger number of nearby flares**, particularly if these are located in the same oil and gas production license area, see Figure 12ab.

Figure 12a: *8 flares in 2017 (rates in MMscf/d) in a 15 km radius from Kwale super-emitter*

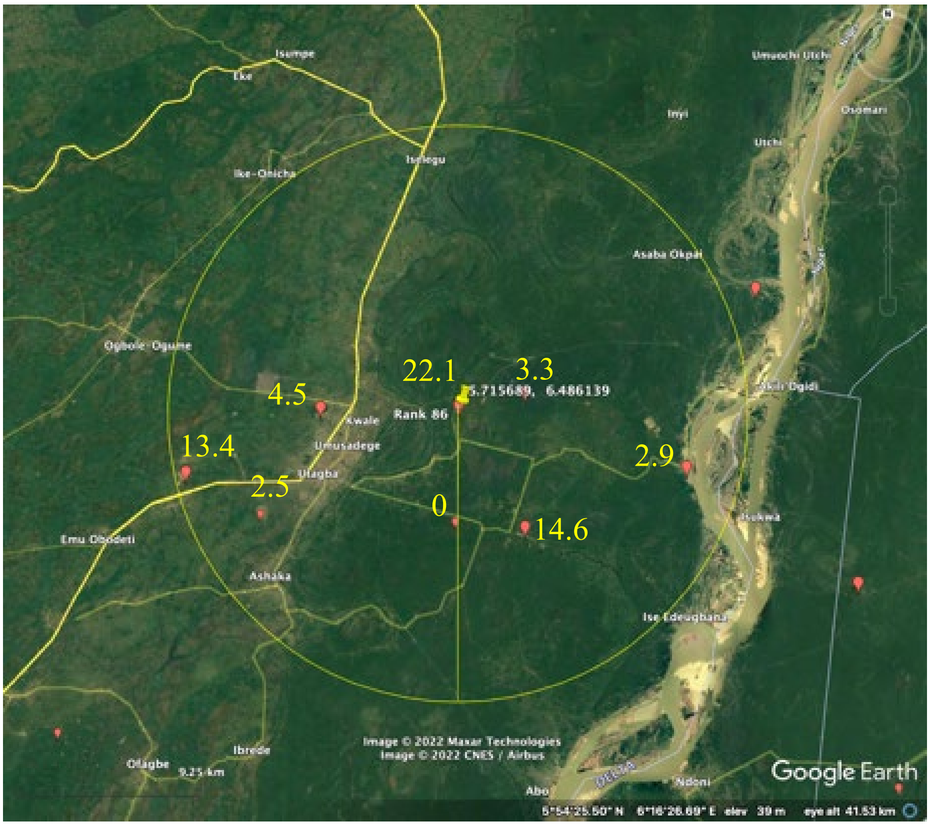
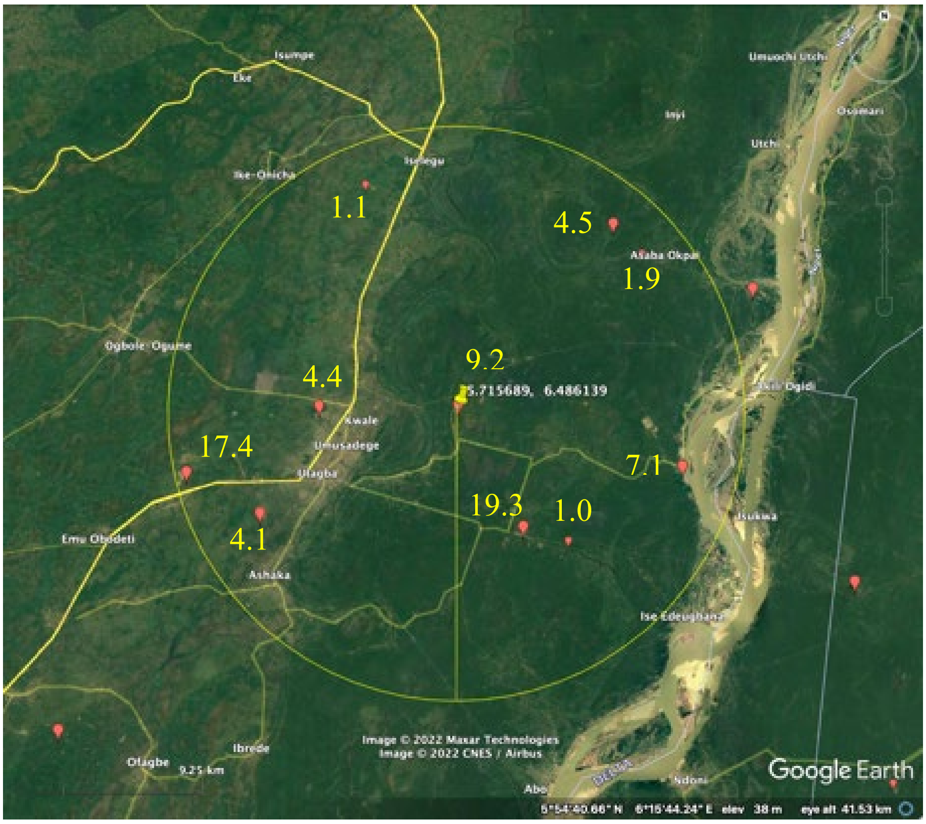


Figure 12b: *10 flares in 2020 (rates in MMscf/d) in a 15 km radius from Kwale super-emitter*



Source: *authors' illustrations based on a combination of Google Earth images with VIIRS data*

6. Overcoming barriers to repurpose flare gas in Niger Delta

The next two sub sections discuss the background to the continued gas flaring in the northern Niger Delta, despite available infrastructure to transport and utilise the associated gas. [23]

6.1. Monetising flare gas through existing gas infrastructure

The issues restricting NLNG utilisation below 70% do not relate only to technical considerations, such as available pipeline compression capacity to accommodate associated gas that is now flared. Another key factor of concern is the prioritisation among the different sources of gas supply to the Bonny LNG plant. **Associated gas should have the highest priority for utilisation as it is an unavoidable by-product in the production of oil**. On the contrary, non-associated gas production can be adjusted to meet gas demand, producing more or less by optimising gas well offtake rates. The persistent volume of Niger Delta gas flared despite the availability of gas evacuation infrastructure suggests that the **associated gas is insufficiently prioritised for use by gas demand centres such as NLNG**.

This would appear to be a potential opportunity of significance, but it requires that third-party access rights are granted for existing gas infrastructure, such as NLNG and its gas pipeline supply network.[24] **Commercial terms for infrastructure access should be reasonable to incentivise associated gas producers**. Gas flaring that is conducted without permit carries zero value, while flare permits carry a penalty of USD 0.50 / Mscf (for fields producing less than 10,000 bopd) and USD 2.00 / Mscf (for fields producing more than 10,000 bopd).[25] Satellite measurements would allow all gas flares to be measured and penalized regardless of their permitting status. Moreover, our analysis will show that three of the four Niger Delta global super-emitters analysed are marginal oil producers (i.e. producing less than 10,000 bopd of oil) and therefore attract the low tier of flare penalties. **The assumption that marginal oil producers flare less and therefore should attract lower penalties does not hold**. Applying **penalties uniformly at realistic levels (USD 2.00 / Mscf or higher) increases the commercial incentive for associated gas producers to accept reasonable terms for the sale of their gas**. Mechanisms for sale of third party associated gas into NLNG infrastructure are a high priority. A combination of uniformly applied and sufficiently high flare penalties, combined with netback gas prices for third-party gas that reward infrastructure owners appropriately for utilisation cost - yet also offer a profit sharing percentage to associated gas producers, would **provide a win-win-win** for associated gas producers, infrastructure owners and government.

[23] Associated gas is a by-product of upstream oil exploration and production. It consists of natural gas that is carried in solution of the crude at reservoir conditions, and is liberated as free gas when pressure and temperature decline as crude oil is produced to surface. Gas in solution at reservoir conditions is sometimes complemented by free gas produced from the reservoir, either from a reservoir gas cap or under pressure draw down by the producing well.

[24] B. Aduloju, "FG to NLNG partners: Allow transportation of third-party gas through joint pipelines", The Cable, 5 April 2022; https://www.thecable.ng/fg-to-nlng-partners-allow-transportation-of-third-party-gas-through-joint-pipelines (accessed 12 August)

[25] Y. Akinpelu, "Analysis: As Nigeria continues to miss gas flaring deadlines, huge revenue is lost", Premium Times NG, 30 April 2021; https://www.premiumtimesng.com/news/headlines/458507-analysis-as-nigeria-continues-to-miss-gas-flaring-deadlines-huge-revenue-is-lost.html (accessed 12 August)

6.2. Okpai power plant – its impact on local flaring and energy supply

6.2.1 Okpai power plant gas demand opportunity

The Okpai power plant was the first JV[26]-sponsored Independent Power Plant (IPP) in Nigeria when it started up in April 2005. It was designed to deliver 480 MW from its integrated combined cycle power plant (ICPP) consisting of two gas turbine generation sets of 165 MW each and a steam turbine of 150MW. It is fed with fuel gas by a 14 km, 18" pipeline from the Nigerian Agip Oil Company's (NAOC) Kwale gas plant. Because the power plant utilises local associated natural gas as fuel, it should make a positive impact in the reduction of flare gas from the local area, particularly for flares in OML 60 license area where Okpai is situated. In addition to the power generation facility, NAOC JV also built a 55 km long 330KV Overhead Transmission Line, with 2 substations, to evacuate the power generated to the Onitsha sub-station.[27] It was developed to meet domestic power demand in the south east region states, including Abia, Anambra, Ebonyi and Imo. The power plant performance was based on the following assumptions: a plant availability of 97 percent; an average load factor during the available period of 91.3 percent; and all generated power to be exported to the grid. These plant specifications were therefore expected to deliver 3.7 GWh per year to the grid. At full capacity, the plant should consume 75 MMscf/d. Based on its availability specifications, the plant was to reduce flaring by 66 MMscf/d, i.e. 0.69 Bcm per year.

6.2.2 Okpai IPP - Clean Development Mechanism assumptions and outcome

The project also conformed with the Nigerian Government's demand to stop natural gas flaring and the project was executed under the provisions of the Clean Development Mechanism (CDM) as CDM Project No. 0553.[28] The CDM application for the Okpai IPP claimed a saving of 15 million tonnes of CO_2e over a period of 10 years (this crediting period was fixed from 9 Nov 2006 to 8 Nov 2016).

On pages 4, 5, 8 and 13 in the CDM Project Design Document[29], there is description of OML 60 facilities for gas reinjection, with a key role for Kwale gas plant to "*export dry gas for reinjection at wells in OML60. The reinjected gas is stored at reservoirs within OML60 for future potential use*". To support the CDM claim for the Okpai IPP, on page 15 and following the applicants (NAOC on behalf of OML 60 JV partners) demonstrate "*how the anthropogenic emissions of GHG by sources are reduced below those that would have occurred in the absence of the registered CDM project activity*". The economics (based on Internal Rate of Return, IRR) of five alternative options were compared to determine the baseline for the CDM application:

[26] The joint venture (JV) partners are as in OML 60 license area with ENI subsidiary Nigerian Agip Oil Company (NAOC) as operator and 20% share. Other JV partners are: Nigeria National Petroleum Company (NNPC) with 60% and Oando Energy Resources 20%.

[27] https://www.eni.com/en-NG/what-we-do/mid-downstream/power.html

[28] The CDM was established under the UN Framework Convention on Climate Change (UNFCCC)

[29] CDM Executive Board, Clean Development Mechanism Project Design Document - Recovery of associated gas that would otherwise be flared at Kwale oil-gas processing plant, Nigeria, 15 May 2006; https://cdm.unfccc.int/UserManagement/FileStorage/T2N9G73GCSUW91EJUE7BJRW9NGIOLU (accessed 12 August 2022)

1. **Gas venting**: was rejected, because it did not comply with Nigerian laws on oil field development and Eni's own internal standards and policy for health safety and the environment, and GGFR standard adopted by Eni.
2. **Gas flaring**: "Continuous flaring of the gas produced in association with oil from the wells in OML 60 presents the most economically attractive course of action…Continuation of flaring is highly attractive". Mention is made of Nigeria anti-flaring laws, but these are being discarded as a) flaring carries much less financial risk relative to payment of penalties; b) the largest share (40 percent) of associated gas in the Niger Delta is flared by oil companies, and c) the anti-flare law cannot be considered binding.
3. **On site use**: "significant [gas] supply surplus relative to onsite power demand", accounting only for 1% of total gas delivered.
4. **Gas reinjection**: "Already carried out at the OML 60 wells for gas storage….additional cost of associated gas….injection means that the economic value if the gas will not be realised by the market and for electricity generation.
5. **Gas for end use:** "investment in gas utilisation projects is a risky business in Nigeria… expensive debt financing for projects in Nigeria…local marker for the recovered gas not in place", uncertainty of supply of associated gas not suitable for LNG, amount of gas insufficient for a dedicated LNG train.

The basis for and the performance of the CDM project was assessed in several studies, including a Nigeria associated gas utilization study by the Columbia Center on Sustainable Development.[30] Another study challenges the CDM on several grounds, including that "the CDM represents a substantial reward provided to oil companies for mitigating an activity which they should not be doing in any case"[31].

The only CDM monitoring report that was produced (dated 10 September 2010) mentions that gas use by Okpai IPP is partly non-associated gas, thus not contributing to gas flare reduction. The same report also mentions that only 36.8% of the targeted CO_2e emission reductions of 1.5 mtpa were achieved for the period 9 November 2006 to 31 December 2009.[32] CDM monitoring for the project has shortcomings as there is no evidence that the contribution of non-associated gas is measured. Furthermore, the **CDM project does not include monitoring of flare rates in the region as a performance metric despite flare reductions being the main justification for the CDM**. The above mentioned verification report is the only one available under United Nations Framework Convention on Climate Change (UNFCCC). This gap is a matter for investigation and possible correction. In July 2017,

[30] P. Toledano and B. Archibong, "Nigeria Associated Gas Utilization Study", Columbia Center on Sustainable Development; https://ccsi.columbia.edu/sites/default/files/content/docs/our%20focus/Nigeria-APG-Utilization-Study-Sept-2016-CCSI.pdf

[31] F. Allen, P. Bond, K. Sharife, "The CDM in Africa can't deliver the money" - report to the UN CDM Executive Board "Call for inputs on the policy dialogue" about CDM flaws in South Africa and Nigeria", January 2012; https://cdm.unfccc.int/public_inputs/2011/eb64_02/cfi/P2MUQY1117HGL6AH8DJLCEY7ZD5VAX

[32] UNFCCC - CDM, Project 0553 : Recovery of associated gas that would otherwise be flared at Kwale oil-gas processing plant, Nigeria https://cdm.unfccc.int/Projects/DB/DNV-CUK1155130395.3/view .

