Gas Flaring in the Niger Delta: the Potential Benefits of its Reduction on the Local Economy and Environment.

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Abstract Nigeria flares 17.2 billion m^3 of natural gas per year in conjunction with the exploration of crude oil in the Niger Delta. This gas flaring expends huge amounts of energy and causes environmental degradation and disease. Even though oil has become the center of current industrial development and economic activities, the links between oil exploration and exploitation processes and the incumbent environmental, health, and social problems in oil producing communities are not well known. This paper examines the potential benefits of a gas flaring reduction on the local economy and environment, including the projected benefits of utilizing associated gas. Also, the carbon monoxide level of ambient air was collected at four villages, and other emissions related to flaring evaluated through related research. The results show that the reduction of gas flaring can improve human health and the environment. This paper concludes that the local livelihood in the Niger Delta can be significantly improved by promoting a shift from flaring the associated gas to collecting it for use as a gaseous fuel and for electricity generation. Although political feasibility poses a significant hurdle, economic and energy initiatives need to be strongly integrated with other policies that promote development.

Introduction

Nigeria flares 17.2 billion[3] m of natural gas per year in conjunction with the exploration of crude oil in the Niger Delta (GGFR 2002). This high level of gas flaring is equal to approximately one quarter of the current power consumption of the African continent (GGFR 2002). This problem has been produced by a range of international oil companies which have been in operation for over four decades (Africa News Service 2003). The economic and environmental ramifications of this high level of gas flaring are serious because this process is a significant waste of potential fuel which is simultaneously polluting water, air, and soil in the Niger Delta. In this paper, I show how a reduction of gas flaring could benefit the local economy and the environment in Nigeria.

As a visitor I was shocked to watch the endless burning of this gas 24 hours a day. Even though we have grown to be fairly dependent on oil and it has become the center of current industrial development and economic activities, we rarely consider how oil exploration and exploitation processes create environmental, health, and social problems in local communities near oil producing fields (where I call “oil producing communities” in the rest of this paper) (O’Rourke and Connolly 2003). For this reason, I hope that this study helps us, as oil users, to be more aware of the actual costs of oil production and to more actively seek corporate accountability in oil-producing communities

There are various reasons for the continuous gas flaring. From a political perspective, as Michael Watts (2001) said “In Nigeria, oil became the basis for important forms of political mobilization,” in which petro-capital became the cause of political violence against those advocating environmental justice or compensation for the costs of ecological degradation. The Nigerian government has not enforced environmental regulations effectively because of the overlapping and conflicting jurisdiction[1] of separate governmental agencies governing petroleum and the environment as well as because of non-transparent governance mechanisms (Kaldany 2001, GGFR 2002). Neither the Federal Environmental Protection Agency (FEPA) nor the Department of Petroleum Resources (DPR) has implemented antiflaring policies for natural gas waste from oil production, nor have they monitored the emissions to ensure compliance with

[1] Since 1988, the Federal Environmental Protection Agency (FEPA) has had the authority to issue standards for water, air and land pollution and has had the authority to make regulations for oil industry. However, in some cases their regulations conflict with the Department of Petroleum Resources (DPR)’s regulations started in 1991 for oil exploration. (Manby 1999)

their own regulations (Manby 1999).

From an economic perspective, the Nigerian government's main interest in the oil industry is to maximize its monetary profits from oil production (ESMAP 2001). Oil companies find it more economically expedient to flare the natural gas and pay the insignificant fine than to reinject the gas back into the oil wells. Additionally, because there is an insufficient energy market especially in rural areas (GGFR 2002), oil companies do not see an economic incentive to collect the gas.

From a social perspective, the oil-producing communities have experienced severe marginalization and neglect (Watts 2000). The environment and human health have frequently been a secondary consideration for oil companies and the Nigerian government. However, although there may be reasons for the continuous gas flaring, there are many strong arguments suggesting that it should be stopped. Corporations' accountability to the people and environment surrounding them imply that oil companies should be required to reinject the gas, to recover it, or to shut down any extraction facilities in which the gas flaring is occurring. This paper, however, calls attention to the fact that in addition to these ethical concerns there are very real potential economic and environmental benefits of recovering the gas as an energy source. Correcting these market failures would be a simple way to ensure that the natural gas currently flared is used more efficiently.

Nigeria currently produces 2.12 million barrels of crude oil per day, making it the twelfth largest oil producer in the world (EIA 2003). Even though Nigeria earns $17.2 billion from oil revenues annually (EIA 2003), it still remains one of the most underdeveloped and corrupt countries in the world (Ashton et al. 1999). Oil money currently provides for nearly 80 percent of government revenue, over 90 percent of foreign exchange earnings, and 90-95 percent of export earnings (EIA 2003). More than 75 percent of this oil is found in the coastal area of the Niger Delta, which is the largest oil reserve in Africa and the tenth largest in the world (Ambio 1995). According to the Ministry of Petroleum Resources, there are 150 oil fields and 1,481 oil wells in the Niger Delta region (Manby 1999).

