Suitability of gas flare locations for Mini Gas-To-Liquid Technology Deployment in Nigeria

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Abstract

Site suitability analysis for Mini Gas-to-liquid (MiniGTL) deployment was carried out for gas flaring (GF) sites, in order to determine prospective utilisation of the natural resource. Results show that most of the GF sites have very low gas yield (81%); only 14 have gas yield suitable for onshore MiniGTL deployment. One of the sites has a potential for supplying fuel to a nearby power plant, three can deliver power to the grid via cables and 6 can support local energy and allied industry development. The gas gathering from 7 hubs could capture about 81% of the total gas flared. This study identified viable economic options which could provide a sustainable approach to monetisation and management of associated gas. The findings provide information to support policy making initiatives that can solve the GF problem in the country. It is recommended that further analysis should be carried out to examine alternative scenarios and the economics of such deployment.

Keywords: Associated gas, Gas flaring; MiniGTL, Spatial assessment, Suitability analysis, Sustainable Resource Management

Introduction

Human impacts on the environment have been significant over the last several decades and have brought about considerable changes to the planet. Flaring or venting of associated gas symbolises one of those human activities which has contributed to changes across the planet. In Nigeria, GF predominantly emanates from the crude oil extraction where the associated gas is eliminated by flaring. Globally, from 1995 to 2006 an estimated annual total of 150 - 170 billion cubic metres (BCM) of associated gas was flared (Elvidge et al., 2007). Another estimate puts the value between 140 – 170 BCM in the periods between 1994 -2008; and a reduction of about 19% was recorded since 2005 (Elvidge et al., 2009). There has been a number of efforts in relation to regulations to stem gas flaring in Nigeria, however this has failed to reduce it (Anikpo et al., 2013).

MiniGTL technology offers an opportunity of reducing GF in Nigeria, however, there has never been any assessment of the viability of its deployment in the country. With this understanding, the study examined spatial attributes which could support the deployment of MiniGTL technology for management of associated gas in Nigeria. Thus, this endeavour is meant to answer the question – Where are the flare viable for deployment of various options of MiniGTL? What are the spatial attributes of flare site which could support MiniGTL deployment? Results of the study are expected to contribute in finding lasting and economically viable solutions to the problem of GF in Nigeria.

With an estimated annual contribution of about 350 million tons of carbon dioxide (CO2) emission into the atmosphere (George, 2014), the impact of GF cannot be over emphasised. For example, GF has contributed to a number of environmental damage across the Niger Delta and this has often spurred social uprisings across the region. Studies have shown that there is retardation of crop growth, decreased yields and more specifically decrease in ascorbic acid and starch content of some crops (Dung, Bombom, & Agusomu, 2008). Moreover, Jike (2004) argued that there is a link between environmental problems of the Niger Delta and the pervasiveness of social miscreants and antisocial behaviours.

With such attendant impact, there could also be a knock-on effect on the capacity of the community, productivity and sometimes relocation (Opukri & Ibaba, 2008). Furthermore, these are likely to increase social vulnerability and subsequently reduce resilience of the people and the environment in dealing with disasters. Ekpoh and Obia (2010) reported an increase in the rate of corrosion of Zinc roof in areas near gas flaring or sea aerosol, thus in the context of social vulnerability such household could be more vulnerable as more of their scarce resources are used in repairing or replacing damaged roof.

Extensive body of knowledge exists on the extent, social, economic and environmental impacts of gas flaring e.g. Anikpo et al. (2013). While new research on the effects would continue to enrich our understanding of the impact of this phenomenon, it is pertinent that research also explores methods and options for managing or eliminating GF. In the light of this, using location analytics, this work explored the potential of locations (GF sites) for utilization of associated gas via the deployment of MiniGTL technology.

Recently the general assembly of the United Nations adopted the Sustainable Development Goals (SDG) to replace the Millennium Development Goals (MDG). The Nation's achievement of many of the MDGs are at best mediocre (United Nations Department of Economic and Social Affairs, 2015). However, the new SDGs (United Nations Department of Economic and Social Affairs, 2015) offers a clear target for the nation to work on, towards addressing some of the problems plaguing the development of the nation. For example, by addressing the issue of GF, some of the SDGs could be partially addressed e.g. Goal 3 (Ensure healthy lives and promote well-being for all at all ages); Goal 11 (Make cities and human settlements inclusive, safe, resilient and sustainable); Goal 13 (Take urgent action to combat climate change and its impacts) and Goal 15 (Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forest, combat desertification and halt and reverse land degradation and halt biodiversity loss).

There are a number of technologies available for utilisation of associated gas. Some examples of the popular ones include cogeneration, GTL and natural gas hydrate. A number of authors have examined the adequacy, efficiency and cost-benefit of GTL (Bao, El-Halwagi, & Elbashir, 2010; Chedid, Kobrosly, & Ghajar, 2007; Keshav, & Basu, 2007; Onwukwe Stanley, 2009). GTL can produce high quality fuels and chemical feedstock products (e.g. Naphtha, Diesel, Jet fuel, Kerosene, Wax and Lube). GTL presents a very attractive opportunity for Nigeria in addressing the GF problem, which is however still not fully harnessed. There is only one project in this respect in Nigeria, the Escravos GTL plant in Escravos with a capacity of about 33,000 barrels per day - a joint venture between Chevron Nigeria Limited and Nigeria National Petroleum Company (Kable Intelligence Limited, n.d.). Other projects are currently in the pipeline in tapping the vast gas resources of the Nation - Olokola LNG project, Bonny Island LNG Plant, Brass LNG and the Southern Swamp Associated Gas Solution (SSAGS) Project.