RINA Services S.p.A., an inspection and certification services company, terminated the CDM verification contract 'due to lack of information and data, as requested by the contract' (sic).

6.2.3 Okpai IPP performance impact on electricity generation

At its shareholder meeting on 5 May 2011, ENI mentioned in response to questions, its intention to plan for **zero gas flaring at Kwale flow station from June 2011**.[33] **This promise did not materialize**. The Okpai power plant also underperformed in terms of local electricity supply. The issues are various and relate to lack of offtake contracts (PPA), lack of payment for electricity supply, grid inadequacies and acts of sabotage.

After much delay, in Q3 2019, Okpai power plant commissioned an expansion of the facility, raising its power generation capacity to a total of 930 MW (see Figure 13). However, by July 2020, no power-purchasing agreement (PPA) had yet been established with the Nigerian Electricity Bulk Trader (NBET) for the increased capacity, due to 'grid inadequacies', and no incremental power had yet been sent to the grid.[34] The performance of the Okpai power plant in terms of electricity generated and gas utilised is shown in Figure 14. **The expansion in capacity has to date not resulted in any increase in electricity supply** on average compared to the period prior. However, power output since the expansion is significantly more irregular.

Figure 13*: Kwale – Okpai IPP power plant*

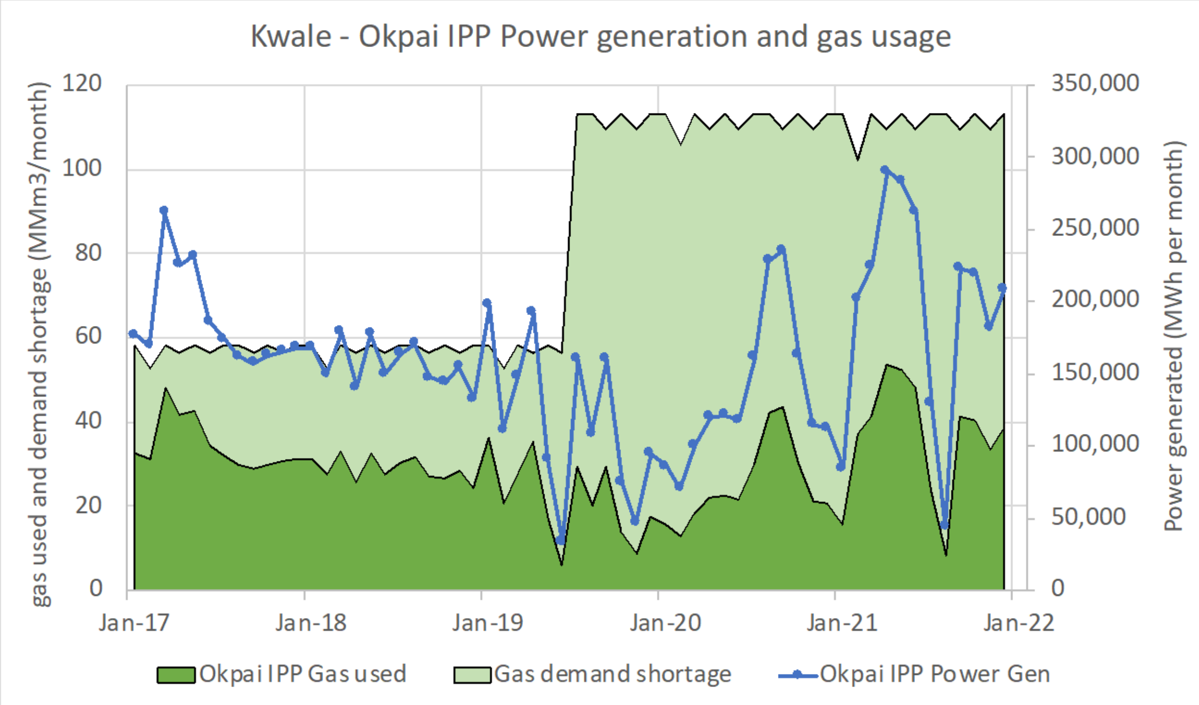
Source*: Google Earth*

[33] https://www.eni.com/assets/documents/Focuses-required-at-the-Shareholders-Meeting.pdf

[34] The inability to provide electrical power to local customers is a common problem in Nigeria that has 13 GW power installed generation capacity, 7 GW transmission capacity and 3 GW actual average distribution (23% of installed capacity), https://www.nigeriaelectricityhub.com/2020/07/06/why-nigerians-are-yet-to-feel-impact-of-expansion-of-1000-mw-okpai-power-plant/ .

The performance of Okpai IPP is all the more disappointing as 43 percent of Nigeria's population do not have access to grid electricity. In 2021, The World Bank approved USD 500 million to support the government of Nigeria in improving its electricity distribution sector. [35]

***Figure 14**: Kwale – Okpai IPP power generation and (shortfall) in gas demand*



***Source:** Source: authors' illustration based on Nigeria Power generation data by the National Bureau of Statistics, https://nigerianstat.gov.ng/elibrary*

***Note**: based on IPP design specifications, the Okpai IPP was targeted to deliver an average of 310,000 MWh per month before its capacity expansion in Q3 2019, and 600,000 MWh thereafter. The power supply of the plant is on average 53% of the design output before the expansion and 26% thereafter. Average power generation before expansion was 163,116 MWh per month and 154,280 MWh per month thereafter.*

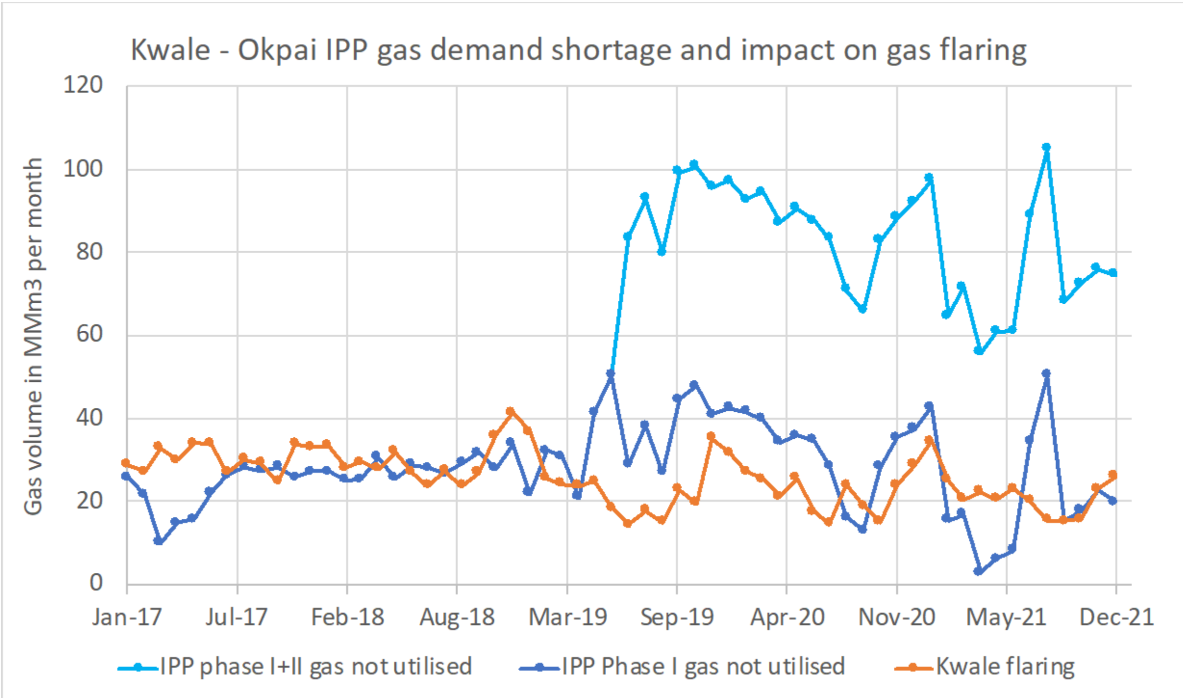
6.2.4 Okpai IPP performance impact on gas utilisation and local flaring

Because the Okpai power plant uses only a fraction of the gas it is supposed to utilise, a comparison was made between the volume of gas locally flared and Okpai's unutilised gas demand. The outcome of this analysis is shown in Figure 15. The data shows that the gas **volume flared by the three flares[36] nearest to the Okpai plant (Figure 16) closely match the shortfall in gas demand from the Okpai IPP**. **This implies that the shortfall in Okpai IPP gas demand is flared, rather than exported to the Ob-Ob plant**. After the Okpai IPP expansion was commissioned, there was no significant change in flaring. The reason is most likely that the expanded capacity is idle due to lack of electricity offtake. It is therefore unknown if the power expansion will result in further reduced gas flaring in the area.

[35] The World Bank, "Nigeria to Improve Electricity Access and Services to Citizens", 5 February 2021; https://www.worldbank.org/en/news/press-release/2021/02/05/nigeria-to-improve-electricity-access-and-services-to-citizens.

[36] These flares are located at the Kwale flow station (lat 5.716, long 6.486), the Kwale gas plant (lat 5.660, long 6.517) and the Asemukwu flow station (lat 5.687, long 6.591). The first two of these three flares are global super emitters.

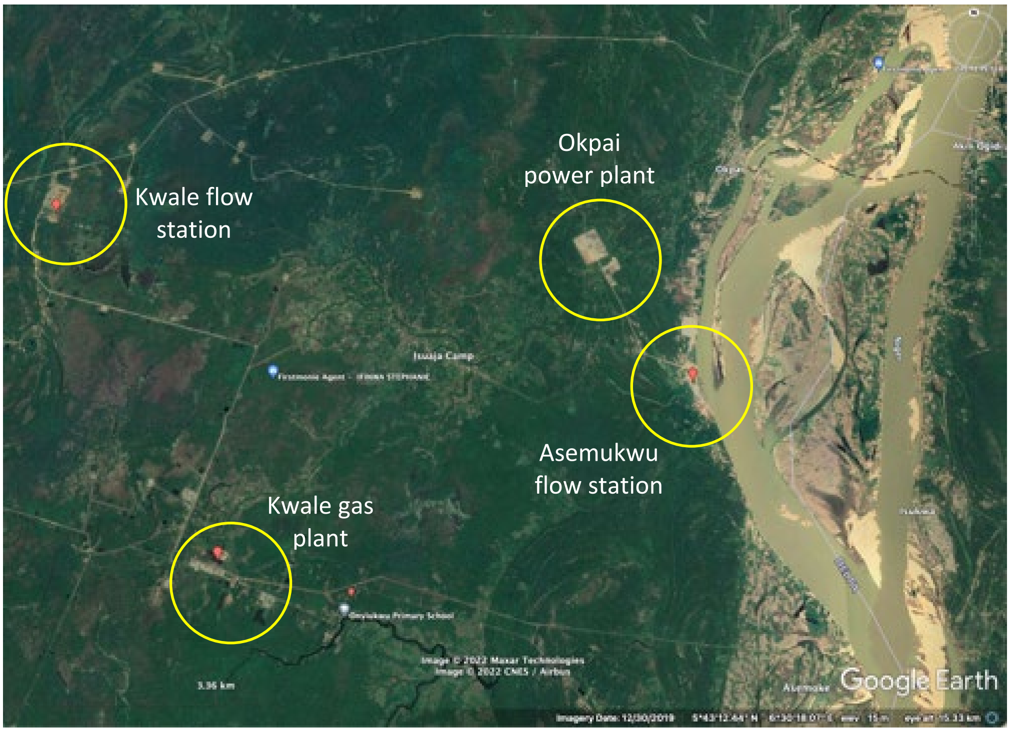
***Figure 15**: Comparison of the Okpai IPP plant shortfall in gas utilisation and local Kwale flaring*



***Source:** authors' illustration based on data by the National Bureau of Statistics https://nigerianstat.gov.ng/elibrary and by Payne institute, Colorado School of Mines https://payneinstitute.mines.edu/eog/viirs-nightfire-vnf/.*

***Note**: Local Kwale flaring volumes (orange line) match the unutilised gas of the Phase 1 Okpai power plant (dark blue line), with corresponding trends, e.g. from August 2019 to June 2020 and from October 2020 to March 2021.*

***Figure 16**: Location of Okpai power plant and surrounding flares*



***Source:** authors' illustration based on a combination of Google Earth images with VIIRS data*

***Note**: The flare locations are shown in orange 'balloons'. There is a fourth flare in the image 2km east from Kwale gas plant, adjacent to the Onyiukwu primary school (flare size is 5% of the Kwale gas plant flare).*

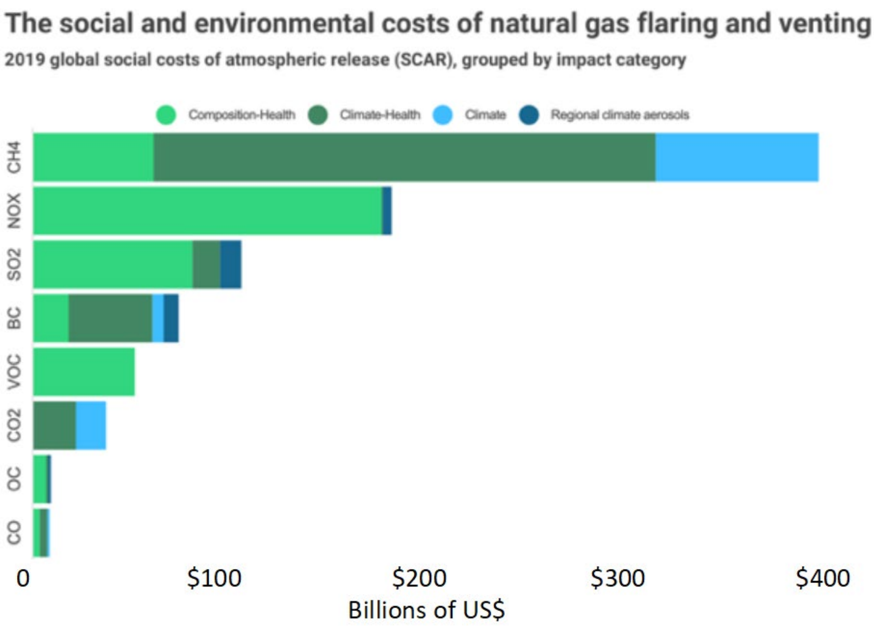
7. Impact of flaring emissions on local communities: air quality, crop yields, energy access

Flaring is not only a significant waste of a valuable energy resource, it also affects air quality and so imposes a serious health risk on nearby communities. Flaring may also cause toxins to enter into agriculture produce and it certainly contributes to global warming, particularly through methane emissions due to poor flare operations.[37] [38] This present section considers the measurement of the social damage that may be caused by flaring but then proceeds to examine the practical remedies that seem increasingly possible.