Because of this massive oil exploration in the Niger Delta, the ramifications for human health, local culture, indigenous self-determination, and the environment are severe. As is the case in most oil producing regions of less developed countries, the economic and political benefits are given significantly more weight by the government than the resulting damage to the environment and human health (O'Rourke and Connolly 2003). Oil exploration causes a range of environmental problems. These include: contamination of both surface and ground water by benzene, xylene, toluene, and ethylbenzene; contamination of soil by oil spill and leaks; increased deforestation; as well as the economic loss and environmental degradation stemming from gas flaring, which is the focus of the rest of this paper (O'Rourke and Connolly 2003).

In order to address the problems of gas flaring, it is necessary to understand why the natural gas is being flared. Because oil and natural gas are mixed in every oil deposit, the natural gas called "associated gas" must be removed from oil before refining (Ashton et al. 1999). Gas flaring is simply the burning of this associated gas. Gas flaring is currently illegal in most countries of the world, where gas flaring may only occur in certain circumstances such as emergency shutdowns, nonplanned maintenance, or disruption to the processing system (Hyne 1999). Currently 56.6 million m^3 of associated gas is flared everyday in Nigeria (Gerth and Labaton 2004). Nigeria has the world's highest level of gas flaring, and it flares 16 percent of the world's total associated gas (GGFR 2002). Due to a lack of utilized infrastructure, approximately 76 percent of associated gas is flared in Nigeria, compared 8 percent in Alberta, Canada (Africa News Service 2003, Watts 2001).

Nigeria has had regulations on the books banning gas flaring for more than a quarter of a century, however they have yet to effectively implement their policies. In 1969, the Nigerian government legislated a requirement that oil companies set up facilities to use the associated gas within five years of the commencement of oil production (Manby 1999). The government also enacted the Associated Gas Reinjection Act in 1979, which charged oil companies to stop the gas flaring within five years (Manby 1999). However, the companies preferred to pay the fine that the government later imposed as a penalty for gas flaring rather than stopping the flaring. Even though the fine for gas flaring has increased from Naira 0, 5 to Naira 10 (U.S. 11 ¢) for every 1,000 ft^3 of gas in 1998 (Manby 1999, Project Underground 2003), this fine is still too low to have an impact on these companies' policy toward gas flaring. Moreover, the approximately $3 million per month of fines that the government receives is just a fraction of what it could impose. The reason fines are not increased is that the Nigerian government owes a big debt to oil companies. The government cannot actually collect most of the fine for gas flaring since it has failed to redeem its own obligation (African Business 2001).

In January 2003, President Obasanjo moved up the official deadline for phasing out gas flaring from 2008 to the end of 2004 (EIA 2003). However, it is difficult to determine whether the government really intends to enforce the 2004 target or whether it is only used in negotiation of new oil contracts (African Business 2001).

International organizations, governments, and the major international oil companies have now started to pay attention to this routine gas flaring. For example, the Global Gas Flaring Reduction Initiative (GGFR), led by the World Bank Group in collaboration with the Government of Norway, has just started a project to establish common guidelines and standards for gas flaring and venting on a global basis. The GGFR aims to improve the legal and regulatory framework for flaring reductions (GGFR 2002). This is not only because flaring is environmentally unfriendly but also because it is literally destroying valuable natural resources. Since the issue of global warming has become more high profile in the world, there has been more attention paid to gas flaring, which produces enormous amounts of greenhouse gases (GHGs) including carbon dioxide (CO_2), methane (CH_4), and propane (Kaldany 2001). In fact, the World Bank estimated that about 10 percent of global CO_2 emission comes from flaring. Nigerian gas flaring alone releases 35 million tons of CO_2 and 12 million tons of CH_4, which has a higher warming potential than CO_2 (Manby 1999, Watts 2001). In addition to the GHGs, the gas flaring also produces hazardous compounds that harm human health and the ecosystem.

Not only is the gas flaring damaging the environment and human health, it is also wasting huge amounts of the country's second most valuable natural resource. In the report of "Africa Gas Initiatives," the UNDP and the World Bank said, "If additional gas utilization projects are not implemented over the next twenty years, over half of Sub Saharan Africa's current known gas reserves could be flared along the Atlantic seaboard" (ESMAP 2001). Additionally, gas flaring in Sub Saharan Africa represents $3 billion of annual economic loss (ESMAP 2001), and the wasted energy resource through flaring in Nigeria equals about 45 percent of the energy requirements of France, the world's forth largest economy (Ashton et al. 1999).

