



Sustainable Environment: A Comprehensive Evaluation of the Effects of Gas flaring in the Niger Delta, Nigeria

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ABSTRACT: The objective of this review is to provide an extensive assessment of the impacts of gas flaring from the ancient to modern life conditions at the Niger Delta as an area of global significance was reviewed from Millennium development goal (MDG) sustainable environmental perspective. These effects of flared gas took so long to persist due to its underdeveloped market, technological deficiency in its conversion into profitable byproducts and/or reinjection into geologic reservoirs until when needed. Findings show that these upstream emissions from flared gas have led to precipitation of acid rain and anthropogenic emissions like GHGs, VOCs, PM and over 250 toxins that have caused innumerable adverse effects on the Niger Delta communities and to the global community as climatic changes and global warming. Categorically, the environmental effects ranged between air, soil, water, heat, light and noise pollution as well as loss of biodiversity, vegetation and inflicted severe impacts on the health, and socioeconomic destitution of the Niger Delta residents including deterioration of the houses they live and shoreline threats as a coastal habitat. Despite the Nigerian government's achievements in recovering the accrued carbon debt through liquefied natural gas (LNG) projects and other strategic measures as attested by international agencies, yet a detailed discussion on the constraints to effective anti-flare deadlines were also highlighted. Also, suggestions for substantial sustainability of the Niger Delta was made towards a climatic justice and zero-carbon footprint.

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Historical Background of Gas Flaring in The Niger Delta: It is well known that Nigeria is endowed with petroleum crude oil in commercial quantities at an estimated reserve around 23 billion barrels (bb) of oil and about 184 trillion cubic feet (tcf) of natural gas, Giwa, *et al.*, (2014). Based on these, Nigeria became the highest African producer of crude oil and 11th on the global table which enlisted her as an OPEC member since 1971 in addition to being the largest proprietor of natural gas reserves in Africa and 7th globally, Mafimisebi Nkwunonwo, (2014) and Ogbe, *et al.*, (2011). Historically, attempts to explore crude oil started in 1908 by the German company known as the Nigerian Bitumen Corporation, Shell D'Arcy was

awarded the rights for exclusive exploration in 1937, the oil prospection was suspended in 1946 due to the second world war and resumed in 1951 when the first oilwell was drilled at Ihuo at Owerri in Imo state. The breakthrough came in 1956 as the first successful oilwell pumped out oil at Oloibiri in Bayelsa state while first exportation took place in 1958 (Obi, *et al.*, 2021b; Ukala, 2010). After this, explorative expansions cut across other parts of the 75,000 km² area of Niger Delta bound southwards by the Atlantic Ocean with coastlines spreading from the bank of the Imo River eastward and Benin River at the west (Ololube, *et al.*, 2013). Geologically, the Niger Delta basin is at the foundation of the top Benin, middle

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Agbada and base Akata formations (Ehirim and Abbey, 2016). It has huge reserves of petroleum crude oil and gas as much as 800 to 1000scfd (standard cubic feet per day) of gas to oil ratio which drew global attraction to the 1958 success recorded by Shell Petroleum Development Corporation (SPDC) (Kaladumo and Ideriah, 2014). As an inland tertiary sedimentary basin with typical features of both structural and stratigraphic complexities arising from formational developments, these structural features are responsible for its hydrocarbon development. The wealth of Niger Delta's structural characteristics came from its synsedimentary tectonics and the accompanying sediment loading (Emam, 2016). With these, the region was endowed with commercial reserves of petroleum crude oil and gas. When this oil is extracted, it comes with natural gas as an associated gas which must be separated before the oil refinery. While the oil was exported massively, there was no identified market for the natural gas as well as no technological means of utilizing it. The only option was to burn it off by flaring and this indicates that gas flaring commenced with the first oil production in 1956. Ironically, this same Niger Delta region that produces the economic fortunes of the country has faced devastating situations from gas flaring while (Ogwu, *et al.*, 2021) reported that the major problems in the Niger Delta are all traceable to the Nigerian oil and gas industry. If Americans are worried about residents up to 17.6 million living within 1 mile from oil or gas wells (Cushing, *et al.*, 2021), then, the Nigerian government is unfair to the Niger Delta people who live within flare zones to the extent that they dry their food using the heat from flare sites. There has been reports of soil, water and air pollution that has caused harm to fishes, crops, vegetation, human health and socioeconomic lifestyle including detrimental effects on the houses they live in. The worsts are the release of GHGs and radioactive forcing (Cushing, *et al.*, 2021), leading to severe irreversible climatic alterations that has attracted global attention in recent times. Clarion calls from several researchers (Ogbe, *et al.*, 2011; Adekomaya, *et al.*, 2016; Ogolo and Onyekonwu, 2015) on the urgent need to end the anthropogenic emissions from gas flaring need to be sustained towards a global attention to this ecological and climatic injustice. It is then the aim of this paper to join in the campaign of raising passionate appeals to stakeholders, opinion analysts and policy makers to join hands for remediating the already accrued carbon debt and other effects linked to gas flaring. Objectively, this will be done by evaluating the correlation between gas flaring and the environmental, socio-economic and health status at the Niger Delta as well as the Nigerian government's efforts so far in handling gas flaring situations. This study is in line