7.1. The local social benefits of reduced flaring

Why are methane emissions important locally? Reducing methane emissions from poor quality flaring has immediate **local benefits**. Above all, the social cost of emissions is reduced sharply, with benefits especially for human health. Estimates of the **Social Costs of Atmospheric Release (SCAR)** by Romsom and McPhail are based on a methodology developed by Shindell.[39] This methodology integrates climate, agriculture, and health effects into a single measure from four key areas. These are: global climate change, regional changes in water cycles induced by aerosols, health impacts from climate changes, and health impacts from air quality. [40] These are represented in the four colours in Figure 17 below.

***Figure 17**: SCAR impact of global flaring and venting by individual chemical emitted*



***Source:** illustration by UNU-WIDER https://www.wider.unu.edu/publication/reducing-wasted-gas-emissions-opportunity-clean-air-and-climate (permission obtained).*
***Note**: Methane has the largest SCAR among the various chemicals emitted from natural gas flaring and venting.*

[37] See Footnote 1.
[38] See Footnote 2.
[39] See Footnote 3.
[40] McPhail and Romsom, UNU-WIDER Blog, October 2021; https://www.wider.unu.edu/publication/reducing-wasted-gas-emissions-opportunity-clean-air-and-climate.

Figure 17 also makes it clear that among the eight chemicals[41] emitted by flaring and venting, methane (CH_4) has a far greater social cost than does carbon dioxide (CO_2). So, reducing these methane emissions by curbing gas flaring and venting provides a great opportunity to reduce the negative impacts on human health as well as on global warming. [42]

Satellite data provides the additional advantage that it enables us to overlay the local context – location of villages, hospitals, schools, agricultural lands etc. - and show where significantly reduced emissions from gas flaring would lead to the most substantial and immediate benefits. These include better human health from improved air quality, fewer damaging particulates and toxic chemical emissions; less toxic chemical absorption in the food chain; improved crop yields because of lower methane levels; and opportunities to repurpose the gas for local community energy access.

A combination of VNF satellite data from flares with Google Earth satellite images show that **communities in relevant parts of Nigeria – including areas affected by the four super-emitters that we have studied - are often located within only a short distance of large gas flares, sometimes at less than 200 meter distance**. Sometimes, community services are exposed to nearby flaring, such as the Kwale village local hospital near Kwale flow station (Figure 23), and the Onyiukwu primary school nearby Kwale Gas plant (Figure 16).

Agricultural land adjacent to high-rate flares is likely contaminated with volatile-organic compounds (VOCs) and other by-products from flaring, particularly when flare quality is poor. Emission factors for flares generally underestimate actual emissions. In the US, under the Clean Air Act, the emission factors were amended after a lawsuit forced the US Environmental Protection Agency (EPA) to carry out a review based on actual refinery data. The review demonstrated that the flare emission of VOCs was four times the amount previously assumed.[43] We might anticipate a similar level of under-estimation for Nigerian flares: an issue worthy of deeper examination.

This is all **highly relevant to the main super-emitters** upon which this paper has concentrated. Satellite imagery shows that the super-emitter flare from the Ob-Ob gas plant (Figures 31, 32) is 1000 metres from agricultural lands (Figure 36); Kwale flow station is on the boundary of crop lands (Figure 22); and Ebendo flow station which is close to Obodougva village, is only 150m distant from communities' agricultural lands (Figure 43). In addition, agriculture fields extend to flares at the boundary of the 'Midwestern Oil and Gas facility of Ogbe village near Kwale (Figures 24, 25). **To protect community health, flares sites should have an exclusion zone based on flare rates and flare quality**. So very substantial social benefits would be realised were these flares to be reduced.

[41] CH_4 (methane), NO_X (nitrogen oxide), SO_2 (sulphur dioxide), BC (black carbon), VOC (volatile organic compounds), CO_2 (carbon dioxide), OC (organic carbon), and CO (carbon monoxide), and see footnote 1.
[42] Hicklin and McPhail, CGD Blog, February 2022; https://www.cgdev.org/blog/practical-proposal-methane-2022-climate-pledges-action
[43] See Footnote 1, and also: Environmental Integrity Project (2015). 'Fact Sheet on Air Pollution from Flares'. Available at: https://environmentalintegrity.org/news/fact-sheet-on-air-pollution-from-flares/ .

7.2. Existing initiatives in Nigeria to reduce atmospheric emissions from oil and gas operations

The impact that gas flaring and its emissions has on local communities has been published frequently, including in a recent report by Stakeholder Democracy Network, an NGO established in 2004, working in the Niger Delta. Its mission is to reduce the negative environmental impact of the oil and gas sector by documenting, and making public, the extent of pollution. It is also working with the Nigerian environmental regulators to strengthen their work and supporting the National Assembly to improve environmental legislation. In one of its recent reports, it finds: [44]

> *"IOCs are seen to have spent decades exploiting local resources, polluting the environment, destroying local livelihoods of fishing and farming, while revenues generated have not led to expected investments in communities, and have diverted attention away from other productive economic activities, towards oil and gas rent streams. This has undermined trust in IOCs, and complicated the operating environment, to a point where they are admitting they cannot resolve the problems."*

Nigeria also participates in a peer-to-peer regulatory support process, convened by the Climate and Clean Air Coalition (CCAC), to help develop **specific emission targets for the oil and gas sector** for Nigeria's Nationally Determined Contribution (NDC) and to convert the targets into regulations. In August 2021, Nigeria submitted its updated NDC to the UNFCCC. This resulted in an increase in Nigeria's climate change mitigation ambition and action against integrated Short-Lived Climate Pollutants (SLCPs), such as **methane.** This climate change commitment should result in a reduction of Nigeria's air pollution. The revised NDC provides for a 60 percent reduction in fugitive methane emissions from the oil and gas sector by 2031, conditional on international support. If these NDCs can be fully achieved, black carbon will reduce by 42 percent, methane by 28 percent, and hydrofluorocarbons (HFCs) by 2 percent, all by 2030. This updated NDC is rated 'almost sufficient' by Carbon Tracker. [45]

The CCAC has been working in Nigeria since 2014, starting with ways to improve action for national planning for SLCPs. Early interventions for the oil and gas industry identified that penalties for companies that did not meet regulations were '***not enough of an incentive to force companies to comply'***. Steps might now be considered to address this issue.

[44] Stakeholder Democracy Nigeria, "Report: Divestment from the Delta Implications for the Niger Delta as international oil companies exit onshore production", October 2021; https://www.stakeholderdemocracy.org/report-divestment/ (Accessed 8 August 2022).
[45] Climate Action Tracker, Nigeria country summary, 11 February 2022 update; https://climateactiontracker.org/countries/nigeria/ (accessed 8 August 2022)

7.3. Approaches to capture the potential benefits of atmospheric emission reductions

The important role of regulation and fiscal measures in highlighting the opportunities for all countries to measure, capture, and use the gas otherwise wasted was highlighted in the United Nations Environment Program (UNEP) and CCAC 2021 Global Methane Assessment. It finds that a methane tax is effective in reducing emissions from the energy sector and leads to an immediate drop in the implementation year. For such methane tax (or penalty) to be implementable, it is not necessary that the government is burdened with the evidence of proof about how much methane companies emit. Recent work by the International Monetary Fund (IMF) and others is spelling out how this is possible:

> "*The IMF has devised a novel way to tackle methane emissions in contexts where satellite-based measurements still need further improvement.*[46] *In the absence of metering or remote measurement of emissions, taxes can be levied based on assumed default methane leakage rates, with rebates given to operators that demonstrate, via continuous monitoring, lower leakage. This creates* ***disincentives for operators to conduct routine gas flaring and venting operations, as these erode their commercial returns, without the authorities having to prove how much methane was emitted****. Conversely, the repurposing of waste gas for local use may now become commercially attractive if penalties for (deemed) methane emissions are set at the right level*." [47]

In a similar manner, VNF data measurements can provide a readily implementable basis for allocating flare penalties on a 'deemed' basis, with opportunity for oil and gas operators to claim potential rebates on penalties, if they can demonstrate on a case-by-case basis that their gas meter readings provide improved records of gas flare rates that are reliable, accurate, accessible, and that are certified by independent third parties.

Regulation and fiscal measures can also provide incentives for companies to repurpose the gas for local community use. Repurposing flare gas can be further facilitated when these measures are combined with information from independent satellite data. VNF datasets can identify those flares that are the most likely candidates to be converted into **gas development opportunities and that have the largest potential impact in terms of SCAR reduction**. Flare size and distance to market are the key two criteria for commercial gas monetization. Opportunities for large-scale gas aggregation and development are particularly promising in countries with the largest number of large flares. Nigeria is foremost example and should be encouraged to develop its ideas in this area. By combining analysis of small-scale gas monetization options with the indicative unit costs of each technology, and satellite measurement data, it is possible to prioritize the options to aggregate, process and then utilise natural gas for local community use (see Table 1. below). For Nigeria, multiple gas monetisation options are likely applicable. But to highlight the scale of the opportunity: If the

[46] IMF, "Fiscal Policies for Paris Climate Strategies - From Principle to Practice", Policy Paper 19/010, Washington DC, 1 May 2019; https://www.imf.org/en/Publications/Policy-Papers/Issues/2019/05/01/Fiscal-Policies-for-Paris-Climate-Strategies-from-Principle-to-Practice-46826.

[47] Romsom and McPhail, "Looking ahead to COP27: from climate pledges to action -- Global Methane Pledge – opportunities and risks", UNU-WIDER Working Paper (in preparation)

amount of 234 MMscf/d **gas flared in the area of interest in Northern Niger Delta is repurposed to Compressed Natural Gas (CNG), it could fuel 192,650 CNG commercial vehicles.**[48] Lessons learned in local gas monetisation can be shared among other countries.

Table 1. Monetization options (prioritized by location and scale) to utilize gas for local economic development

Gas options	In-field applications	Pipeline	Gas-to-Wire	CNG	Mini-LNG	Mini-GTL	Petro-chemicals	LNG export
Russia 2080 MMscf/d		Connect supply to pipelines			Road transport		Large scale flare gas aggregation	Yamal expansion
Iran 1838 MMscf/d			Replace fuel oil for power gen	52 MMscfd (37 flares are 1-2MMscfd) 4.1 mln CNG vehicles				1740 MMscf/d (10 mtpa)
Iraq 1739 MMscf/d			Replace fuel oil for power gen					1710 MMscf/d (10 mtpa)
USA 956 MMscf/d	Fuel for high activity shale production	Connect supply to (new) pipelines	Further phase out coal		Transport by road, river, lake and train			Increase APG supply to existing LNG
Nigeria 749 MMscf/d	Electrification of oil and gas fields		Electrical energy access	Expand CNG vehicles, now only 3,800				Increase APG supply to existing LNG
Indonesia 240 MMscf/d		Facilitate open access to pipelines at reason-able tariffs	Electrical energy access	island energy access with maritime transport of CNG			Production of fertiliser through methanol	
India 200 MMscf/d	Offshore electrification 70.5 (81.4) MMscf/d flared on 10 (21) platforms (80 km radius)		Electrification agriculture areas in Rajasthan and Mehsana with 2.7 and 3.0 MMscf/d flares	32 MMscf/d (21 flares are 1-2MMscfd) 1.8 mln CNG vehicles				

***Source**: reproduced from Romsom and McPhail (2021b), see Footnote 2.*

In the previous sections of this paper, the regional perspectives on natural gas flaring were provided. These illustrate the importance of considering the impact of all the connecting infrastructure, regional gas utilisation (and lack thereof), and regional social impact on communities. The following sections of the paper evaluate the gas flare performances and local context of the four global super-emitter flares in the east Warri area individually. These are the Kwale flow station, Kwale gas plant, the Ob-Ob gas plant and the Ebendo flow station. It is clear from these evaluations how closely is the detailed flare performance analysis (as shown by satellite data) inter-related with oil production operational performance. The satellite data can identify events that are indicative of much increased emissions, such as methane. Policy needs to be increasingly cognisant of these inter-relationships.

[48] A. Igbojionu, C. Anyadiegwua , E. Anyanwub , B. Obah, C. Muonagor," Technical and economic evaluation of the use of CNG as potential public transport fuel in Nigeria", Elsevier Scientific African 6 (2019) e00212; https://www.sciencedirect.com/science/article/pii/S2468227619307732 .

8. Kwale flow station super-emitter flare performance trends

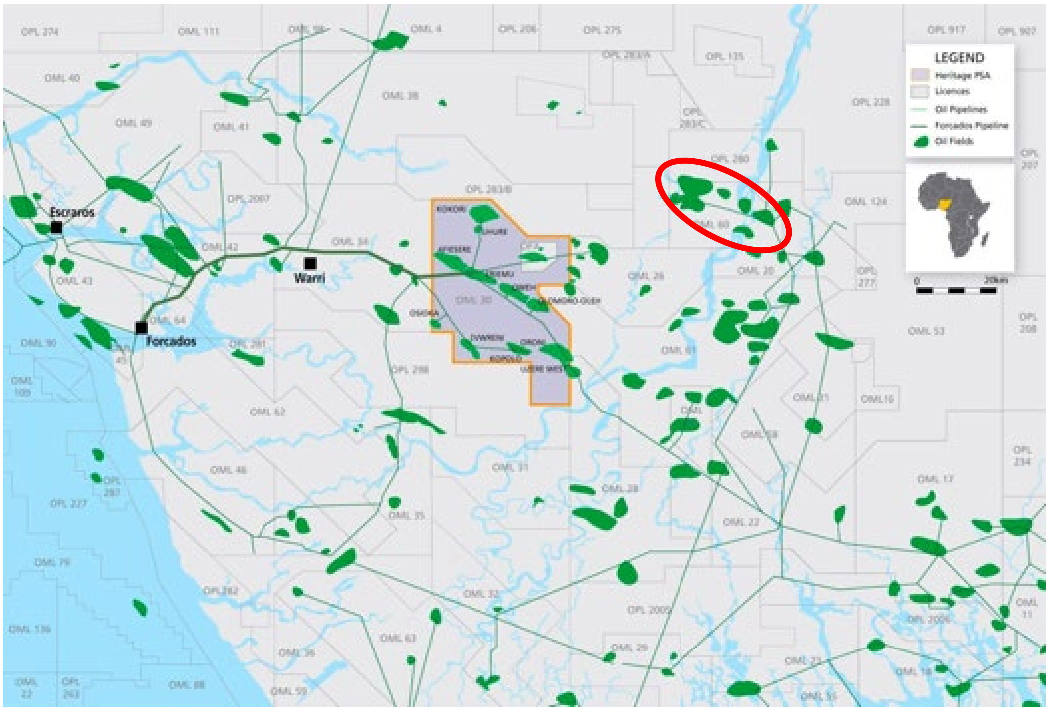
The Kwale flow station flare showed a significant drop in flare rate from 2017 to 2020. It was this flare that triggered the wider analysis on flaring performance and trends in the East Warri region. The Kwale oil pumping station (Sterling Beneku flow station) handles oil production from the OML 60 licence area (see Figure 18) with seven producing fields operated by NAOC, a subsidiary company of ENI. OML 60 licence ownership is split between Nigeria National Petroleum Company (NNPC) at 60% interest, ENI (20%) and Oando Energy Resources (20%).