Despite the common use of flares in the oil industry in Nigeria, remarkably little study of the gas flaring impacts has been conducted in the Niger Delta. Even in such an industry-intensive region as Alberta Canada, there are not many studies about the emissions of gas flaring conducted because of expense (Johnson 1999)

Accordingly, I intend to analyze how flare reduction in Nigeria can be linked to poverty alleviation through the reduction of pollution, fuel for local power and industry, and other resource benefits to local communities. With regard to environmental benefits, the reduction of gas flaring would decrease particulate emissions and GHGs. Moreover, since traditional biomass such as fuelwood and charcoal is still used for 97.3% of total energy in Nigeria, substituting the liquefied petroleum gas (LPG) produced by associated gas for fuelwood and charcoal would mitigate eye and respiratory disease from cooking stoves; adverse deforestation; and heavy time burdens for collecting the wood (EC and UNDP 1999, ESMAP 2001). The poor people in rural areas rely on the direct combustion of biomass such as wood, crop residues, and dung for activities that require heating or lighting because they lack access to electricity and modern fuels. Thus, the increase of availability of natural gas energy, currently being flared, would in turn help improve infrastructure and introduce a suitable pricing mechanism. Also, supplying modern energy service to Nigerians who still cook with traditional solid fuels and lack access to electricity would probably represent a significant improvement of living standards. This study shows that the associated gas currently flared in Nigeria, if used efficiently and effectively, has the potential to fulfill easily and cheaply a requirement for industrialization and to conserve the environment for local people at the same time.

Methods

In order to analyze the potential benefits of the reduction of gas flaring on local oil-producing communities, economic and environmental studies were conducted.

Economic Study The workbook created by GGFR was employed to perform an economic analysis of using the associated gas flared from the oil field. The workbook consists of a financial spreadsheet model capable of evaluating the economic costs and benefits of using associated gas for power production, industrial gas use and LPG production in a 15 year span with fixed 2004 prices. (GGFR 2004). Also, it indicates the different options for reducing gas flaring and using associated gas for local purposes. The options comprise four scenarios. Scenario 1 is “Use of the associated gas for power production at the oil field and transmission of power to the nearest electricity grid.” Scenario 2 is “Scenario 1 plus extraction of LPG at the wellhead.” Scenario 3 is “Transportation of the associated gas in a new gas pipeline to a site where it can be used by a new or existing power company to power production and / or by industries.” Lastly, scenario 4 is “Scenario 3 plus extraction of LPG at the wellhead.” Base on input data, including the amounts of the associated gas, local demand for energy and distances to markets, and financial fuel prices and economic cost of fuels, the workbook identifies which utilization options seem most relevant (GGFR 2004).

Two gas-flaring communities, Imiringi and Obama, were screened for small-scale utilization of associated gas. Site selection was based on the data availability for the amount of the associated gas. The required data were obtained through each flowstation, the documents of U.S. Energy Information Administration (EIA), African Gas Initiative, and OPEC, and personal observations. Table 1 shows some of the required data. As Table 1 shows, the Obama flowstation flares twice more than the Imiringi flowstation. The Imiringi flowstation, however, is about twice as close as the gas power grid and the power company than the Obama flowstation. This is because Imiringi is located close to the capital of Bayelsa state, and Obama is deeper towards the coast.

	Imiringi	Obama
Daily flow of associated gas (m^3/day)(1)	538,091	1,076,182
Distance from oil field to existing power grid (km) (2)	4	2
Distance from oil field to existing or new power company (km) (2)	20	50
Maximum LPG domestic/local demand (ton) (3)	35,000	35,000
Cost of CO_2 emission - low value case (USD / ton CO_2) (4)	0	0
Cost of CO_2 emission - low value case (USD / ton $CO_{2)}$ (4)	20	20
Cost of diesel at oil field (USD / liter) (5)	0.18	0.18
Cost of fuel at industries (USD / liter) (5)	0.09	0.09

Table 1. Some of the required data for the workbook
(1) each flowstation, (2) guesstimated, (3) African Gas Initiative: Main Report (ESMAP 2001),
(4) default of the GGFR's workbook, (5) OPEC

Environment Study In the summer of 2003, I stayed in the Niger Delta for 10 weeks, working with a Nigerian non-government organization, Our Niger Delta (OND). The Niger Delta is one of the largest wetlands in the world, encompassing over 70,000 km^2 (NDDC 2004) and is located on the coast of southern Nigeria (Figure 1). The Niger Delta has four ecological zones: coastal barrier islands, mangroves, freshwater swamp forests, and lowland rainforests (Ambio 1995). The Niger Delta also contains enormous biodiversity, including unique and rare species. During my stay in the Niger Delta, I visited four villages in Bayelsa state: Imiringi, Gbarain, Obama, and Anyama, to take carbon monoxide (CO) samples and discuss the impacts of oil exploration with local villagers. Imiringi (Kolo Creek Flowstation) and Gbarain (Etelebou Frowstation) are located approximately two kilometers from a gas flare flowstaion equipped with a gas scrubber which is used to remove water and air pollutants such as hydrogen sulfide (H_2S) (Langenkamp 1994). These flowstations are operated by Shell Petroleum Development Company of Nigeria

Limited (SPDC). Obama (Obama Frowstation) is located less than one kilometer away from another flowstation that is not equipped with a gas scrubber, owned by Nigerian Agip Oil Company Limited (AGIP). Lastly, Anyama region is entirely free of the gas flaring.