There have been recorded successes across some countries in turning associated gas into useful products instead of flaring it. Such examples include, the M'Boundi oil field in the Republic of Congo, where associated gas feeds two power plants through a 350MW gas to power project and supplies electricity to over 300,000 people (Yesyrkenov, 2012). Also Rosneft recently received an award for reducing gas flaring at its Komsomolskoye oil field where a compression station treat and produce clean natural gas (Yesyrkenov, 2012). A very unique example of total elimination of GF can be seen in Kuwait by the Kuwait Oil Company. Here, they were able to utilise almost 99% of the associated gas produced, to increase electricity production and service gas demand (World Bank, 2014).

The SSAGS is the only project that has been reported to target associated gas in the country while the Escravos GTL project mentioned earlier is a huge project which requires a significant gas yield – not suitable for currently flared associated gas across the country (due to low yield). However, this low yield site could be harnessed by the deployment of MiniGTL. According to the World Bank (2004) there are a number of viable options for utilisation of associated gas:

a. On-site power production and transmission to existing power grid
b. On-site power production and supply of electricity to nearby settlement
c. Collection and supply of large gas consumers (e.g. Power plants) via pipelines
d. Collection and conversion to liquefied petroleum gas, solely or combined with other mean of use

The combination of these options and especially options (b) and (d) are suitable for small scale utilisation (low yield sites). World Bank (2004) also concluded that, options (a) and (b) are the most relevant (and/or a combination with option (d)) for many countries in the tropics and subtropics. Furthermore, World Bank (2004) highlighted that subsidies are not essential in order to achieve economic and financial viability of such endeavour. But, huge mile distance, low gas yield and price distortion due to domestic fuel subsidies, may make it necessary for incentives that would stimulate the investment in associated gas utilisation. It was also revealed that there is little economic difference between transporting gas via pipeline to existing power plant and onsite power generation for onward transmission to the national grid (World Bank, 2004).

MiniGTL technology is one of the most promising for utilisation of associated gas or re-injected usually flared in the country. Fleisch (2012) pointed out that, there are currently different variants of this technology suitable for flares of very small gas yield (>0.5MMscfd), large flares (□10MMscfd) as well as for onshore and offshore locations. There have been a growing number of options in technology and companies offering solutions to potential customers (either for tackling gas flaring or harnessing resources on marginal fields). This development has increased the financial attractiveness of the technology, which has further reduced the capital expenditure (Fleisch, 2014). The work of Fleisch (2014) examined several companies and their MiniGTL technology offerings. The work carried out comparisons based on plant scale applicability, base plant parameters, risk and commercial readiness of these companies and their technologies.

From the foregoing, the need and the relevance of MiniGTL is quite obvious, however, there is a clear and urgent need to process and analyse available data to provide useful information that can support decision for utilization of associated gas. Suitability analysis has evolved over the years. Suitability analyses almost always identify sites that are suitable for a specified purpose. Therefore, it is possible to identify location with the best attribute or combination of attributes for a development based on the understanding that some places more suitable than others.

The evolution and growth of this technique has been supported by the growing availability of spatial data and growth of geographic information technology. This current study applies suitability analysis technique in finding flare sites suitable for deployment of MiniGTL technology based on their spatial attributes and estimated gas yield. Suitability analysis has been used in the identification of potential site for social services deployment (Case & Hawthorne, 2013) and identification of potential landfill sites (Demesouka, Vavatsikos, & Anagnostopoulos, 2013;

Gbanie, et al., 2013). Feizizadeh and Blaschke (2013) examined agricultural land suitability (dry-farm and irrigated agriculture) in the Tabriz region of Iran, based on soils, climatic conditions and water availability to support strategic land use planning. Berry and BenDor (2015); and Kumar and Shaikh (2013) extended the application of suitability analysis by incorporating potential areas vulnerable to sea level rise in their suitability analysis of future coastal development. The work of Rahman et al. (2013) showcased the application of suitability analysis in aquifer management. The study presented a spatial multi-criteria decision support system to identify sites suitable for managed aquifer recharge in North Gaza. Working in the Malayan forest, Reza, Abdullah, Nor, and Ismail (2013) carried out a habitat suitability mapping for umbrella species to support protected area management and conservation planning. Liu, Zhang, Zhang, and Borthwick (2014) combined opportunity and protection maps to create a land use suitability map for urban land use in Beijing.

Suitability analyses could be grouped into two classes, site selection and site search (Cova & Church, 2000). In the case of site selection, the aim is to identify a finite area with particular characteristics (spatial or non-spatial) which meets specified objectives and constraints. Such problems require the identification of the best site for a particular use or activity within a set of potential sites; such potential sites had relevant characteristics already collated, thus the task involves ranking and rating the sites and as such highlighting the best out of available sites (Malczewski, 2004). Mathematical programming is often employed to carry out such analysis. For site search problem, the idea is to find the boundary of a potentially best site or an area where such site may be found. In carrying out this analysis, overlay analysis is often used.