Producing fields in OML 60 contain both light and medium sweet crude oil (typically 25° to 45° API), condensates and natural gas. Production and export facilities within OML 60 owned by the NAOC joint venture (JV) include: [49]

- 94 production and injection wells, of which 24 are currently on production;
- flow station located at Kwale-Okpai (with gross handling capacity 50-60 Kbpd);
- Kwale gas plant;
- Kwale-Okpai IPP gas fired power plant;
- export pipelines, including a 10/14 inch line linking the Irri, Kwale and Akri fields with the Ebocha oil centre in OML 61, and a 24 inch gas line connecting the Kwale flow station and Kwale gas plant to the Obiafu-Obrikom gas plant in OML 61.

Two super-emitter flares are located in the OML 60 licence area. At the time this study was conducted, there was no access to OML 60 production data. Consequently, there was no opportunity to review flare performance against oil rate.

Figure 18*: Location of the two super-emitter flares in the OML 60 licence area (red oval)*

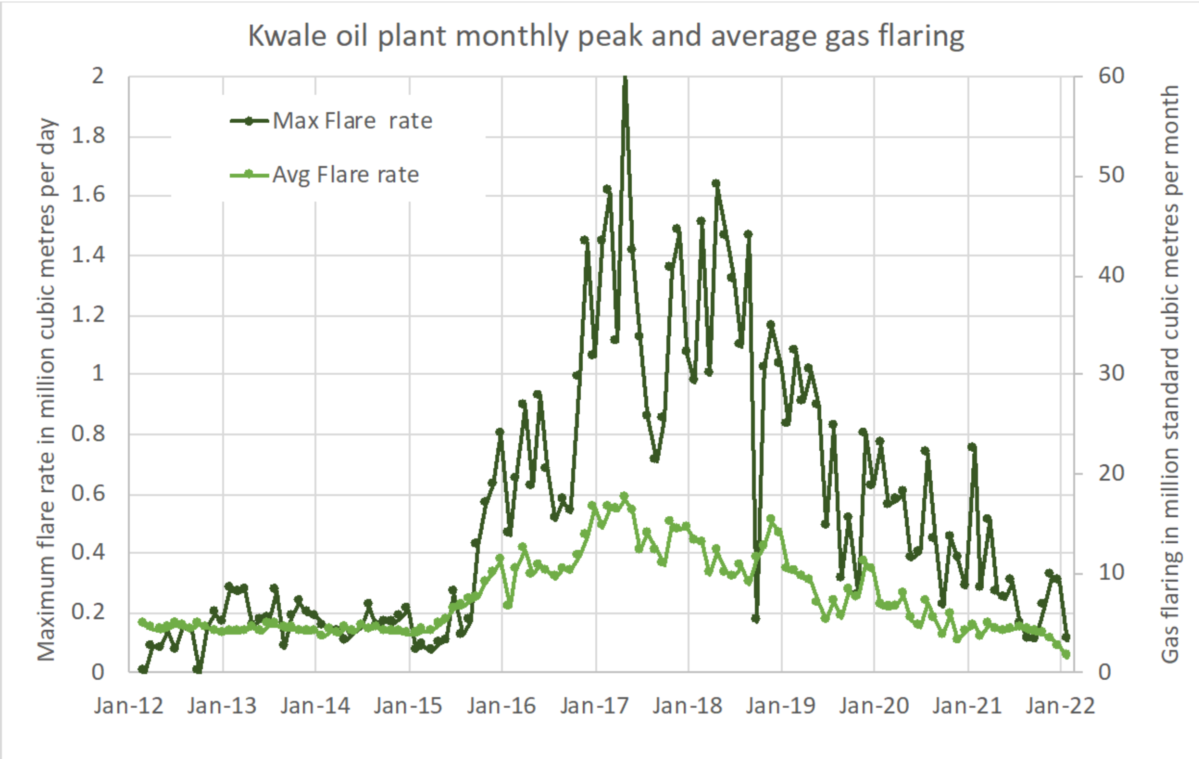


Source*: Heritage Oil Ltd, http://www.heritageoilltd.com/media/27714/heritage_activity_update_june_2013.pdf.*

[49] Oando Energy Resources acquired OML 20 in 2014; https://www.oandoenergyresources.com/projects/oml-60

The Kwale oil pumping station facility showed a marked increase in gas flaring from mid 2015 onwards. The highest flare rates in 2017 coincided with the original date for Okpai IPP expansion, for which additional gas production capacity had been made available (Figures 19, 20, 21).

***Figure 19**: Monthly average and maximum daily peak flare rates for Kwale flow station*



***Source:** authors' illustration based on VNF data from Payne institute, Colorado School of Mines https://payneinstitute.mines.edu/eog/viirs-nightfire-vnf/.*

***Note:** The scales of the peak (left) and average (right) rates on the vertical axes are selected such that peak and average flare rate curves would coincide in case of constant flaring. Increased separation between the curves is indicative for the occurrence of incidental flare events impacting overall flare performance.*

***Figure 20**: Kwale flow station flare rate variability*

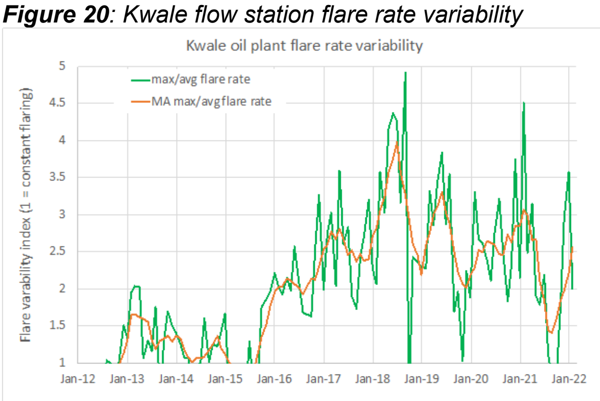
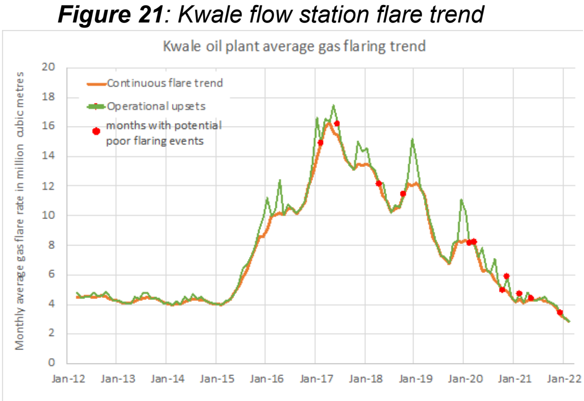


***Figure 21**: Kwale flow station flare trend*



***Source:** authors' illustration based on VNF data from Payne institute, Colorado School of Mines https://payneinstitute.mines.edu/eog/viirs-nightfire-vnf/.*

***Note:** In the period 2012 to mid 2015, flaring at Kwale flow station was at a moderate and constant rate, but this then worsened in the period thereafter, until early 2021 when flare performance was similar to the earlier period.*

Figure 19 illustrates how not only the average gas flare increased from mid 2015 onwards (light green line), but also that monthly peak flare rates increased significantly, much above the historic ratio of 1/25.[50] This flare rate variability is shown in detail in Figure 20. Even though the Kwale flow station average flare rates decreased from mid 2020 onwards to rates similar to those observed before mid 2015, flare variability remained elevated at much higher levels. The cause of this increased flare-rate variation is not clear, but worth investigating to establish if these are indicative of either gas rate variations or process instabilities. Figure 21 shows the overall flare trend (orange curve) with super-imposed flare rate events that significantly exceed the trend (green curve). Moreover, based on an assessment of flare temperature, the graph highlights during which months potential periods of poor flare quality operations occurred (red dots).

Figure 22a and 22b show details of the Kwale flow station and its super-emitter flare (Lat=5.716, Lon=6.486 deg.). Dwellings can be observed just outside the western perimeter of the Sterling Beneku (Kwale) flow station, indicated by the red oval. The yellow arc depicts a 500m radial distance to the flare. The nearest dwelling is located at only 330m distance.

***Figure 22a**: detail of the location of the super-emitter flare at Kwale (Sterling Beneku) flow station*

***Source:** authors' illustration based on a combination of Google Earth images with VIIRS data*

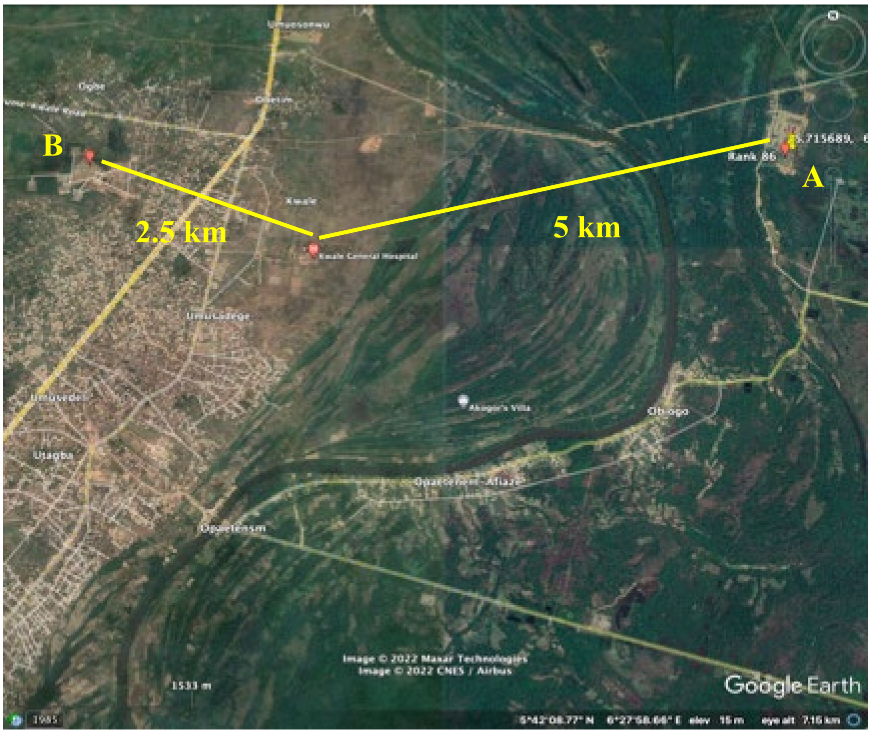
[50] **Flare rate variability** is calculated as the peak flare rate in a given month divided by the average rate in that month. A peak rate over average rate of 1/30 indicates an almost constant flare rate during the month. Before 2015, the peak over average ratio for Kwale flow station was 0.2 million m^3 / 5 million m^3 = 1/25, as can be inferred from the scales on the left and right axis, respectively of the graph in Figure 18.

Figure 22b: Detail of the Sterling Beneku (Kwale) flow station, showing dwellings located near the boundary fence area (enlargement of the red oval area in Figure 22a above)

Source: *authors' illustration based on a combination of Google Earth images with VIIRS data*

The Kwale flow station flare (A) is 5 km from Kwale village (and a local general hospital), Figure 23, while another local flare (B) is located at the edge of the village. Flare B combusted 4.5 and 4.4 MMscf/d in 2017 and 2020, respectively.

***Figure 23**: Local area where the Kwale flow station flare is situated*



Source: *authors' illustration based on a combination of Google Earth images with VIIRS data*

Flare B in Figure 23 is located at Kwale and Ogbe village (Lat=5.716, Lon=6.421 deg.). There are some dwellings that are at less than 200m distance from the flare. Figure 24 image is from December 2019, while earlier images show that these dwellings predate 2015.

It seems evident from this close proximity between dwellings and the flares that the possible social damage referred to in Section 7, but also the possibilities for local benefits could be substantial in this locality.

***Figure 24**: Local area of where flare B is situated*

***Source:** authors' illustration based on a combination of Google Earth images with VIIRS data*

***Note:** the yellow arc that extends from the flare location has a radius of 500m.*

Focusing further into the area near flare (B) shows that agriculture fields extend to the boundary of the 'Midwestern Oil and Gas facility" (Figure 25).