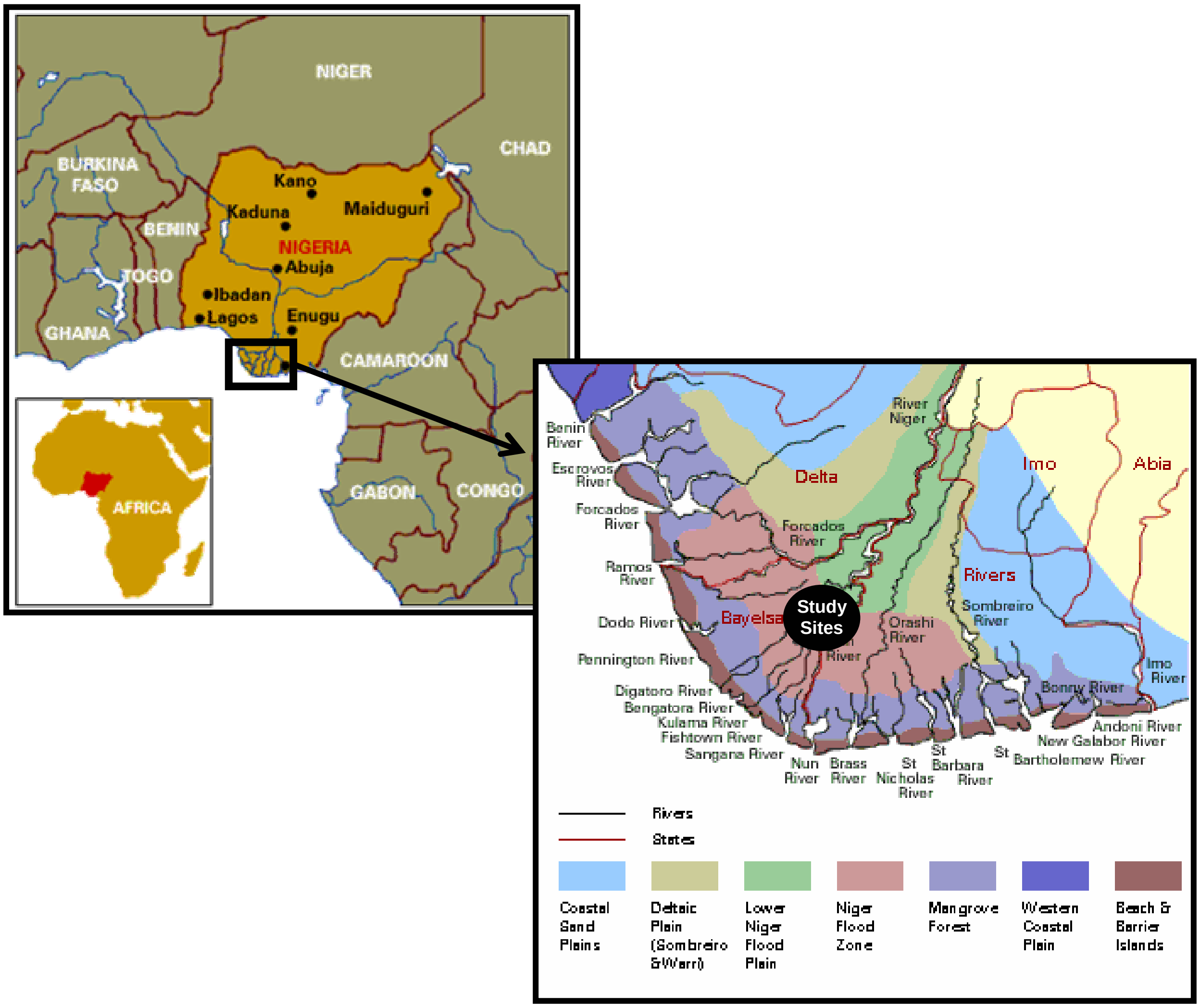

Figure 1. Map of Nigeria and the Niger Delta (Source: Urhobo Historical Society)

CO was measured using Onset's HOBO Carbon Monoxide Logger (HOBO) at four villages between June and August 2003. HOBO is a device used to record only CO level in parts per million (ppm). I recorded the date and time each time I took a sample and set the time interval for one minute. While the CO level of ambient air was monitored for a four-hour average over five different days in Imiringi, Gbarain, and Anyama, I could only take a CO sample for one day in Obama (August 6, 2003) due to time and distance constraints. I measured CO outside in an attempt to avoid other CO sources such as cooking stoves and vehicles.

In addition to CO emission, in order to study other emissions of gas flaring, I reviewed the Alberta Research Council (ARC) report released in 1996. This report is the one of the most comprehensive academic papers to examine other emissions. In their study, the ARC conducted field measurements of products of incomplete combustion downwind of flare plumes at a low-sulphur content gas (called “sweet gas”) site and another downwind from flares of a higher sulphur content gas (“sour gas”) site. However, because Nigerian gas has low sulphur content, only the data of sweet gas site is examined here (Ashton et al. 1999). Table 2 shows other parameters along with the sample collection in ARC study (Strosher 1996).