Cova and Church (2000) identified two methods used in computational site search analysis: site search modelling and suitability mapping/land screening. Screening entails elimination of finite area based on their attributes. Suitability mapping involves scoring finite land area based on their ability to support intended use i.e. suitability mapping for irrigated farming. Furthermore, the analysis could also result in the identification of where the potentially good site could be found. In the case, where there is a very clear definition of spatial attributes required for designation as best site, then site search modelling is employed (but no predetermined set of candidates). Essentially this, operation could be carried out using spatial optimisation techniques available within GIS.

From the foregoing, it is evident that techniques and insights from geospatial data and spatial analysis can be brought to bear on many of the problems inhibiting sustainable development across the country. Application and development in the areas of GIS, remote sensing and information technology have presented a number of tools and mechanisms for identifying and solving various problems. This can be seen in the application of GIS and remote sensing in providing answers to questions about the location, condition, trends pattern and implication. All of these have significant implications in supporting the deployment of proactive measures for total environment management, policy making and efficient resource allocation.

Materials And Method

Method

Spatial analysis utilises, relative position of spatial features (topology), connectivity, adjacency, orientation and containment for deriving useful information. Comparison of location to ascertain their suitability can be carried out within GIS using spatial and attribute queries. A number of approaches are relevant for this. Weighted suitability rank places with relative suitability values computed based on the assigned weight of various criteria. Cost path analysis, identifies the least cost (time, distance or other criteria) path between two or more locations. Boolean suitability analysis examines a location for the suitability or otherwise using logical conditions (true or false, present or absent etc.). Boolean and weighted suitability approaches were adopted for the study. Furthermore, buffer analysis complemented by centre identification was also used to find potential collection point for gas gathering option for MiniGTL deployment.

Data

A total of 224 gas flare sites were collated after the filtering of 32,713 incidences identified by the Visible and Infrared Imagery and Radiometric Suite (VIIRS) Night Fire algorithm version 1.0 through version 2.1 from 17th of March 2013 to 13th of October, 2014 (Figure 1). The work of Elvidge et al., (2013) has extensive details of the method used for estimates computation from the VIIRS. Derived estimated were sourced from the Gas Flare Tracker website. Estimated daily output were compiled and presented in cubic metres, which were subsequently converted to Mmscfd.

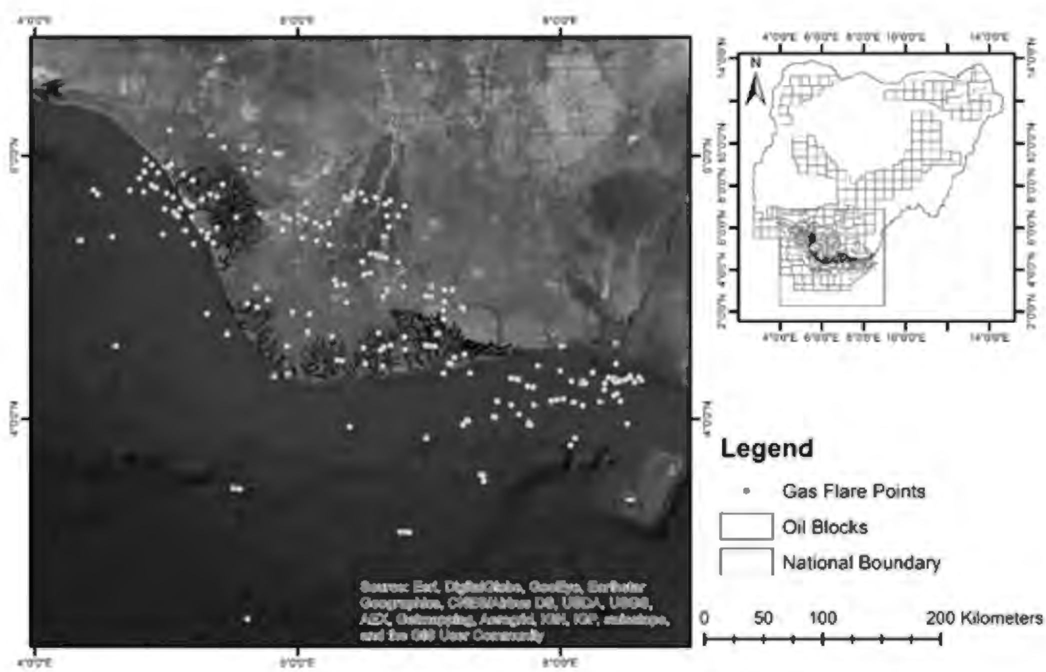

Figure 1: Location of gas flaring recorded by VIIRS measurement between 2013 and 2014
Source: Authors' representation and Google map imageries

Population data were collated from Geodata Institute maintained web site - ww.worldpop.org.uk (GeoData Insitute, nd). This dataset has a spatial resolution 100m resolution around the equator. Methods and analysis used for computation of this dataset can be found in the work of Linard, Gilbert, Snow, Noor, and Tatem (2012)

Table 1: Descriptive statistics of the estimated amount of gas flared across the study period.

Estimated Quantities (MMscfd)					
		N = 224			
Range	Minimum	Maximum	Mean		Std. Deviation
Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic
5.5116	0.0117	5.5233	0.6423	0.0552	0.8263

Source: Authors' computation

Results and Discussion

Estimated gas yield across the site varies widely (Table 1), with an average yield of 0.64MMscfd. Cluster analysis was carried out to group the GF sites into homogenous class on the basis of their estimated gas yields. There are five significantly different classes of GF sites (Table 2).