__Figure 25__: Example of gas flaring site encroaching on adjacent local community and agricultural fields

Source: authors' illustration based on a combination of Google Earth images with VIIRS data

9. Kwale gas plant super-emitter flare performance trends

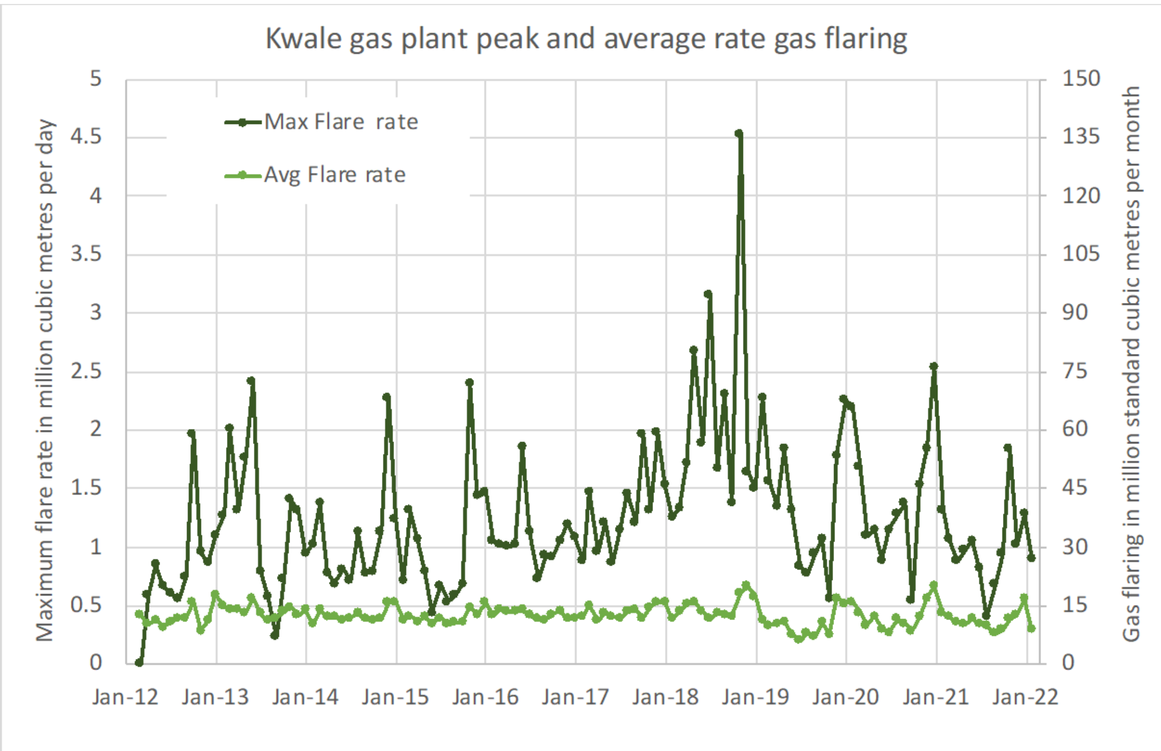
The Kwale (oil and) gas processing plant, commissioned in 1975, recovers associated gas that otherwise would be flared (see Figure 26). However, it is itself also a global super-emitter flare, when not all the gas it processes can be utilised. Just as at the Kwale flow station, the Kwale gas plant receives production from oil and gas fields within the OML 60 license area. After an upgrade in 1987, the plant also provides dry gas for reinjection into OML 60 fields for future use. It is the source of gas for the nearby Okpai gas-fired power plant that is supplied through a dedicated 14 km gas line from the Kwale gas plant. In view of the persistent high flare rates from this area, it is questionable if the gas reinjection scheme was maintained after the Okpai IPP was commissioned. A fraction of the Kwale gas plant is also used for onsite power needs and there is a further gas line connecting the Kwale plant to the Obiafu-Obrikom (Ob-Ob) gas processing plant 34 km to the south east. The Ob-Ob plant connects to other Nigerian gas infrastructure, including the Bonny Island LNG plant that thus is able to receive associated gas from the Delta State region for the production of LNG. There are multiple options to treat and utilise the produced associated gas at or connected to this processing plant (reinjection, IPP power plant, export to Ob-Ob plant and beyond, local OML 60 use). This raises questions as to why existing evacuation infrastructure has not prevented the occurrence of two global super-emitter flares in addition to a number of other small-to-large size flares in this licence area.

***Figure 26**: Kwale gas plant with gas flares*

***Source:** authors' illustration based on a combination of Google Earth images with VIIRS data*

From 2012 to 2019, the Kwale gas plant shows an average flare rate of 13 million m^3 per month. From 2019 until January 2022 this dropped to 11.5 million m^3 per month (Figure 27). This is the period when the Kwale-Okpai IPP expansion capacity became available with expected increase in gas utilisation demand. In this latter period there was a considerable increase in rate variability as shown in Figures 28 and 29. The months December 2018, December 2019, January 2021 and January 2022 show remarkable seasonal increases in flare rates, among the highest seen at any time since 2012. Also noticeable is the increased flaring, coinciding with Kwale flow station, from late 2015 until mid 2016. This increase was most likely due to the vandalizing of the Okpai/Onitsha 350 KVA Power line by cable vandals on 10 November 2015. Two of the four legs of a power transmission tower were cut by vandals, causing the tower to hang precariously.[51] Earlier, in November 2013 another attack occurred on the gas pipeline that supplies the Okpai power plant.[52] Such attacks occur with regularity[53] and repairs are often delayed until the end of the dry season (in the month of May) when vehicle access is possible. In this case, main repair works were delayed until July 2016 (eight months after the incident)[54], when monthly flare rates started to reduce again (Figure 29).

***Figure 27**: Monthly average and maximum daily peak flare rates of Kwale gas plant*



***Source:** authors' illustration based on VNF data from Payne institute, Colorado School of Mines https://payneinstitute.mines.edu/eog/viirs-nightfire-vnf/.*

***Note:** The scales of the peak (left) and average (right) rates on the vertical axes are selected such that peak and average flare rate curves would coincide in case of constant flaring. Increased separation between the curves is indicative for the occurrence of incidental flare events impacting overall flare performance.*

[51] Vanguard, 17 November 2015; https://www.vanguardngr.com/2015/11/power-supply-drops-by-480mw-as-vandals-attack-okpai-onitsha-tower/

[52] PM News, 24 Nov 2013; https://pmnewsnigeria.com/2013/11/24/tcn-blames-power-rationing-on-vandals/

[53] NNPC, "Meeting of GACN 2020 South East Gas Utilization forum", October 2020; https://gacn.com/wp-content/uploads/2020/09/Improving-Steady-Supply-of-Power-in-the-South-East-COO-Gas-Power-NNPC.pdf.

[54] Bizwatch Nigeria, 2016; https://bizwatchnigeria.ng/power-planned-transmission-repairs-cut-supply-300mw/

***Figure 28**: Kwale gas plant flare rate variability*

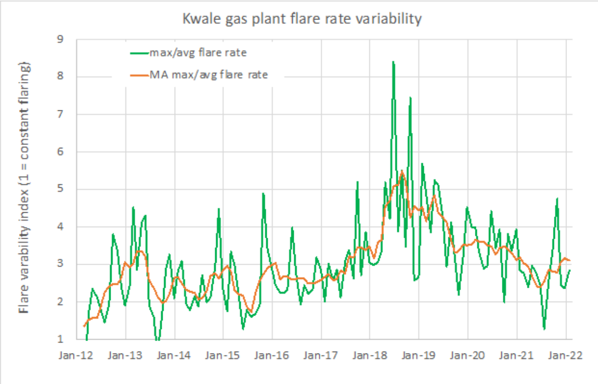
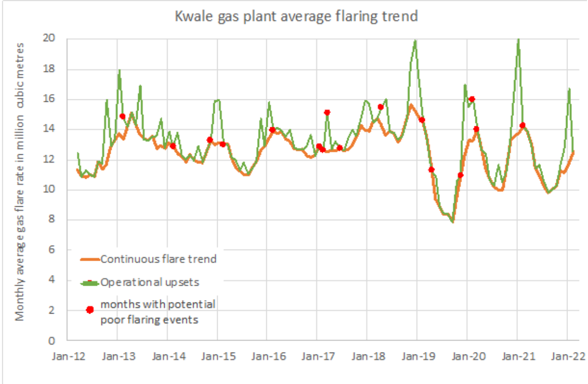


***Figure 29**: Kwale gas plant flare trend*



***Source:** authors' illustration based on VNF data from Payne institute, Colorado School of Mines https://payneinstitute.mines.edu/eog/viirs-nightfire-vnf/.*

***Note:** From 2017 onwards, flare variability (a measure of short-term gas processing instability, Figure 28) of the Kwale gas plant doubled from an average factor 2.5 to 5, declining somewhat from mid 2019 onwards. However, from late 2018 the longer-term trend of Figure 29 shows larger swings between higher-rate and lower-rate periods. This is indicative to longer-term fluctuation in gas supply and/or gas processing infrastructure availability.*

As with Kwale flow station, also Kwale gas plant has community dwellings in close proximity to the super-emitter flare as shown in Figure 30.

***Figure 30**: The Kwale gas plant shows dwellings located near the boundary fence area.*

***Source:** authors' illustration based on a combination of Google Earth images with VIIRS data*

***Note**: The yellow circle depicts a 500 m radius from the main Kwale gas plant flare, with nearest dwellings (red oval) within 350m distance.*

10. Obiafu - Obrikom gas plant super-emitter flare performance trends

The Obiafu-Obrikom (Ob-Ob) plant is located 34 km south east of the Kwale gas plant and 80 km north-west of Port Harcourt Nigeria (Figures 31, 32). The plant aggregates associated and non-associated gas from the wider Niger Delta region east of Warri. Its shareholding is the same as for the two earlier super-emitter flaring sites, with Agip/ENI (20%) operator, and NNPC (60%) and Oando Energy Resources (20%) as JV partners. In 2006, the Ob-Ob plant completed an upgrade project to supply an increased volume of 400 MMscf/d of sales export gas to the NLNG plant on Bonny Island and to reduce flaring. Since then, Ob-Ob's capacity to supply NLNG has been further increased to 1,070 MMscf/d. The Ob-Ob plant also provides gas for domestic use. The 48" Obiafu-Obrikom-Oben (OB3) Gas Pipeline gas pipeline is an important extension of the domestic role of the Ob-Ob plant. However, since it was reported as 80% complete in 2016, further progress has been very slow and it has yet to be completed and commissioned.[55] Once in use, this pipeline can transport 2 Bcf/d of gas, but capacity will also be assigned to non-associated gas projects such as the Asa North-Ohaji South (ANOH) green field gas condensate development project, that will produce 600 MMscf/d. Therefore, **the key question is to what degree additional infrastructure capacity will assist in a further reduction in flaring when multiple gas utilisation options already exist**. Such flaring has proven persistent to date. The flaring performance of the Ob-Ob plant is presented in Figures 33, 34 and 35. Figure 2 highlights the number of VNF flare measurements for the Ob-Ob flares. In the period 2012-2021, VNF satellites registered 5900 records, of which 3896 were positive flare rates measured, 245 zero rates and 1759 were missing observations (due to cloud cover).

From October 2019 onwards, a marked increase in Ob-Ob flaring was measured, with a particular spike in gas flaring in November 2019, when in a single day the average amount of gas for a month was flared. This high-flaring period lasted for about half-a-year, and is likely related to the start of gas and condensate production at the Obiafu-41 discovery.[56] The gas of this discovery is processed at the Ob-Ob plant but is designated for the Kwale Okpai power plant, in support of its capacity expansion. However, gas utilisation of Okpai IPP has been much below expectation, see Section 5.2. **As condensate production is highly valuable, gas producers are generally reluctant to reduce production when gas demand is lacking. Hence they flare to keep condensate production going.** Although Ob-Ob plant has large capacity to direct gas to the NLNG plant, **flaring at Ob-Ob and other regional flares indicate that this infrastructure opportunity is insufficiently utilised, most likely due to commercial obstacles** (See section 5.1). The need to adapt Ob-Ob gas processing to the changed conditions of Obiafu-41 production could be the reason why this period also coincides with potential poor flare quality, indicated by low flare temperatures observed by VNF.

[55] Global Energy Monitor, GEM Wiki; https://www.gem.wiki/Obiafu-Obrikom-Oben_Gas_Pipeline .
[56] E. Gupte and S. Elliott, "Eni starts producing gas, condensate at Nigerian Obiafu-41 discovery", S&P Global Commodity Insights, 23 October 2019; https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/natural-gas/102319-eni-starts-producing-gas-condensate-at-nigerian-obiafu-41-discovery

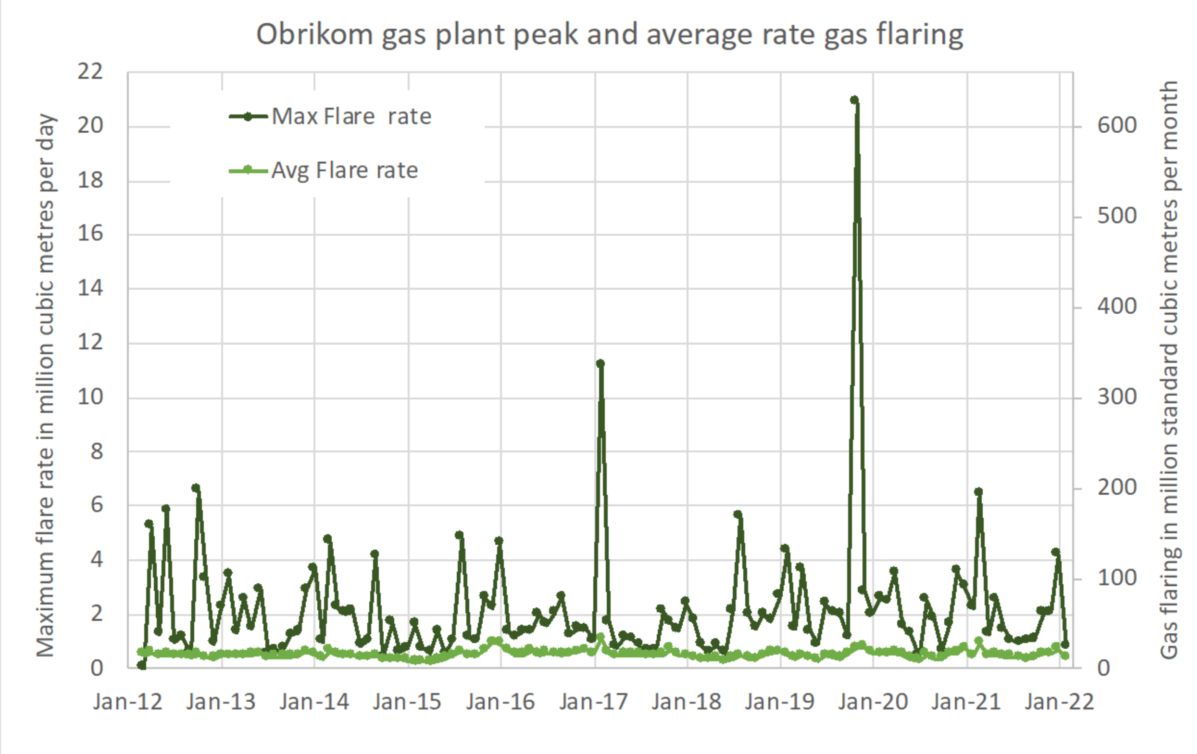
***Figure 31**: The Ob-Ob gas plant is located adjacent to the Orashi river and the Obrikom town*