with one of the principal objectives of the Niger Delta Development Commission (NDDC) which stipulates thorough research on the environmental status of the Niger Delta region. To achieve this, the present study was structured in a way that after this historical trend of gas flaring development in the Niger Delta, next was an inventory of the emissions from flared gas in this region and to cascade on the consequences of these emissions with a focus on critical atmospheric, environmental, noise, heat and light pollution as well as socio-economic and health effects recorded in literature. Also, a detailed attention was drawn to the effects of inhaling flared gas emissions with a focus on carbon monoxide. A correlation between GHGs and global warming in the context of flared gas as well as a highlight on the effect of gas flaring facilities' proximity to both biotic and abiotic components of this localized ecosystem were also discussed. An assessment of achievements of MDG 7 with respect to sustainable environment towards a zero-carbon footprint was also made. A detailed performance appraisal of interventionist agencies on the environmental sustainability of the Niger Delta from the colonial government through several military and civilian governments with a focus on the NDDC was also demonstrated. The concluding section came after evaluating the constraints to realistic anti-flare deadlines and the Nigerian government's achievements so far in reducing the accrued carbon debt. Finally, there were recommendations to the way forward for a cleaner soil, water and air quality in the Niger Delta.

Inventory of Flared Gas Emissions and their Consequences in the Niger Delta: Gas flaring can only be allowed as a safety measure to dispose associated gas or to relieve built up pressure during emergency, testing or equipment failure (Emam, 2016; Edino, *et al.*, 2010; Chang, *et al.*, 2017; Fagbami, *et al.*, 2015). From this safety standpoint to a permanent production activity, gas flaring has taken an unplanned effect of heat and noise on the host environments to the extent of making most host communities uninhabitable. It has also caused human displacement with the antecedents of a dilapidated ecological habitat. In fact, it has been a controversial practice (Rahimpour, *et al.*, 2011), as it became a severe case too delicate to evict. The upstream and downstream emissions from gas flaring are rather ubiquitous especially to climatic changes. This associated gas flaring is a source of significant amount of global GHGs and other poisonous emissions. The volume of pollutant gases emitted depends on the combustion efficiency of the flare system, while the brightness and colour depend on the original composition of the generated associated gas. One established factor is the effect of proximity to the

flare facilities as disclosed in table 1, showing the distribution of pollutant gases within Shell Petroleum

Development Corporation (SPDC) facilities and a location with no history of gas flaring (Eneka village).

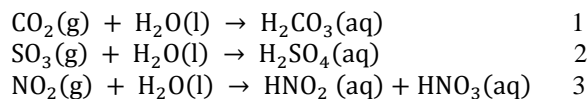
Table 1: Air quality of selected Niger Delta locations: a non-flare area and 200 m from two flare stacks (Nwaichi and Uzazobona, 2011).

Location	CO ($\mu\text{g}/\text{m}^3$)	CO ₂ ($\mu\text{g}/\text{m}^3$)	SO ₂ ($\mu\text{g}/\text{m}^3$)	NO ₂ ($\mu\text{g}/\text{m}^3$)
Non-Flare area (Eneka Village)	5.71	5.54	<0.01	<0.01
Flare area (SPDC, Agbada 1)	55	59.25	7.45	16.3
Flare area (SPDC, Agbada 2)	11.2	69.05	24.2	37.3

The results show remarkable increase of emissions towards the flare site. These emissions have taken turns to affect the environment, air quality, noise and heat levels as well as socioeconomic life of the Niger Delta residents until now.

Atmospheric Effect: Up to 2013, about 0.456 million tons of the global black carbon emission as part of PM_{2.5} came from the Niger Delta of Nigeria which can be linked to gas flaring and other incomplete combustions of fossil fuel (Giwa, *et al.*, 2014). Also, Black carbon's destructive role in human health, physical visibility and the ecosystem is of immense global concern. For instance, notwithstanding that black carbon resides in the atmosphere for few days, 1 g of it can warm the atmosphere hundreds of times than 1 g of CO₂ floating on the atmosphere in 100 years making the contribution of black carbon to global warming to be about 70% that of the CO₂ (Giwa, *et al.*, 2014; Giwa, *et al.*, 2016). In addition, the residual (unburnt) components consist of methane and VOCs. Findings reveal that within 20 years of exposure, 1 kg of CH₄ is 62 times more damaging compared to exposure to 1 kg of CO₂ (Mafimisebi and Nkwunonwo, 2014) and 25 times as a potential global warming greenhouse gas than CO₂ based on their masses (Kaladumo and Ideriah, 2014). Specifically, the GHGs and VOCs have been labelled in photochemical formation of Tropospheric Ozone and this bad ozone consequently is harmful to both plant and humans (Emam, 2016; Ghorbani, *et al.*, 2013; Nwosisi, *et al.*, 2019). Also, more than 250 toxins have been identified within flared gas including dioxin, H₂S, toluene, xylene, styrene, benzopyrene, naphthalene, benzene and its metabolites etc. (Giwa, *et al.*, 2014; Mafimisebi and Nkwunonwo, 2014; Obi, *et al.*, 2021a; Obi, *et al.*, 2021b; Giwa, *et al.*, 2017; Ekpoh and Obia, 2010; Ismail, and Umukoro, 2012). The Niger Delta have been selected as a case study in this review since Nigeria gas flaring through this region is responsible for 18 million metric ton of GHGs and other lethal emissions (Obi, *et al.*, 2021a). The atmosphere naturally conducts self-purification periodically by rinsing off excessive pollutant loads with suspended liquid scrubbers. With water vapour and fog as the primary scrubbing or precipitation media, the atmosphere enriched with oxides of Carbon, Sulphur and Nitrogen from anthropogenic