About 37% of the total GF belongs to clusters 1, 2, 3 and 4 (Figure 2) with mean yield ranging between 0.89 – 5.44MMscfd. These 4 classes represent potential sites for deployment of MiniGTL technology based as they have a relatively high gas yield. Cluster 5, with a cluster centre of approximately 0.23MMscfd has the lowest yielding GF sites across the region; it also has the highest number of members - 63% of the total GF sites.

Table 1: Cluster centres and frequency of gas flare estimated quantities

	Clusters' Centre (MMscfd)				
Clusters	**1**	**2**	**3**	**4**	**5**
Gas yield	0.8951	5.4421	3.9256	1.8716	0.2253
No. of Cases	60	2	4	17	141

Source: Authors' computation

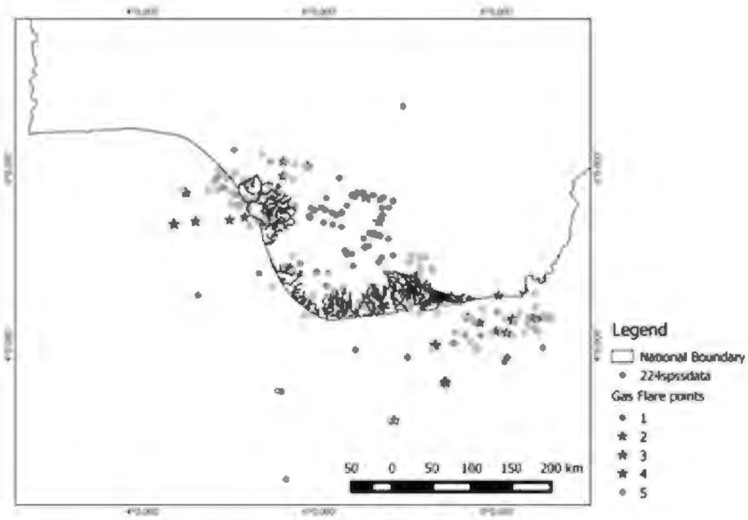

Figure 2: Classification of gas flare by cluster analysis

Source: Authors' representation

MiniGTL technology has potential for application across a wide range of low gas yield situation, onshore and offshore applications. However, firstly we consider the following characteristics in evaluating suitability of GF sites for MiniGTL deployment:

GF sites should

1. Have a gas yield ≥1MMscfd and
2. Be located onshore and
3. Be within reasonable distance of one or more power plants or
4. Be within reasonable distance of a segment of the national grid or
5. Be within reasonable distance of potential consumers.

Conditions 1 and 2 were rated as the most important while 3 – 5 were considered as alternatives for deployment if conditions 1 and 2 were met.

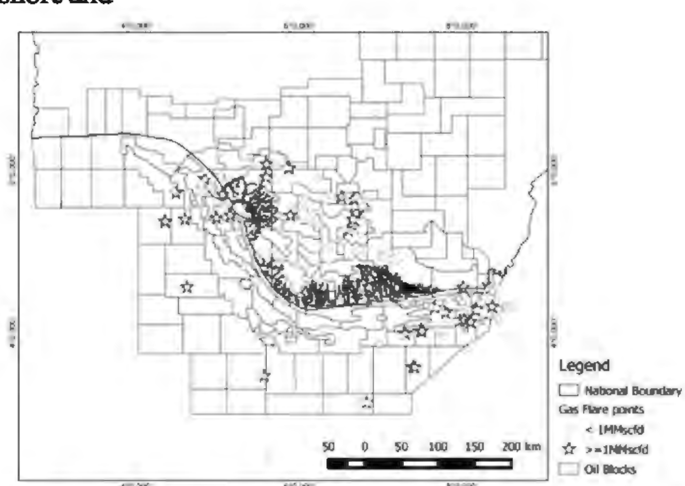

Figure 3: Flares with gas feed rate ≥ 1MMscfd relative to their location on the oil blocks

Source: Authors' representation

Condition 1: Gas Feed Rate ≥1mmscfd

For this condition, there are 42 gas flares (Figure 3), and these are concentrated around the south-west and the south-eastern extent of the Nigerian oil blocks. With yield ≥1MMscfd, it is clear where the potentially viable GF sites for MiniGTL deployment are across the region.

Conditions 1 And 2: Onshore Flares with Feed Rate ≥ 1mmscfd. These two conditions resulted in 14 GF sites (Figure 4). The differentiation between the onshore and offshore was to narrow down the number to those with potentially lower start-up cost. The result shows clearly that there are more potentially viable GF sites offshore than onshore. However, the higher cost of deployment of MiniGTL for offshore GF sites, and distance to market or a long last mile distance are likely to pose a significant challenge to potential investors. This is the rationale behind the thinning of the offshore sites for now. The gas yield across 14 GF sites identified ranges between 1.01MMscfd and 2.3MMscfd (Table 3).