***Source:** authors' illustration based on a combination of Google Earth images with VIIRS data*

***Figure 32**: The Ob-Ob flaring site located in the southern area of the gas plant*

***Source:** authors' illustration based on a combination of Google Earth images with VIIRS data*

***Figure 33**: Monthly average and maximum daily peak flare rates of Obiafu-Obrikom (Ob-Ob) gas processing plant*



***Source:** authors' illustration based on VNF data from Payne institute, Colorado School of Mines https://payneinstitute.mines.edu/eog/viirs-nightfire-vnf/.*

***Note:** The scales of the peak (left) and average (right) rates on the vertical axes are selected such that peak and average flare rate curves would coincide in case of constant flaring. Increased separation between the curves is indicative for the occurrence of incidental flare events impacting overall flare performance.*

***Figure 34**: Obrikom gas plant flare rate variability*

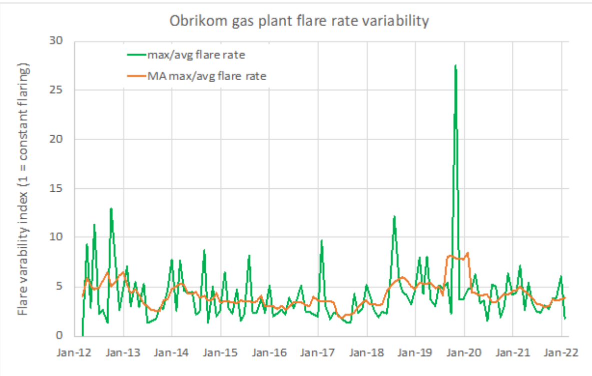
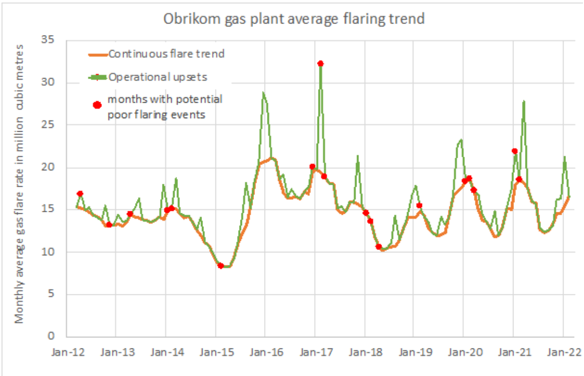


***Figure 35**: Obrikom gas plant flare trend*



***Source:** authors' illustration based on VNF data from Payne institute, Colorado School of Mines https://payneinstitute.mines.edu/eog/viirs-nightfire-vnf/.*

***Note:** In November 2019, Ob-Ob plant had a major short-term flaring event, when in a single day the average amount of gas for a month was flared (Figure 32, 33). The seasonal fluctuation with end-of-year peak flaring is apparent from 2016 until to date (Figure 34) and is synchronous with seasonal flaring trend in the Kwale flow station and Kwale gas plant from end 2018 onwards.*

Dwellings and agricultural fields can be seen on the perimeter of the Ob-Ob plant, with nearest community in close distance to the flares at the eastern boundary (Figures 36, 37).

***Figure 36**: The Obrikom village is situated just outside the 1000m radius of the main flare of the Ob-Ob gas plant*

***Source:** authors' illustration based on a combination of Google Earth images with VIIRS data*

***Note:** apart from dwellings (details below), also agriculture fields can be observed with a 1000 m radius (yellow circle) of the Ob-Ob plant, for example on the west bank of the Orashi river (see also Figure 30).*

***Figure 37**: Dwellings are observed within a 1000m radius of the main flare of the Ob-Ob gas plant, to the north and north east (left image) and to the east (right image)*

***Source:** authors' illustration based on a combination of Google Earth images with VIIRS data*

***Note:** The nearest dwellings are 340 m from the nearest Ob-Ob plant flares (right image).*

11. Ebendo flow station super-emitter flare performance trends

Contrary to the other three Niger Delta super-emitters described earlier, the Ebendo flow station (Figures 43 and 44) is not operated by Agip/ENI, but by Energia Limited as part of the OML 56 licence area. Interest shares for the field and facilities are: Energia Limited 55% and Oando Energy Resources 45% (see Appendix A). The Ebendo flow station (capacity 10,000 barrels of oil per day, bopd) processes production from the Obodeti/Ebendo marginal oil field and is connected by a 6-inch diameter, 8.5 km pipeline to the oil gathering facility at Umasadege (Flare 'B' in Figures 23-25). From there, oil is further transported to the Kwale flow station and onwards via NNPC's Forcados pipeline to Brass Oil Terminal on the coast (see Figures 8, 38). OML 56 contains light sweet crude oil (typically 50° to 52° API), condensate and natural gas. In 2014, Energia drilled four development wells in addition to the earlier recompleted Ebendo-1 discovery well. This increased production to 1,800 bopd in 2014 and peak oil production was obtained at 4,500 bopd in 2015 (4,344 bopd in 2018).[57] The Nedo modular associated gas plant (25 MMscf/d capacity), majority owned by Xenergi, was commissioned in 2011 and is located adjacent to the Ebendo flow station. It produces natural gas liquids (NGL), propane and liquefied petroleum gas (LPG), from the associated gas. Energia reports plans to upgrade the capacity of the plant, construct a pipeline to transport the lean gas to a nearby gas line, construct compressed natural gas (CNG) plant and an Independent Power plant to be trunked into the national grid.[58]

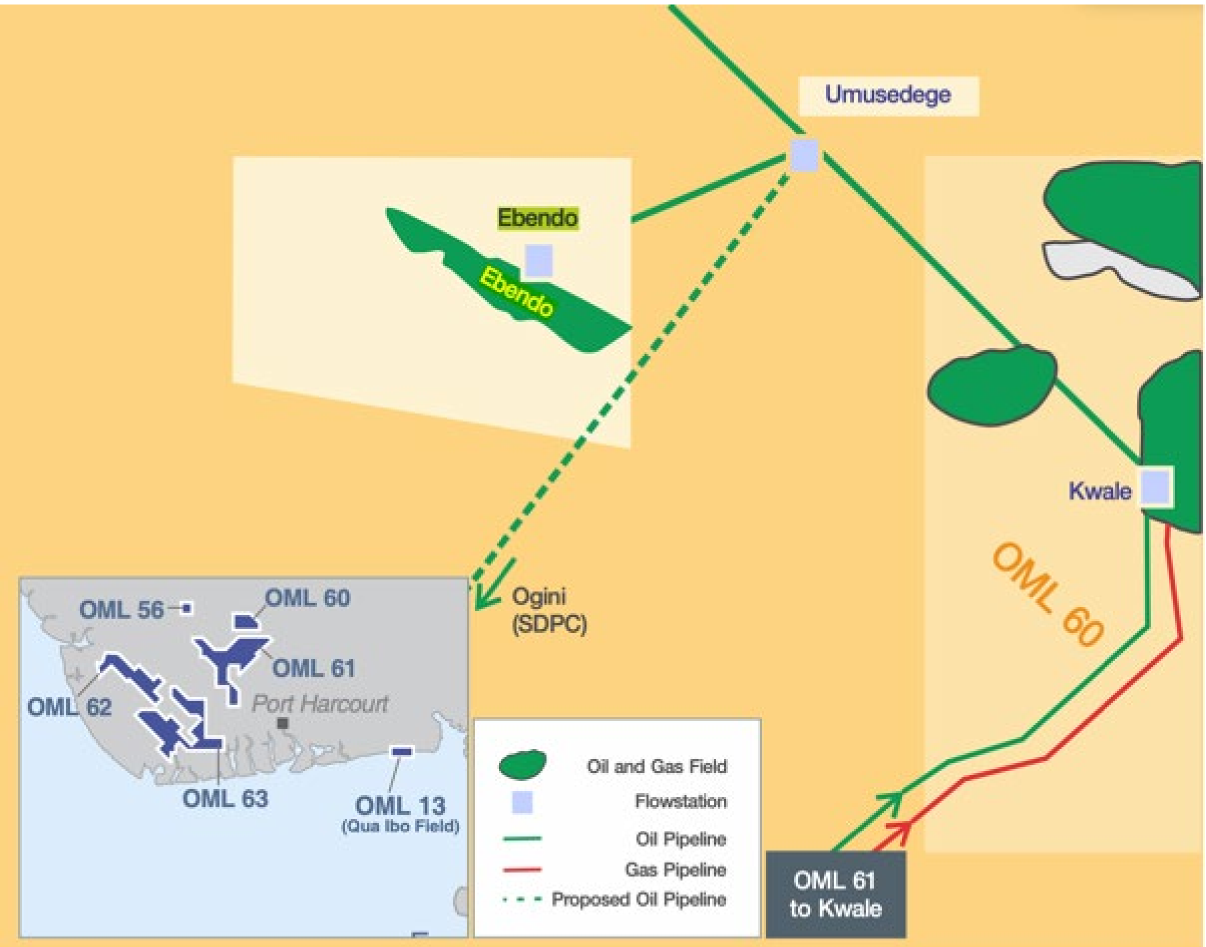
The increased production from the Obodeti/Ebendo field late 2014 onwards is noticeable in Ebendo's flaring performance, see Figures 40 to 42. The gas-oil ratio inferred from the gas volumes flared and reports of oil produced, is very large at 3,500-3,900 scf/bbl, compared to 1,000 scf/bbl expected. **This is indicative of non-associated gas also being produced and stripped to recover the natural gas liquids, while the gas is flared as waste**.

It is worth noting that with oil prices around USD 100 per barrel, international LNG prices at USD 10 per Mscf (see Footnote 21), and with a gas-oil-ratio of 3,500 – 3,900 scf / bbl, it follows that **for every barrel produced worth USD 100, a gas volume is wasted that has a potential sales value of USD 35 to USD 39**, if this gas would be monetised at international gas prices. In this case, Ebendo facility is not connected to gas export infrastructure. However, this calculation highlights the importance to preserve natural gas through reinjection (e.g. at nearby OML 60 facilities), or through connection to pipelines feeding gas processing plants.

Ebendo marginal oil facility ranked 124th on the list of 2020 global super-emitters. To highlight the scale of its flaring, we compared it with the facility that ranked 123rd, i.e. Abu Dhabi Oil company LNG (ADNOC LNG) in the Arabian Gulf. **Both assets flared 17.4 MMscf/d in 2020. However, Ebendo flow station capacity is only 10,000 bopd with peak oil production in 2015 at 4,500 bopd, while ADNOC LNG is much more complex, has an area that is 25 times larger, and had a throughput of 5.6 mpta LNG in 2016** (see Figure 39).

[57] Offshore Technology, "Obodeti/Ebendo Conventional Oil Field, Nigeria", 27 April 2022, https://www.offshore-technology.com/marketdata/obodeti-ebendo-conventional-oil-field-nigeria/ .
[58] Energia Limited, "Gas Production", https://energiang.com/gas-production/ .

Figure 38: Ebendo field and oil evacuation infrastructure



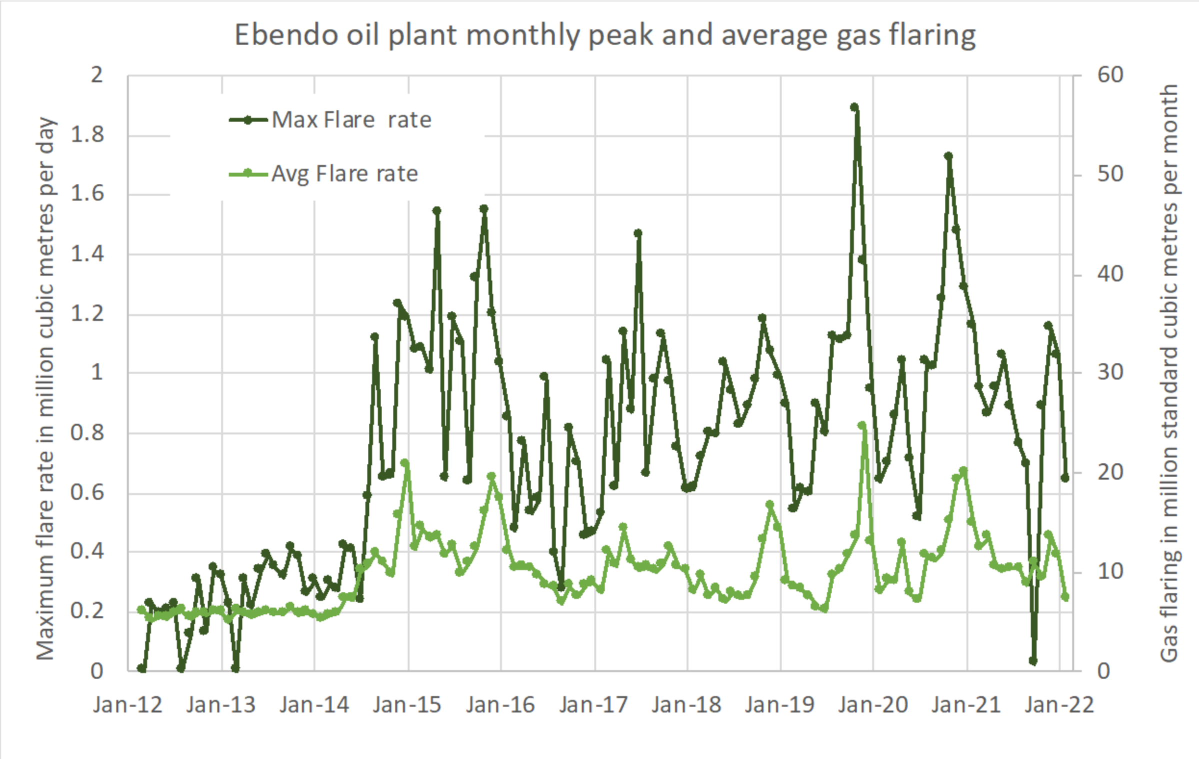
Source: *Oando Energy Resources, corporate profile 2019, https://www.oandoplc.com/wp-content/uploads/2022/02/Oando-Corporate-Profile-2019.pdf*

Figure 39*: Ebendo field and oil evacuation infrastructure (left) and ADNOC LNG facility (right)*

Source: *authors' illustration based on Google Earth images*

Note: *Flare locations are highlighted by the red marks; the relative scale of both facilities is indicated by the projection of Ebendo flow station (located top right) in the image of the ADNOC LNG site (right).*

***Figure 40**: Monthly average and maximum daily peak flare rates of Ebendo flow station*



***Source:** authors' illustration based on VNF data from Payne institute, Colorado School of Mines https://payneinstitute.mines.edu/eog/viirs-nightfire-vnf/.*

***Note:** The scales of the peak (left) and average (right) rates on the vertical axes are selected such that peak and average flare rate curves would coincide in case of constant flaring. Increased separation between the curves is indicative for the occurrence of incidental flare events impacting overall flare performance.*