Parameter	Sweet Gas Flares
Volume of Flare (m^3)	8,600
Stack Height (m)	12.0
Stack Exit Velocity (m/s)	3.2
Wind Speed (m/s)	1.9
Flame Length (m)	4.5
Combustion Efficiency (%)	62.0

Table 2. Conditions for the sample collection measured 5 m above a sweet gas flame (Strosher 1996)

Furthermore, collecting associated gas yields human health and environmental effects as a secondary benefit by promoting a shift from direct combustion of biomass fuels in inefficient and polluting stoves to clean, efficient gaseous fuels. The study of evaluating of and control strategies for traditional and modern environmental hazards, particularly health-damaging and climate-warming air pollution from fuel use in developing countries has conducted by the United Nations Development Programme (UNDP) and Daniel M. Kammen and Kirk Smith who are professors at the University of California, Berkeley. Hence, I reviewed their study in order to examine how shifting the biomass fuel to the gaseous fuel by utilizing the associated gas can play a role on local environment and human health as an indirect benefit.

Results

In 1999, Nigeria completed its biggest gas project, the West African Gas Pipeline (WAGP) as part of a gas flaring reduction scheme (EIA 2003). The $400 million, 1,033 km pipeline will transport the gas from the Niger Delta through Benin, Togo, and Ghana to be used in those countries (Commery 2002). The facility is expected to process 7.15 billion m^3 of LNG annually

(EIA 2003). Yet, such a large-scale project is not designed to directly benefit local economies. Smaller projects are more effective and efficient for the local community because they are easier to bring to fruition and therefore quicker to achieve efficiency and positive economic returns.

To examine the potential for such local projects, the costs and benefits of small-scale projects for utilizing associated gas in Imiringi and Obama were examined using the methodology detailed in the GGFR's workbook. The results of both economic and financial analysis in each of four scenarios for Imiringi and Obama are shown in Tables 3 and 4, respectively. These analyses were conducted for a 15 year span with fixed 2004 prices. The economic analysis gives the economic benefit of utilization of associated gas given different estimated costs of CO_2 emissions. (GGFR 2004). The financial analysis shows the viability of this use of associated gas from the point of the view of an investor, oil producer, or owner of the associated gas. (GGFR 2004). In these Tables, "Benefits" is how much would be earned by utilizing associated gas, and "Costs" shows the costs of investment, operation, and maintenance. "Net Benefits" is profits (benefits – costs). Lastly, "Relative Benefits" compares the value of the proposed scenario with the baseline flaring costs paid under the status quo.

The results (Table 3) show that if the SPDC continues to flare in the next 15 years in Imiringi, Nigeria[2] will lose $ 63.4 million (valuing CO_2 at $0 per ton) to $ 140.9 million ($20 per ton CO_2). Likewise, if the AGIP does not stop flaring over the next 15 years in Obama, Nigeria also loses a huge amount of money, ranging from $ 126.7 million ($0 per ton CO_2) to 281.9 million ($20 per ton CO_2) (Table 4).

Also, Tables 3 and 4 show the potential economic benefits from utilizing the associated gas. In Imiringi, for the case that CO_2 emission is free, the socially optimal scenario is Scenario 4, which is LPG production and gas transmission to power plant and industries. For the case of CO_2 emission costing $20 per ton, the preferred alternative is Scenario 2, which is power and LPG Production at the oil field. From the point of view of investors, scenario 4 is the most profitable in Imiringi. Similarly in Obama, Scenario 4 given free CO_2 emission, Scenario 2 for $20 per ton CO_2, and Scenario 4 for investors are the most money-making solutions.

[2] Scenarios addressed in the GGFR's workbook fail to explain the distribution of profits between the government and oil-producing communities. Therefore, I refer Nigeria as amongst the local communities, the government, and oil companies.

Economic Analysis **($ 0 per ton CO_2)**	**Benefits**	**Costs**	**Net Benefits**	**Relative Benefit**
Present Flaring Scenario	0	63.4	-63.4	-
Scenario 1	67.9	47.1	20.8	84.2
Scenario 2	113.3	70.9	42.4	105.8
Scenario 3	40.6	12.9	27.7	91.0
Scenario 4	86.0	36.7	49.3	112.7
Economic Analysis **($ 20 per ton CO_2)**	**Benefits**	**Costs**	**Net Benefits**	**Relative Benefit**
Present Flaring Scenario	0.0	140.9	-140.9	-
Scenario 1	84.2	47.1	37.1	178.1
Scenario 2	134.6	70.9	63.7	204.6
Scenario 3	47.6	12.9	34.7	175.7
Scenario 4	96.6	36.7	59.9	200.8
Financial Analysis	**Income**	**Costs**	**Net Income**	**Relative Income**
Present Flaring Scenario	0	0	0	-
Scenario 1	58.3	44.2	14.1	14.1
Scenario 2	96.9	66.6	30.3	30.3
Scenario 3	34.8	12.2	22.6	22.6
Scenario 4	84.3	34.5	38.8	38.8

Table 3. Results of economic analyses and financial analysis for utilization of associated gas in Imiringi (Net Present Value million USD in a 15 year span with fixed 2004 prices)