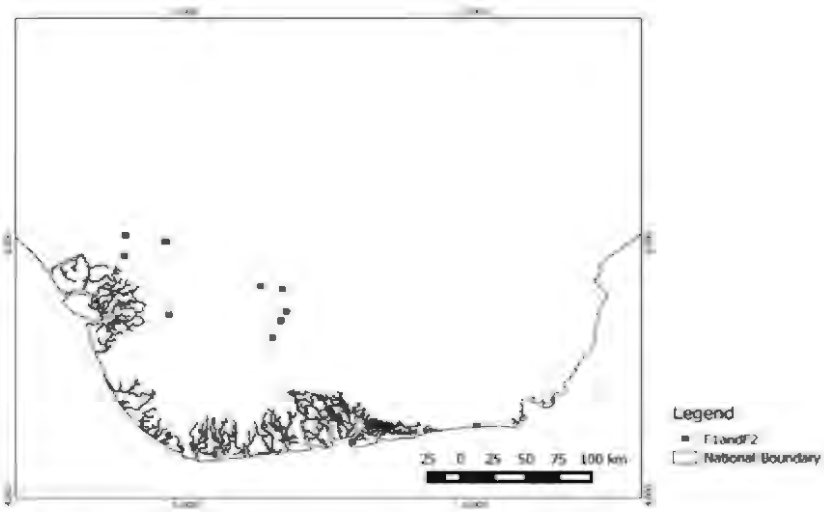

Figure 4: Gas feed □1MMscfd and onshore gas flares. Source: Authors' representation

Table 1: Flare points, their gas feed rates and rank

Flare ID	Oil Block	Gas Feed Rate (MMscfd)	Rank
3271 4	OML 111	1.7272	4
3271 5	OML 04	1.9198	2
3271 7	OML 41	2.2815	1
3272 2	OML 60	1.7635	3
3272 3	OML 60	1.2057	11
3273 5	OML 61	1.2598	9
3274 2	OML 61	1.5192	5
3275 0	OML 34	1.2807	8
3275 1	OML 58	1.1506	13
3276 6	OML 13	1.5110	6
3279 6	OML 11	1.1909	12
3288 3	OML 55	1.0088	14
3290 7	OML 04	1.3500	7
3290 8	OML 111	1.2577	10

Source: Authors' computation

Conditions 1, 2 and 3: Onshore flares with feed rate ≥ 1MMscfd and close to existing Power Plants

The combination of these conditions (1, 2 and 3) identified GF sites with potential for supplying fuel to power plant. The rationale therefore, is that since there are various products that can be derived from MiniGTL technologies as well as different technologies offering different end products, it is thus, necessary to consider using these products in powering existing power plant.

From the previous subset of 14 sites, there is one site within 500 metres of an existing power plant (Figure 5). The identified site is located within OML 61 oil block, and within 500 metres radius of Omoku II Power Station and 1km of Omoku Power Station. The flare is located within the Nigeria Agip Oil Company facility at Omoku, Rivers State. The site has an estimated gas feed rate of about 1.52MMscfd with a potential to generate about 131.33MWh per day (using a power generation potential of 86.4kWh per Mscf).

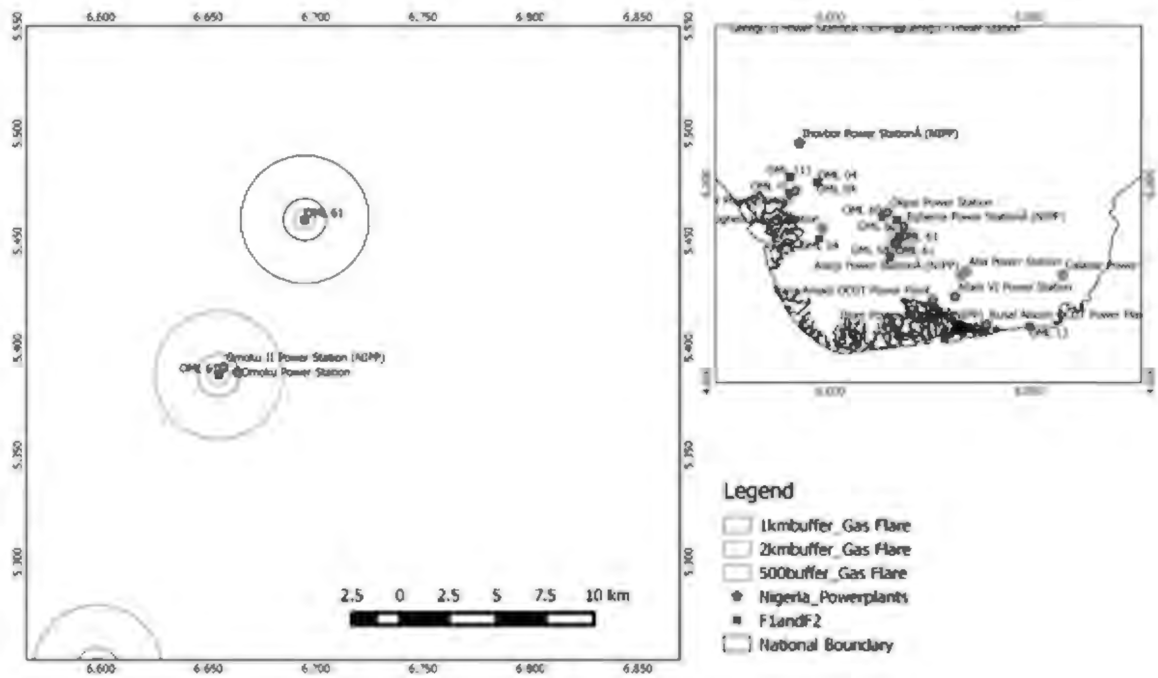

Figure 5: Gas flares within reasonable distance of power plant(s)
Source: Authors' representation

Computed distances to the nearest power plant were presented in Table 4 and gave an indication of the level of viability of this option (supplying fuel to a nearby power plant). From the result (Table 4), it is evident that at these distances many of the GF sites will require extensive delivery cost either via pipeline or tanker delivery. Therefore, the ranking of the GF sites is indicative of the additional cost likely to be incurred for each of the GF sites if this option is considered. With the distances recorded, it is evident that except for Flare # 32742, all other sites are relatively far from existing and planned power plants. This implies that other possibilities need to be examined for the remaining GF sites.