***Figure 41**: Ebendo flow station flare rate variability*

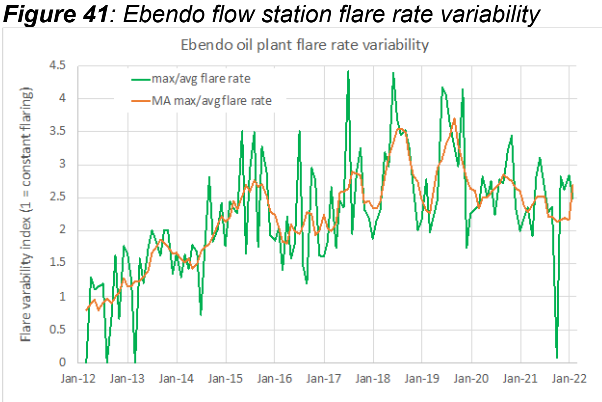
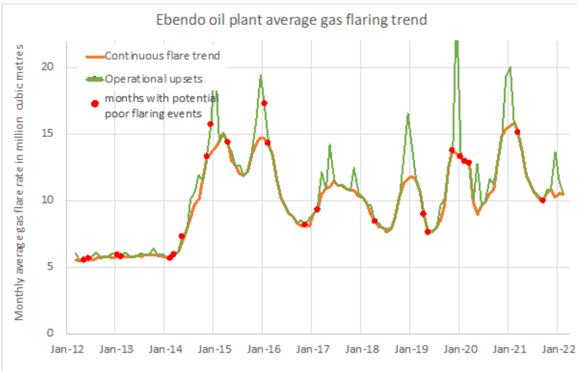


***Figure 42**: Ebendo flow station flare trend*



***Source:** authors' illustration based on VNF data from Payne institute, Colorado School of Mines https://payneinstitute.mines.edu/eog/viirs-nightfire-vnf/.*

***Note:** The increased oil production from the four development wells drilled in 2014 is noticeable in the increase flaring of associated gas. Monthly gas flare rates of 15 MMm^3 per month are high in view of the marginal oil production of 4,300 to 4,500 bopd (implying a gas-oil ratio of 3,873 scf/bbl or the commingled flaring of non-associated gas).*

Figure 43: The Ebendo plant located near Obodougva village

***Source:** authors' illustration based on a combination of Google Earth images with VIIRS data*

***Note**: The yellow circle represents a 1000m radius around the Ebendo flare. Agriculture fields can be seen as close as 150m distance from the flare. Emu-Ebendo town is located just south of the plant.*

Figure 44: Detail of the Ebendo plant

***Source:** authors' illustration based on a combination of Google Earth images with VIIRS data*

12. Conclusions and Key Lessons

This paper has carried out an in-depth assessment of the flaring from oil and gas facilities in Nigeria. It has shown both the main trends in these emissions over time with Nigeria as one of the most successful countries to reduce flaring with a reduction from 21.4 billion cubic meters in 2005 to 7.2 billion cubic meters in 2020. Notwithstanding this earlier success, over the combined period 2017-2020, Nigeria contributed significantly to overall global flaring, particularly regarding its 19 "super-emitters". In the Niger Delta area, east of Warri, flaring from 2017 to 2020 increased by 24%, from 51 flares wasting 188 MMscf/d gas, to 62 flares wasting 234 MMscf/d gas. This volume of 234 MMscf/d is enough to power more than 192,650 CNG commercial vehicles. The value of these 62 gas flares in 2020 is estimated at USD 730 million per year, based on Q4 2021 LNG prices.

The patterns of performance of these most substantial emitters have been studied in greater detail and this has shown the large potential of further natural gas savings if these flare volumes were to be reduced significantly. In 2020, the 4 super-emitters identified flared more than 65 MMscf/d (28% of the east of Warri volume flared), sufficient gas to fuel 53,500 commercial CNG vehicles. These 4 super-emitters wasted more than USD 200 million per year against Q4 2021 LNG prices.

Finally, the paper has sought to document the significant benefits to local communities in the vicinity of the main flares that could be achieved if these flares were to be reduced in volume and if flare quality were to be improved.

The key lessons from this assessment are summarised below in three stages: first we present nine findings and observations of four Nigerian super emitters in the Niger Delta region, using satellite data to monitor flare performance, and evaluate the potential impact on local communities. We then spell out the several advantages of using satellite data and imagery to detect and analyse individual flares, and finish with a set of ten general observations that have emerged from the analysis, and which also may be relevant for other gas producing countries.

12.1. Detailed findings from analysing four Niger Delta super-emitter flares

1. The Kwale flow station flare showed a significant drop in flare rate from 2017 to 2020 and declined significantly in the global ranking of super-emitter flares, from 86th in 2017 to 309th in 2020. In the same period, the other super-emitter in the same OML 60 license area, Kwale gas plant, increased its flare rate and moved up in the global flare ranking from 161st to 108th. Given this variation in flare rates, this assessment includes not only reviews of the 4 super emitter flares, but also addresses whether flaring in the wider area improved and how local communities are affected.

2. The Ebendo flow station in 2020 ranks as the world's 124th largest super-emitter flare. It shares the same flare rate as the Abu Dhabi Oil company LNG (ADNOC LNG) in the Arabian Gulf. Yet the Ebendo flow station capacity is only 10,000 bopd, with peak oil

production in 2015 at 4,500 bopd. This compares with ADNOC LNG, a facility that is much more complex, has an area that is 25 times larger, and has a throughput of 5.6 mpta LNG in 2016.

3. Both the Kwale gas plant and the Kwale flow station global super-emitter flares are similar to the Ebendo flow station and result from marginal oil production. The exception is the fourth super-emitter: the large Obiafu-Obrikom gas plant. The value of the gas wasted is excessively large (and truly world scale) compared to the marginal value of oil produced from these minor oil production license areas.

4. The Kwale gas plant raises questions as it why it is itself also a global super-emitter flare, when not all the gas it processes can be utilized. There are multiple options to treat and utilize the produced associated gas, including: gas reinjection, use at Kwale-Okpai Independent Power Plant (IPP), export to Obiafu-Obrikom gas plant and beyond, and local OML 60 use. Prioritisation of associated gas utilisation is key in reducing gas flaring since it is an unavoidable by-product in the production of oil.

5. Continuity in flare rates and limited flare variability of the 4 super-emitters suggest that flaring is mostly routine and structural with some impact from incidental upsets in asset operations.

6. For the two super-emitter Kwale and Obiafu-Obrikom gas plants, the flare variability and impact from incidental process trips are higher than the flow station super-emitters, at a factor 3.6 and 6.5% share, respectively. High variability in flare rates can signal methane emissions. This indicates that gas plants have a more variable operating performance, due to the presence of more complex process (i.e. rotating) equipment. The two super-emitter Kwale and Ebendo flow stations have flaring variability of a factor 2 on average and 5% of the volume flared due to incidental process trips. Moreover, based on an assessment of flare temperatures, the analysis highlights months with poor flare quality operations - and the likelihood of methane emissions at each of the four super-emitters, with poor flare quality frequency increasing at Kwale flow station. Each of the four super-emitters show excessive routine flaring as part of normal oil and gas operations.

7. Satellite images show there are dwellings and villages that are located very close to each of the four super-emitters and other high-rate flares.

8. Agricultural lands adjacent to high-rate flares are likely contaminated with volatile-organic compounds (VOCs) and other by-products from flaring, particularly when flare quality is poor.

9. The Kwale-Okpai IPP failed to deliver on its project expectations for delivering power to the local region and to reduce gas flaring significantly. Its Clean Development Mechanism assumptions are questionable and its objectives were not delivered on.

12.2. Satellite data to evaluate operational performance - its advantages as diagnostic tool

Satellite observations are proven useful as a complementary tool to diagnose oil and gas operations. However, satellite technology can be used more fully, and VNF datasets can further add value as a diagnostic tool:

1. Publicly available since 2012, VNF gives access to very large number of measurements, i.e. twice daily (cloud cover permitting) to estimate physical properties and continuity of flares.
2. VNF pinpoints the exact flare locations of individual assets that can be identified.
3. Together with other spatial data and information, VNF can identify which individual flare emission sources are best suited to repurpose the wasted gas, e.g. local energy access projects, LNG infrastructure.
4. VNF discerns flare rates over 4 orders of magnitude.
5. VNF can detect individual flaring events, such as incidents and accidents.
6. VNF data analysis can distinguish routine flaring from system upsets. This is significant since flare-rate instabilities are likely to correlate with methane emissions. Policymakers need to be increasingly cognisant of these inter-relationships.
7. Upscaled VNF daily flare data to monthly rates enable performance trends to be continuously assessed throughout the asset lifecycle.
8. VNF data complemented with other sources of information can establish whether additional infrastructure capacity is actually needed, when there are already multiple gas utilisation options which are not being used (fully) to reduce flaring to date.
9. Regional and country-wide VNF data assist development of regulations and fiscal measures to reduce and avoid emissions from flaring (including methane). Applying satellite data to reduce emissions at source allows Nigeria to benefit directly from its own emission reduction efforts and obtain substantial additional revenues (estimated fines related for flaring amounted USD 270 million in 2020).

12.3. Ten observations from the study that have general applicability

1. Nigeria’s extensive regulatory and fiscal framework for gas flaring and associated petroleum gas use should be implemented. Natural gas flaring has been banned in Nigeria since 1984 (under the Associated Gas Re-Injection Decree, 1979) unless permission is granted in writing by the Minister. Companies are also required to submit plans for associated gas to be re-injected or alternative plans for gas utilization. Continuous monitoring of implementation is needed. For example, it is questionable

if Kwale gas plant's gas reinjection scheme in OML 60 was maintained after the Kwale Okpai IPP was commissioned, in view of the persistent high flare rates from this area. In addition to creating significant benefits for local communities and their health, regulation and fiscal measures support companies efforts to repurpose the gas for local community use.

2. **Opportunities for large-scale gas aggregation and development are particularly promising in countries with the largest number of large flares**. Nigeria is a foremost example and should be encouraged to develop its ideas in this area. By combining analysis of small-scale gas monetization options with the indicative unit costs of each technology and satellite measurement data, it is possible to prioritize the options to aggregate, process and then utilise natural gas for local community use.

3. **VNF datasets can identify those flares that are the most likely candidates to be converted into gas development opportunities** and that have the largest potential impact in terms of Social Cost of Atmospheric Release (SCAR) reduction. To protect communities and their health, flares sites should have an exclusion zone based on flare rates and flare quality. A 2014 US Environmental Protection Agency review, based on actual refinery data, demonstrated that the flare emission of VOCs was four times the amount previously assumed. We might anticipate a similar level of under-estimation for Nigerian and for super-emitter flares more generally.

4. When evaluating flare performance trends, it is important to include a regional analysis of all flares in addition to analysis of individual flares. The remarkable synchronicity in individual flare performance analysed shows the interconnectivity of oil and gas infrastructure with flare volumes shifting to different flares in the same area. Interconnectivity enables gas utilisation for domestic energy supply or exports, creating economic and social value. Regional flare analysis can highlight deficiencies in infrastructure access or utilisation. For example, aggregated volumes of gas flared locally in Kwale closely match the shortfall in gas demand of Kwale Okpai Independent Power Plant. The Okpai plant was specifically developed to help improve domestic energy access, given that 43 percent of the population in Nigeria has no access to grid electricity.

5. Repurposing of flare gas can contribute significantly to reducing energy security concerns, particularly when flaring assets are already connected to gas infrastructure. Interconnectivity of Niger Delta flaring assets with NLNG plant facilitates LNG exports at a time when Europe – a key Nigeria export market, is seeking replacement gas supplies. While NLNG is operating at less than 70 percent capacity, the amount flared in the northern Niger Delta during 2020, equalled 43 percent of one LNG train gas intake, equivalent to 1.5 mtpa of LNG output.

6. The persistent volume of gas flared in the Niger Delta despite the availability of gas evacuation infrastructure suggests that the associated gas (an unavoidable by-product of oil production) is insufficiently prioritised for use by gas demand centres such as NLNG. Mechanisms for sale of third party associated gas into NLNG pipelines and plant

are a high priority. A combination of uniformly applied and sufficiently high flare penalties, combined with netback gas prices for third-party gas that reward infrastructure owners appropriately for utilisation cost - yet also offer a profit sharing percentage to associated gas producers, would provide a win-win-win for associated gas producers, infrastructure owners and government.

7. The Climate and Clean Air Coalition's work in Nigeria on pollutants such as methane found that the penalties for oil and gas companies which did not meet regulations were 'not enough of an incentive to force companies to comply'. Penalties for gas flaring should apply equally for all gas that is flared. The analysis shows that the assumption that marginal oil producers flare less and therefore should attract lower penalties does not hold. Three of the four Niger Delta global super-emitters analysed are marginal oil producers. Applying penalties uniformly at realistic levels (USD 2.00 / Mscf or more) increases the commercial incentive for associated gas producers to accept reasonable terms for local gas utilisation or third-party infrastructure access.

8. The International Monetary Fund noted recently that (higher) carbon taxes or penalties can also be extended to broader emissions sources, for example, methane emissions from extractive industries. This can encourage reductions in emissions-intensive activity, operating on the "polluter pays" principle. The IMF has regular Article IV consultations with all oil and gas producing countries. The 2021 Global Methane Assessment finds that a methane tax is effective in reducing emissions from the energy sector, leading to an immediate drop in the implementation year. A key element of the methodology proposed by IMF is that (methane) penalties are based on 'deemed' emissions, with rebates for oil and gas operators that can prove that they emitted less.

9. Updated Nationally Determined Contributions (NDCs) can include commitment to reduce air pollution. In Nigeria's case, its revised NDC provides for a 60 percent reduction in fugitive methane emissions from the oil and gas sector by 2031, conditional on international support. If these NDCs can be fully achieved, in Nigeria, black carbon will reduce by 42 percent, methane by 28 percent, and hydrofluorocarbons by 2 percent by 2030.

10. Market based climate measures such as those being discussed under Article 6 of the Paris Agreement can benefit from lessons from the UNFCCC Clean Development Mechanism (CDM), which allowed rich countries to buy emission reductions from developing countries through carbon credits. In Nigeria, a CDM project was justified based on reduced flaring. However, it should have included monitoring (and verification) of regional flare rates as a mandatory performance metric, as well as strict measurement of gas rates. This would have avoided ambiguity between utilisation of flare-related associated gas versus non-flare related non-associated gas. Furthermore, the baseline scenario against which a CDM is evaluated should be in compliance with the law, consistent with oil and gas license requirements, and follow good oil field practices (which routine flaring is not).