Economic Analysis **($ 0 per ton CO_2)**	**Benefits**	**Costs**	**Net Benefits**	**Relative Benefit**
Present Flaring Scenario	0	126.7	-126.7	-
Scenario 1	119.8	84.0	35.8	162.5
Scenario 2	204.6	124.4	80.3	207.0
Scenario 3	68.1	23.4	44.8	171.5
Scenario 4	153.0	63.6	89.4	216.1
Economic Analysis **($ 20 per ton CO_2)**	**Benefits**	**Costs**	**Net Benefits**	**Relative Benefit**
Present Flaring Scenario	0.0	281.9	-281.9	-
Scenario 1	149.4	84.0	65.4	347.3
Scenario 2	243.8	124.4	119.4	401.3
Scenario 3	75.2	23.4	51.8	333.7
Scenario 4	167.0	63.6	103.3	385.2
Financial Analysis	**Income**	**Costs**	**Net Income**	**Relative Income**
Present Flaring Scenario	0	0	0	-
Scenario 1	102.8	78.9	24.0	24.0
Scenario 2	175.0	116.8	58.2	58.2
Scenario 3	57.9	22.1	35.8	35.8
Scenario 4	149.1	59.9	69.8	69.8

Table 4. Results of economic analyses and financial analysis for utilization of associated gas in Obama (Net Present Value million USD in a 15 year span with fixed 2004 prices)

Scenario 1 - Power production at the oil field and transmission of power to the nearest electricity grid
Scenario 2 - Scenario 1 plus extraction of LPG at the wellhead
Scenario 3 - Transportation of the associated gas in a new gas pipeline to a site where it can be used by a new or existing independent power producer / power company to power production and /or by industries
Scenario 4 - Scenario 3 plus extraction of LPG at the wellhead

According to CO samples, CO is not much emitted from the gas flaring. Figure 2 shows the means of CO concentrations in Imiringi (0.95 ppm), Gbarain (1.01 ppm), Obama (5.05 ppm), and Anyama (0.94 ppm) and the National Ambient Air Quality Standards of the US Environmental Protection Agency (9.00 ppm) (USEPA 2003).

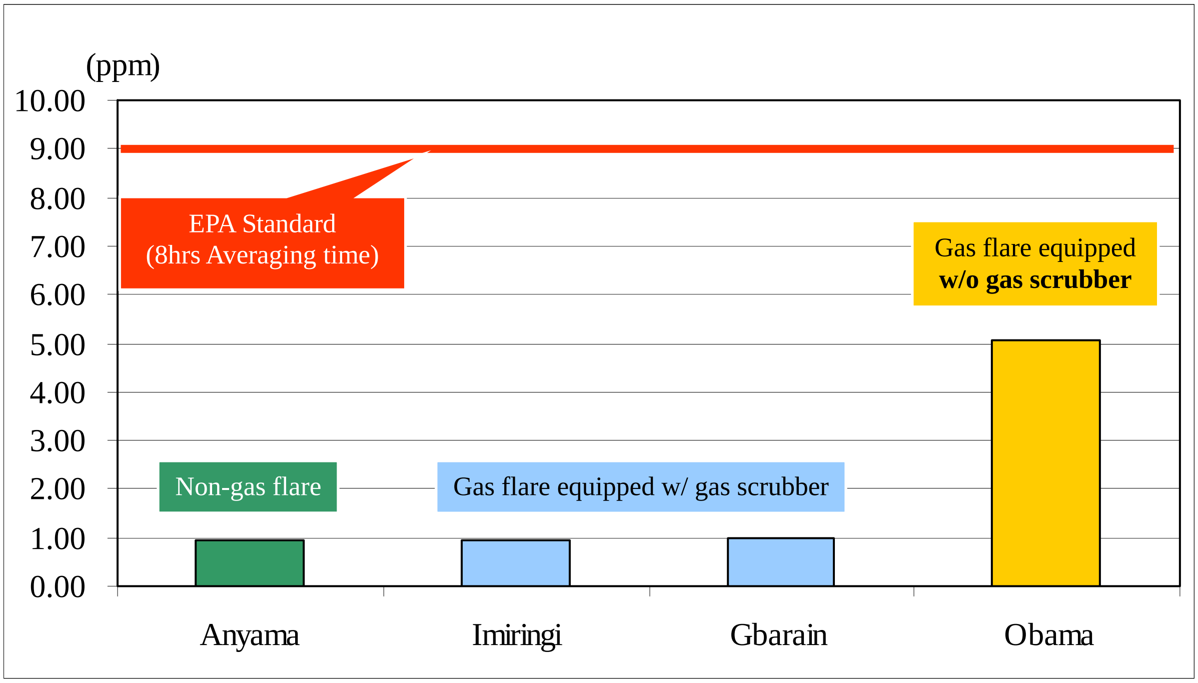

Figure 2. CO levels of ambient air measured by HOBO in the summer of 2003

Even between the gas flaring regions (Imiringi and Gbarain) and non-gas flaring region (Anyama), there is not many differences. However, it is worth mentioning that there is a significant difference between regions downwind of smokestacks equipped with gas scrubbers and those not so equipped. Although the CO levels are still lower than EPA standards, the CO concentration in Obama is five times higher than in other communities. Additionally, the colors of flames were different. While the flame of gas flaring with the gas scrubber was transparent, the gas flared without a gas scrubber produced lots of black smoke (Figure 3).