Table 1: Ranking of gas flares in relation to proximity to power plants

Flare ID	Oil Block	Nearest power Station	Type	Distance to nearest power plant (km)	Rank
3271 4	OML 111	Sapele Thermal Power Station	oil	15.064 9	8
3271 5	OML 0 4	Sapele Thermal Power Station	oil	23.241	10
3271 7	OML 4 1	Sapele Thermal Power Station	oil	6.841 5	2
3272 2	OML 6 0	Okpai Power Station	Gas	7.703 1	3
3272 3	OML 6 0	Egbema Power Station	Gas	9.803 7	5
3273 5	OML 6 1	Omoku Power Station	Gas	7.790 3	4
3274 2	OML 6 1	Omoku II Power Station	Gas	0.435 0	1
3275 0	OML 3 4	Delta - Ughelli Power Station	Gas	11.1523	6
3275 1	OML 5 8	Omoku II Power Station)	Gas	15.2492	9
3276 6	OML 1 3	RusalAlscon OCGT Power Plant	Gas	42.9685	13
3279 6	OML 1 1	Trans-Amadi OCGT Power Plant	Gas	41.1918	12
3288 3	OML 5 5	Trans-Amadi OCGT Power Plant	Gas	49.2877	14
3290 7	OML 0 4	Sapele Thermal Power Station	Oil	24.2412	11
3290 8	OML 111	Sapele Thermal Power Station	Oil	14.5586	7

Source: Authors' computation

Conditions 1, 2 And 4: Onshore flares with feed rate ≥ 1MMscfd and close to power grid

The second alternative considered is the distance to the existing power grid. The result shows that 2 GF sites (on OML 111) were found to be within 5 kilometres radius of the Benin to Sapele grid line (Figure 6). The combined gas yield of these two sites is approximately 3MMscfd. With a power generation rate of 86.4kWh per Mscf, the two sites have a potential of delivering 258.3MWh of electricity per day. Furthermore, ranking of the GF sites by distance to power grid shows that most of them are □10km away from the power grid (Table 5) and three are within 6km of a power grid line. Thus, if the option to generate power onsite and transmit via cables to the national grid option is considered, the ranking gives an indication of the potential for additional cost of these options.

Table 1: Ranking of distance from flares to nearest power grid

Flare ID	Oil Block	Grid			Distance (Km)	Rank
		Origin	Destination	Status		
32714	OML 111	Benin City	Sapele	Existing	4.2942	2
32715	OML 04	Benin City	Ughelli	Existing	13.8047	5
32717	OML 41	Sapele	Effurun	Existing	5.4046	3
32722	OML 60	Onitsha	Aba	Existing	47.1971	14
32723	OML 60	Onitsha	Aba	Existing	35.1459	12
32735	OML 61	Owerri	Yenagoa	Planned	22.6781	10
32742	OML 61	Owerri	Yenagoa	Planned	20.8728	8
32750	OML 34	Aladja	Ughelli	Existing	20.9072	9
32751	OML 58	Owerri	Yenagoa	Planned	16.0223	7
32766	OML 13	Eket	IkotiAbasi	Planned	12.4089	4
32796	OML 11	Afam	Port Harcourt	Existing	39.1414	13
32883	OML 55	Owerri	Yenagoa	Planned	32.8035	11
32907	OML 04	Benin City	Ughelli	Existing	14.8583	6
32908	OML 111	Benin City	Sapele	Existing	3.5529	1