12.4. Final reflections on the benefits of actions to reduce atmospheric emissions at source

Lastly, countries often think that to meet their targets for emissions reductions they need to commit government funds to new investments and on innovations, and to compensate those who may see a consequent loss in real incomes. However, as Nigeria shows, countries have the potential to increase fiscal revenues by applying existing satellite technologies, while making a significant contribution to reducing emissions and to improving health outcomes. It demonstrates how the dilemma between reduced emissions and development needs can be reconciled. The Gas Flare Tracker offers global relevance to capture both economic value (less wasted gas and increased fiscal revenues) and social value (significant reductions in health-damaging emissions) from the improved management of natural gas flaring and venting.

In global terms and based on average gas prices of USD 4/MMBtu, initiatives to repurpose flare gas could provide an additional natural gas sales value of USD 40 billion each year for governments globally, assuming 75 percent of the gas flared and vented is captured. Since most wasted gas occurs in oil and gas operations in more than 30 low-and middle-income countries that are highly dependent on oil and gas production;[59] these savings could provide huge benefit for UNSDGs when the USD 100 billion per annum from OECD countries to developing countries to support climate is yet to be realized.

The Global Methane Pledge (GMP) supports these local and global benefits. Nigeria together with 120 countries signed the GMP to reduce global methane emissions by at least 30 percent by 2030; funding of USD 300 million is pledged by philanthropies. Nigeria is a signatory to the Energy Pathway, launched June 2022, as a key GMP 'implementation step' to capture 'maximum potential' of methane abatement in oil & gas, and eliminate routine flaring.

[59] Roe and Dodd, Chapter 2 in Addison and Roe (2018) for the data on dependence. The low- and middle- income countries in this list include Nigeria, Ghana, Bolivia, Chad, Congo, Cameroon, Egypt, and Sudan.

12.5. Next steps to use satellite methodology to assess and compare operational effectiveness of key Nigerian production assets, e.g. FPSOs

As a follow up to this project, a similar detailed flare assessment based on VIIRS satellite data is proposed for four Nigerian FPSO facilities, including Agbami, Yoho, Bonga and a 4th asset yet to be selected. While the initial project focused on onshore flaring in the wider region east of Warri in the Niger delta, this new project will compare offshore flaring for a common type of assets (Floating Production, Storage and Offloading facilities). Agbami asset is Nigeria's largest super-emitter flare, globally ranked as 26th (during the period 2017-2020), despite the asset being designed and the development approved as a zero-routine flaring asset[60].

The project will compare the flaring and oil production characteristics of these installations, with the aim of determining the most suitable methodology for benchmarking their emission performance. Detailed flare performance analysis can identify events that are indicative of much increased methane emissions. By collating and assessing monthly oil production rates for these assets and comparing these with upscaled monthly flare rates, assessments will be made of trends in flare intensity. In other aspects, the methodology and deliverables will follow the approach for the first project.

[60] This study was subsequently completed in March 2023 and a separate report 'Nigeria's super-emitter flares, an evaluation of trends and causes of natural gas wastage – An analysis of five offshore global super emitter flares and their related field performances' is available.

13. Comments from ENI and follow up responses

EnergyCC and Oxford Policy Management (OPM) sent copies of the Nigeria super-emitters onshore report (this report) and the subsequent offshore study report in draft to the operators of four onshore super-emitters in the Niger Delta, the operators of the five offshore super-emitters, and to Nigeria LNG, with the request to review the draft and correct any factual errors. The comments from all the companies that provided responses are reproduced in full in the offshore report, as the comments received primarily related to that report. The comments from ENI however are also replicated here, as some of the future actions they propose may apply to their onshore activity as well as their offshore activity. The comments were provided through ENI Nigeria's Public Affairs Department, and were as follows:

> *With reference to your mail of June 22nd 2023, I am writing to you as Head of Eni Nigeria Public Affairs Department.*
>
> *Before going through the main concepts, let me strongly highlight and confirm that Eni applies and respects the Country legislations always acting in transparency and cooperation with the Environmental Regulatory Agencies and Authorities as per Country's Governmental Laws.*
>
> *As a second aspect, I would frankly appreciate the transparency of your Report which gave us the possibility to have an additional check of our data and environmental strategies on which, as you know, we are fully focused.*
>
> *With regard to your Report, we would firstly highlight some inconsistencies (see below, the main points):*
>
> 1. *Flaring Measurement – some misalignment between our data and the ones provided;*
> 2. *Gas Production Capacity and Injection – Current FPSO design configuration is able to reinject 95% of associated gas;*
> 3. *Oil Spills – No subsea spills reported in the last 8 years. We are periodically carrying out subsea Campaigns which did not highlight any issue on this matter;*
>
> *In terms of proposed solutions to improve our Flaring/Methane Emissions, we are currently working on the following actions:*
>
> 1. *Firstly, it is really important to mention that Abo FPSO is currently under total shutdown, which has been planned and implemented to improve both, HSE and operational performance (even to the detriment of Production);*
> 2. *OGMP Campaign execution, through which all the methane emissions will be accounted by accredited 3rd party (within 2023);*
> 3. *Flare Metering installation within current year to have a precise account of flaring;*
> 4. *A third Compressor is being installed to have redundancy during maintenance activities and reduce flaring;*
>
> *Following the above actions, for which we will have a clear picture within end of the current year, we will be able to define further solutions and strengthen the current strategies to improve our emissions framework.*

EnergyCC and OPM appreciate the acknowledgement of the Report and the efforts taken by ENI to follow up and provide the comments above. The ongoing efforts by ENI as highlighted by the four actions are highly appreciated and are expected to make a very positive impact going forward.

Regarding the three inconsistencies highlighted by ENI, the authors of the Report addressed these by providing the following responses:

1) *Flaring Measurement – some misalignment between our data and the ones provided*:
In their response, ENI acknowledge to be installing flare metering this year (2023). Without such flare metering available to date, it is unclear how ENI would compare their flare rates with satellite measured flare rates. The satellite flare rate measurements are based on a standard and consistent methodology adopted by World Bank and other leading institutions such as IEA, NEITI, etc. Once ENI's flare metering for Abo FPSO is operational, it would be interesting to compare the metered data with satellite data. Self-reporting of flaring in the absence of calibrated metering and independent verification may lead to under-estimation in flare rates. This was highlighted by the Guardian NG in their March 2023 article: under-reporting of self-declared flare data, when compared with World Bank satellite data, worsened with increased penalties on gas flaring (https://guardian.ng/features/focus/gas-flaring-crafty-operators-tax-evasion-endanger-children-unborn-babies/).

2) *Gas Production Capacity and Injection – Current FPSO design configuration is able to reinject 95% of associated gas:*
The flare evaluations reports (including Abo FPSO) consistently highlight that even if assets are designed for zero flaring (i.e. able to re-inject the produced gas), in practice these assets are flaring at super-emitter rates. One key reason is that gas-reinjection facilities are costly to maintain and hence re-injection capacity has a tendency to reduce over time. With the Abo development, the key operational challenge appears to be in managing the subsea facilities. Multiple references to blocked flow lines and impaired gas injection wells are included in the Abo asset evaluation. Therefore, ENI's statement on 'current FPSO design configuration' is less relevant if the subsea facilities are not able to inject the gas processed by the FPSO topsides into the subsurface. Moreover, most developments under-estimate the contribution of free reservoir gas in late field life production phase. In addition, associated gas rates depend on oil production policy. The analysis has shown that aggressive production policies cause a significant increase in associated gas production (and a decline in oil reserves) that can exceed the volumes that can be re-injected and hence result in excess flaring.

3) *Oil Spills – No subsea spills reported in the last 8 years. We are periodically carrying out subsea Campaigns which did not highlight any issue on this matter;*
Although ENI's statement says that no subsea spills were reported, this does not imply that no such spills may have occurred. There are several publicised reports of Abo's blocked subsea flow-lines, wells and other subsea equipment, and repeated efforts

were reported to unblock these. It is therefore possible that faulty subsea equipment and the subsea intervention operations may have resulted in subsea discharges. Some of the reports about the state of Abo's subsea infrastructure also highlight that problems were inadequately diagnosed and poorly resolved. The subsea oil leak referenced in the Report is based on a separate earlier study by Visio Terra during 2018 and 2019. Visio Terra is a reputable company founded in 2004, see https://www.visioterra.fr/web/spip.php.

APPENDIX A

Flare data from four super-emitters in the northern Niger Delta region

Global flare ranking[61]	Nigeria flare ranking	Name	Type	Location Latitude	Location Longitude	2017-2020 gas volume flared (Bcm)	Operator	JV Partners
121	5	Kwale gas plant	Onshore plant	5.660	6.517	0.666	NAOC (ENI)	OML 60 JV NNPC 60% ENI 20% Oando 20%
124	6	Obiafu-Obrikom gas plant	Onshore plant	5.386	6.657	0.658	NAOC (ENI)	OML 61 JV NNPC 60% ENI 20% Oando 20%
131	8	Ebendo flow station	Onshore plant	5.685	6.360	0.637	NAOC (ENI)	OML 56 JV Energia 55% Oando 45%
182	14	Kwale flow station	Onshore plant	5.716	6.486	0.520	NAOC (ENI)	OML 60 JV NNPC 60% ENI 20% Oando 20%

OML 60 – Kwale gas plant performance	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Flare rate (million m^3/d)	0.318	0.464	0.414	0.405	0.421	0.413	0.496	0.368	0.547	0.382
Global flare ranking						161	120	202	108	
Flare rate variability (1 = constant flare)	2.1	2.7	2.5	2.4	2.6	3.0	4.4	3.9	3.6	2.9
% flare volume due to structural issues	94%	93%	96%	96%	96%	95%	93%	92%	92%	93%
% flare volume due to incidental process trips	6%	7%	4%	4%	4%	5%	7%	8%	8%	7%

OML 61 – Obiafu-Obrikom gas plant performance	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Flare rate (million m^3/d)	0.383	0.393	0.299	0.365	0.498	0.412	0.378	0.465	0.547	0.505
Global flare ranking						162	186	144	109	
Flare rate variability (1 = constant flare)	5.4	3.7	4.5	3.5	3.1	2.9	4.5	6.7	4.1	3.8
% flare volume due to structural issues	97%	95%	96%	90%	95%	90%	95%	89%	95%	91%
% flare volume due to incidental process trips	3%	5%	4%	10%	5%	10%	5%	11%	5%	9%

[61] Out of 10,800 global flares.

OML 56 – Ebendo flow station performance	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Flare rate (million m^3/d)	0.081	0.132	0.232	0.499	0.332	0.379	0.378	0.494	0.492	0.397
Global flare ranking						182	184	131	124	
Flare rate variability (1 = constant flare)	1.0	1.5	1.8	2.5	2.0	2.5	3.0	3.0	2.7	2.3
% flare volume due to structural issues	97%	98%	94%	91%	97%	95%	93%	88%	93%	94%
% flare volume due to incidental process trips	3%	2%	6%	9%	3%	5%	7%	12%	7%	6%

OML 60 - Kwale flow station performance	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Flare rate (million m^3/d)	0.078	0.132	0.100	0.186	0.407	0.626	0.446	0.352	0.261	0.137
Global flare ranking						86	148	213	309	
Flare rate variability (1 = constant flare)	-	1.5	1.2	1.1	2.1	2.6	3.1	2.6	2.6	2.1
% flare volume due to structural issues	97%	98%	98%	96%	96%	95%	96%	94%	92%	97%
% flare volume due to incidental process trips	3%	2%	2%	4%	4%	5%	4%	6%	8%	3%

APPENDIX B
Abbreviations and units

APG	associated petroleum gas
ANOH	Asa North-Ohaji South green field gas condensate development project
bbl	barrel (1 bbl is 0.159 m^3)
bopd	barrels of oil per day
BC	black carbon
bcm	billion (= one thousand million) cubic meter
Btu	British thermal unit—measure of the energy content in fuel (1 Btu = 1.06 J)
CCAC	Climate and Clean Air Coalition
CDM	Clean Development Mechanism
CH_4	methane
CNG	compressed natural gas
CO	carbon monoxide
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
DFID	Department for International Development (UK)
EPA	US Environmental Protection Agency
EU	European Union
FCDO	Foreign, Commonwealth and Development Office
FOSTER	Facility for Oil Sector Transparency and Reform
FPSO	Floating Production Storage and Offloading
GGFR	Global Gas Flaring Reduction Partnership, led by World Bank Group
GHG	Greenhouse gas (such as carbon dioxide, methane, and others)
GMP	Global Methane Pledge
GTL	Gas to liquids
HFCs	Hydrofluorocarbons
ICPP	integrated combined cycle power plant
IOC	International Oil Company

IMF	International Monetary Fund
IPP	Independent Power Producer
IRR	Internal Rate of Return
JV	Joint Venture
Kbpd	thousand barrel per day (of liquids)
LNG	liquefied natural gas
LPG	liquefied petroleum gas
m	meter
m^3	cubic meter
Mln	million
mm	millimeter (one-thousandth of a meter)
MMBtu	million British Thermal Units—measure of the energy content in fuel (1 BTU = 1.06 J)
MMscf/d	million standard cubic feet per day
Mscf	thousand standard cubic feet
mtpa	million tonne per annum
NAOC	Nigeria Agip Oil Company (a subsidiary compant of ENI)
NBET	Nigerian Electricity Bulk Trader
NDC	Nationally Determined Contribution
NGL	natural gas liquids
NNPC	Nigeria National Petroleum Corporation
NOSDRA	National Oil Spill Detection and Response Agency
NH_3	ammonia
NO_x	chemical compounds made from elemental nitrogen and oxygen
NLNG	Nigeria LNG at Bonny Island
Ob-Ob	Obiafu-Obrikom gas processing plant
OC	organic carbon (partially oxidized VOCs)
OPML	Oxford Policy Management Ltd
OML	onshore mining leases
PPA	Power Purchase Agreement
SCAR	social cost of atmospheric releases

SCLP	short-lived climate pollutants
Scf/bbl	standard cubic foot of natural gas per barrel of crude oil
SDG	UN Sustainable Development Goal
SO_x	chemical compounds made from elemental sulphur and oxygen
SO_2	sulphur dioxide
UNEP	United Nations Environmental Program
UNFCCC	United Nations Framework Convention on Climate Change
US$	United States dollar
VIIRS	Visible Infrared Imaging Radiometer Suite
VNF	VIIRS Nightfire. VNF is produced with data from VIIRS on board two satellites
VOC	volatile organic compound