Figure 3. Gas flare of Obama, where a gas scrubber was not equipped

Discussion

Although there are three options to stop the gas flaring: by reinjection, utilization for local market, and utilization for export, flaring is still the most common practice to dispose of the waste gases that are produced during conventional oil exploration in Nigeria. The reason is because for oil companies to gain maximum economic profit, flaring is the most efficient way to dispose of the associated gas. Also, Nigeria has huge natural gas deposits, so that it is more economical to use non-associated gas to produce the natural gas as energy source. Indeed, associated gas recovery costs four times more than the straight extraction of non-associated gas (ESMAP 2001). Moreover, because the Nigerian government is politically unstable and non-transparent, it is difficult for them to enforce the proper policies and to make coherent government policies. Plus, oil companies and the government are willing to gain the short-term profits rather than long-term profits. These driving forces have led to keep the oil flowing at minimal cost without considering of local environment and people, and the gas flaring is a consequence of cost minimization strategy. There is no question that gas flaring is ubiquitous in the Niger Delta.

This paper intended to rebut these arguments by using the GGFR's workbook and to evaluate the benefits of local economy. As Table 3 and 4 show, I showed that the local communities and investors could gain the benefits from utilization of associated gas by utilizing with the consideration of long-term profits such as more than a 15 year span. Even though all scenarios are able to earn the profits, scenario 4, which is LPG production and gas transmission to power plant and industries, would be the best solution to reduce the gas flaring for both communities in

Imringi and Obama. However, since this economic analysis counts only the economic benefits, the further considerations such as social and environmental benefits are required. Moreover, the further study of the distribution of profits is also needed to address the actual benefits that local communities can obtain.

Gas flaring is not only the cause of economic loss, but also the cause of environmental degradation and health risk. Theoretically, the combustion processes with complete combustion create relatively innocuous gases such as carbon dioxide and water (Leahey and Preston 2001). However, because the flaring efficiency depends on wind speeds, stack exit velocity, stoichiometric mixing ratios, and heating value, the flaring in reality is rarely successful in the achievement of complete combustion (Leahey and Preston 2001). Although my result does not show the gas flaring produces a significant amounts of CO (figure 2), the flaring process with incomplete combustion emits a variety of compounds, including methane, propane, and hazardous air pollution such as volatile organic compounds (VOCs), polycyclic aromatic hydrocarbons (PAHs), and soot (Kindzierski 2000). And, it could assume that the gas flaring not equipped a gas scrubber like in Obama village produces much more those pollutants than a gas flaring equipped with a gas scrubber.

From the ARC study, Table 5 indicates predominant VOCs and PAHs compounds measured 5 m above of the sweet gas flare in Alberta (Strosher 1996). Benzene, naphthalene, styrene, acetylene, fluoranthene, anthracene, pyrene, xylene, and ethylene were the most abundant compounds found in any of the emissions examined in the sweet oilfield (Strosher 1996). The ground level concentration for products of incomplete combustion would depend on the distance. For example, the average levels at distances of 3 km from the flare would be 20 % of maximum concentration (Strosher 1996).

VOCs	Amount (mg/m^3)	PAHs	Amount (mg/m^3)
Acetylene	53.7	Acenaphthene	2.9
Benzene	144.5	Acenaphthylene	23.2
Ethylene	29.0	Anthracene	42.1
Hexane	8.5	Benz(a)Anthracene	17.3
Naphthalene	99.4	Benzo(g,h,i)Fluoranthene	10.2
Styrene	75.5	Chrysene	2.2
Toluene	18.2	Fluoranthene	51.4
Xylene	29.8	Pyrene	32.4

Table 5. Predominant VOCs and PAHs compounds measured 5 m above of the sweet gas flare in Alberta (Strosher 1996)

The effects on human health are all related to the exposure of those hazardous air pollutants emitted during incomplete combustion of gas flare. These pollutants are associated with a variety of adverse health impacts, including cancer and non-cancer, neurological, reproductive, and development effects (Kindzierski 2000). Table 6 indicates the potential health effects from the exposure of some selected hydrocarbon compounds shown in Table 5.

Compound	Health Effects	Volume of Acceptable Daily Intake
Benzene	Blood disorder, including reduced number of red blood cells and aplastic anemia, pancytopenia, leukemia	Not established but toxicant any level
Naphthalene	Destroying the membrane of the red blood cells with the liberation of hemoglobin, cataracts, headache, confusion, excitement, malaise, profuse sweating, nausea vomiting, abdominal pain, irritation of bladder	0.096 μg/m^3
Styrene	Irritant of the skin, eyes, and mucous membranes, and central nervous system effects	Not established
Toluene	Central nervous system effects which leads to narcosis, incoordination, emotional liability, headache, and fatigue	0.12 μg/m^3
Xylene	Central nervous system effects which leads to delayed development, decreased fetal body weight, and altered enzyme activities	0.12 μg/m^3

Table 6. Potential health effects for hydrocarbon compounds measured above a sweet gas flame (USEPA 2003)

Benzene is a well know cause of leukemia, and perhaps other hematological neoplasm and disorders. Storosher calculated that with 86,400 m^3/day of the associated gas volume and 60 m^3/min of the flow rate, the concentration of benzene at 5,000 m is approximately 0.25 μg/m^3, which is more than two times higher than the an annual average benzene concentration of the lifetime risk of 1:1,000,000 for adult leukemia (0.096 μg/m^3) (Argo 2002).