Source: Authors' computation and African Development Bank 2008 data

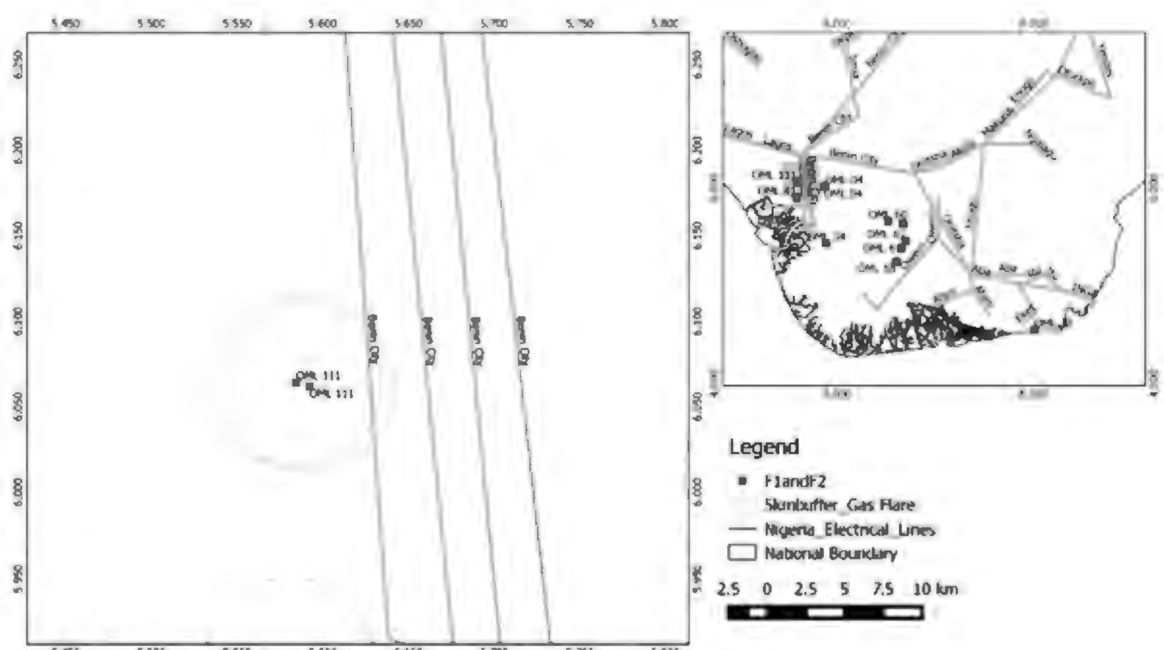

Figure 6: Gas flare site nearest to power grid
Source: Authors' representation

Conditions 1, 2 and 5: Onshore flares with feed rate ≥ 1MMscfd and close to highly populated area

The consideration for distributed power generation was also examined to showcase opportunities for local or last mile delivery of electricity (or even other forms of products) to potential consumers. In respect of this, the population was used to identify high density areas around each GF site. Contiguous areas with comparatively higher population density (i.e. potential consumers of MiniGTL plant products) were delineated. Euclidean distance (Table 6) between the polygons delineated and the GF sites were computed for each of the 14 sites (i.e. Onshore and with gas yield ≥ 1MMscfd).

Analysis shows that 6 out of the 14 flare sites are very close to potential consumers of products from the MiniGTL plants (if deployed at these locations). It should be noted that very high population density areas were considered in this analysis. However, it is very likely that most of flare sites (across the region) are located near communities which are likely to be potential consumers of the products and even spur the growth of other allied industries across such communities.

Table 1: Distance to potential consumers of MiniGTL products

Flare ID	Oil Block	Gas feed rate (MMscfd)	Daily Power Potential (MWh)	Potential Yearly Electricity (GWh)	Distance to Nearest Potential Consumer Population (Km)	Rank
32714	OML 111	1.7272	149.2335	54.4702	16.1168	12
32715	OML 0 4	1.9198	165.8673	106.2132	16.3371	13
32717	OML 4 1	2.2815	197.1225	126.2275	8.012 8	7
32722	OML 6 0	1.7635	152.3638	97.5663	13.7922	10
32723	OML 6 0	1.2057	104.1751	66.7086	8.837 2	8
32735	OML 6 1	1.2598	108.8433	69.6979	0.000 0	1
32742	OML 6 1	1.5192	131.2572	84.0506	0.000 0	1
32750	OML 3 4	1.2807	110.6542	70.8575	8.888 6	9
32751	OML 5 8	1.1506	99.4144	63.6601	0.018 9	4
32766	OML 1 3	1.5110	130.5469	83.5958	0.115 8	5
32796	OML 1 1	1.1909	102.8955	65.8892	0.168 9	6
32883	OML 5 5	1.0088	87.1638	55.8154	0 .0000	1
32907	OML 0 4	1.3500	116.6400	74.6905	17.4188	14
32908	OML 111	1.2577	108.6679	69.5856	15.4394	11

Source: Authors' computation

GF sites located in OML 111 and OML 04 have the least ranking in terms of distance to very highly populated area. Considering the six closest, they may serve to provide power to potential household consumers as they are within reasonable distance. These are not likely to warrant subsidies from government to potential investors according to World Bank (2004) analysis of GTL deployment in developing countries.