Nevertheless, these amounts of pollutants in Alberta could be only the fraction of those in the Niger Delta because of lower efficiency and poorer operative system. Also, the volume examined in ARC study was 8,600 m^3/day, which is over thousands times less than the average volume flared per day in the Niger Delta.

Additionally, the communities I visited in the Niger Delta believed that the gas flaring cause acid rain that results in the corrosion of the metal sheets used for roofing. Yet, Shell official stated that since the Nigerian gas is a low-sulphur content gas, there is no possibility of causing acid rain as a result of gas flaring (Okonta and Douglas 2001). There is not enough research has been done to prove the correlation between the gas flaring and the corrosion, so that the further study is needed.

Gas is being increasingly seen as a viable alternative source of energy to speed up development needs in Africa. In Nigeria, while the gas is wasted through the air, creating harmful air pollutants, biomass is still the mainstay of cooking and other heating. As matter of fact, the natural gas currently flared in Nigeria can serve the cooking needs of 320 million people not served by modern fuels (Goldemberg 2000). Recently, there has been more attention on introduction of modern energy for small-scale as a key strategy for promoting sustainable development in rural area (Goldemberg 2000) because the lack of adequate energy services in rural area has serious environmental and health effects.

The simple household solid-fuel such as fuelwood and crop residues stoves do not obtain high combustion efficiency (Smith 1999), so that they emit a large number of pollutants including particulate matter, CO, carbon dioxide, methane, nitrogen dioxide, formaldehyde, and PAH such as benzo[a]pyrene (Ezzati and Kammen 2002). The emissions from incomplete combustion not only contribute to climate change as greenhouse gases (GHG), but also have major adverse health impacts including acute respiratory infections, chronic obstructive pulmonary disease, asthma, nasopharyngeal and laryngeal cancer, tuberculosis, perinatal conditions, adverse pregnancy outcomes, and eye irritation (Ezzati and Kammen 2002). For instance, CO and other particulate levels are 10 times higher than the standards (Uma and Kim Oanh 1999). In contrast, the air pollution from gas stoves is nearly zero. Also, the test of all the biomass stoves including coal stoves shows that gas actually produce fewer GHGs per unit of energy sources than biomass fuels used in traditional ways (Smith 1999). In fact, because the stoves are numerous though small, overall household biomass combustion accounts for six to eight percent of global GHG emissions (Smith 1999). This implies that reducing these emissions will benefit health and mitigate GHGs at the same time. Thus, shifting the biomass fuel to the gaseous fuel by utilizing the associated gas could play a large role in reducing the air pollution, health risk, as well as deforestation.

Consequently, the reduction of gas flaring for small-scale utilization would benefit not only local communities but also an investor, oil producer, or owner of the associated gas. Although the reduction of gas flaring itself is usually accompanied by increasing costs, when the economic benefits of improved health as well as environment are counted, there is a net economic benefit for industries, agriculture, the government, oil companies, and for those household energy options involving a shift from traditional use of coal and biomass. Living standards in the Niger Delta can be significantly improved by promoting a shift from flaring the associated gas to collecting it for gaseous fuels and electricity.

Associated gas recovery, however, is not an easy job to do in a country like Nigeria. Like other petro-capital nations, Nigeria has slower rates of economic development, higher levels of corruption, higher military spending, and is more vulnerable to economic shock (Ross 2001). Oil has the power to weaken nations and to strengthen the transnational oil companies. Although reducing gas flaring is crucial to global and local environment and for human health, the company can still say "the budget constraints and consequent delays to schedule are putting pressure on the flares-down programme and the 2003 target will be challenging if oil production is significantly higher than planned" (SPDC 2002). Thus, this current political, economical, and social system between the government and international oil companies is required to change significantly.

Greater public disclosure of data on the environmental, social, and financial impacts of gas flaring is needed by the Nigerian government and oil companies. The government needs to strengthen their capacity to act as a regulator and facilitator of oil exploration and to provide better transparency mechanisms. For oil companies, supporting small-scale projects for utilizing associated gas may be good for their reputation within and outside Nigeria. This will also improve economic activities in the Nigeria Delta, leading to more employment and therefore less violence. There is also a need for more and better data on parameters for economic analysis as well as on hazardous pollutants released into the environment from gas flaring. Additionally, virtually no epidemiological or toxicological data are available on exposed communities from gas flaring in Nigeria. Therefore, significant research is required to better measure and to evaluate impacts of gas flaring. Providing local communities with education on the importance of a reduction of gas flaring by non-government organizations is essential to make communities united to stop gas flaring. Although political feasibility poses a significant hurdle, economic and energy initiatives need to be strongly integrated with other policies that promote development.

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