Table 1: Summary statistics for identified gathering points based on 10km buffer

Gathering Point	N	Mean (Mmscfd)	Sum (MMscfd)	% of Total Sum	% of Total N	Minimum (Mmscfd)	Maximum (MMscfd)
1	1	0.0204	0.0204	.01%	0.45%	0.0204	0.0204
2	3	0.8620	2.5861	1.80%	1.34%	0.1277	2.1493
3	2	0.6899	1.3798	.96%	0.89%	0.1352	1.2447
4	3	2.4915	7.4745	**5.20%**	**1.34%**	**0.2909**	**5.5233**
5	3	0.7305	2.1916	1.52%	1.34%	0.6381	0.8730
6	2	0.9268	1.8536	1.29%	0.89%	0.8860	0.9676
7	1	0.8898	0.8898	.62%	0.45%	0.8898	0.8898
8	3	2.1071	6.3213	**4.39%**	1.34%	**0.0297**	**4.3195**
9	2	0.3631	0.7263	.50%	0.89%	0.2910	0.4353
10	2	1.1911	2.3822	1.66%	0.89%	0.8712	1.5110
11	1	1.1606	1.1606	.81%	0.45%	1.1606	1.1606
12	1	0.3740	0.3740	.26%	0.45%	0.3740	0.3740
13	51	0.7987	40.7357	**28.31%**	**22.77%**	**0.0117**	**5.3609**
14	1	0.8559	0.8559	.59%	0.45%	0.8559	0.8559
15	1	0.0437	0.0437	.03%	0.45%	0.0437	0.0437
16	1	0.4090	0.4090	.28%	0.45%	0.4090	0.4090
17	4	0.5014	2.0055	1.39%	1.79%	0.1515	0.7302
18	4	0.5304	2.1214	1.47%	1.79%	0.3563	0.6613
19	3	0.1037	0.3111	.22%	1.34%	0.0531	0.1366
20	32	0.3941	12.6104	**8.76%**	**14.29%**	**0.0417**	**1.1909**
21	2	1.8511	3.7023	2.57%	0.89%	1.6517	2.0506
22	1	1.8436	1.8436	1.28%	0.45%	1.8436	1.8436
23	41	0.4734	19.4083	**13.49%**	**18.30%**	**0.0183**	**1.7635**
24	2	0.9427	1.8853	1.31%	0.89%	0.4627	1.4227
25	1	0.9257	0.9257	.64%	0.45%	0.9257	0.9257
26	42	0.4216	17.7062	**12.31%**	**18.75%**	**0.0179**	**2.3045**
27	12	0.9669	**11.6023**	**8.06%**	**5.36%**	**0.1460**	**2.2815**
28	1	0.2209	0.2209	.15%	0.45%	0.2209	0.2209
29	1	0.1306	0.1306	.09%	0.45%	0.1306	0.1306
Total	224	0.6423	143.8779	100.00%	100.00%	0.0117	5.5233

Source: Authors' computation

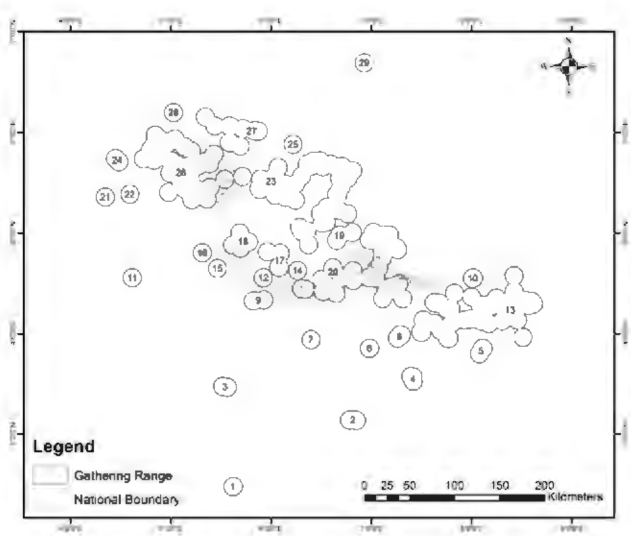

Figure 7: Buffer regions (10km) created for gas gathering.

In this respect, an analysis was carried out to identify potential gathering sites; in essence, identify locations near to some GF sites to serve as gathering site, and use those sites as MiniGTL deployment location – hubs. A buffer of 10 kilometres around each of the GF sites (off and onshore) show that 29 potential gathering ranges could be identified (Figure 7). These ranges represent a collection of GF sites within 10km radius of one another that could be collected to on point for deployment of MinGTL. As such the site could be connected via pipeline to deliver the associated gas to a hub within the gathering range.

The distance used for the creation of the buffer could be varied to simulate different scenarios of gathering ranges and potential viability for policy decisions. Summary of gas yield (Table 7) for each of the gathering ranges (hubs) shows that with 7 sites around 81% of the total flared gas could be captured (and monetised) and this constitutes about 82% of the total GF sites (184). From the 224 GF sites, it is therefore possible to designate 29 collection points; this can be further narrowed down to 7 most viable sites for immediate investment. Deployment of MiniGTL this way could significantly improve the economy of scale and efficiency of the MiniGTL facilities when deployed at these locations.

Conclusions

From the dataset collated for this study, about 19% of all the GF sites have gas yield □1MMscfd, thus it is possible to conclude that most of the GF sites are low yield sites. In order to facilitate, the ease of deployment, from the dataset only 6% of the GF sites are onshore and have gas yield (>1MMscfd). Among these onshore and relatively high yielding GF site, only one is highly viable for supplying fuel to a nearby power plant. It could also be concluded that six of the onshore GF sites are close enough to offer onsite power generation and distribution to nearby human settlement.

With the indication that most of the GF sites are low yield, gathering of associated gas from various sites offer another alternative to utilization of the associated gas. The example showcased in this study shows that a significant proportion of the GF site could be monetised, if this option is adopted even with a handful of collection sites (hubs).

From the results, it is very clear that the utilisation of associated gas in Nigeria would require combination of various options. This conclusion is based on the fact that there is a considerable variation in the attributes and spatial characteristics of these sites. This multifaceted approach, offers opportunity at stemming further environmental and social damages while contributing to social and economic development of the impacted communities.

It is expected that this work will stimulate further analyses and discussion among stakeholders in utilisation of this valuable resource, thereby, serving in addressing the problem of gas flaring and its impact across the Niger Delta. Extensive body of work exists on the impact and extent, the failure of legislative frameworks and so on. It is, thus, pertinent that research and analyses needs to focus more on solutions as well as their viability in addressing GF in Nigeria.

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