emissions are hydrolyzed according to the following stoichiometric relations (Abdulkareem, *et al.*, 2012):



Naturally, atmospheric CO₂ is responsible for the slight acidity of rain water up to pH of 6.0 which has been rated to be harmless. However, the contributions of anthropogenic CO₂ with these other acidic gases (SO₂ and NO₂) in the atmosphere expressed in equations 1 to 3, rainwater acidity can range between 2.0 and 4.0 in pH which is quite devastating to any living tissue (Ekpoh and Obia, 2010). From equations 1 to 3, the resultant dilute acid solutions formed are precipitated as acid rain which comes down as toxic rainfall causing skin disorders and carcinogenic effects, alteration of compositional parameters of sea and domestic water quality. Also, it causes damage to vegetation, discoloration of walls, corrosion and leakage of roofing sheets, deterioration of monuments, accumulation of debris on rooftops and structures of economic values despite the unquantified effects on the aquatic ecosystem (Ekpoh and Obia, 2010; Abdulkareem, *et al.*, 2012; Adoki, 2012; Udoekem, 2013).

Environmental Impacts: Petroleum crude oil exploration and exploitation are accompanied with destruction of existing ground surface leading to both environmental and socioeconomic implications (Ehirim and Dagogo, 2016). Public opinion has faulted oil spillage and gas flaring as root causes of the present level of environmental dilapidation in the Niger Delta (Akpomuvie, 2011). Its spillage has been proven as a major contributor to soil saturation with trace metals which increases the human exposure and bioaccumulation of these metals (Zabbey, and Babatunde, 2015). Majority of the spilled oil are not recovered and the root cause of the spillage has been linked to inadequate pipeline inspection and maintenance as well as the use of pipelines that has exceeded their life expectancy leading to corrosion and ease of sabotage, (Emoyan, 2008). Most of emitted GHGs come from flare stacks and majority of the world's flare sites are localized at the Niger Delta

region (Adoki, 2012) of Nigeria. This region with exceptional biodiversity is the world's largest wetland, second largest mangrove in the world and third largest drainage basin in Africa but now saturated with over 123 gas flaring sites (Giwa, *et al.*, 2014; Ogwu, *et al.*, 2021; Giwa, *et al.*, 2017; Zabbey, and Babatunde, 2015; Ana, 2011; Tawari and Abowei, 2012; Ite and Ibok, 2013) currently in operation while (Olujobi, 2020), puts it at 144 with all adding to pollution of the air, soil and water. In addition, the emissions also contain VOCs such as benzene, H₂S, toluene and xylene (Anosike, 2010), that make the water highly toxic for the ecosystem. The dark coloration and soured taste of this rain water due to saturated PM and soot content makes it undrinkable (Adoki, 2012; Nkwocha and Pat-Mbano, 2010; Orimoogunje, 2010). With limited access to healthy drinking water, majority of the Niger Delta resident resort to shallow boreholes and hand-dug wells since the water table is less than one meter in the rainy seasons. Based on this, spilt petroleum crude oil becomes easier to sip into drinking water, (Emoyan, 2008). Even after sand filtration, acidified water has been reported (Adoki, 2012; Ana, 2011) in shallow hand dug water wells in several communities in the Niger Delta. Poisoned water bodies have also been reported (Abdulkareem, *et al.*, 2012), that are both undrinkable and cannot sustain the fish domain the Niger Delta was formerly known for. Other major opportunity costs of these anthropogenic emissions comprise the rise in sea level, coastal erosion, wildlife extinction, loss of biodiversity, acidified water penetration into coastal aquifer and other lethal endemic effects of acid rain on the coastal ecosystem in this area as highlighted in (Abdulkareem, *et al.*, 2012; Adoki, 2012; Emoyan, 2008; Tawari and Abowei, 2012).

Noise, heat and light pollution: It has been proven that the flare system also emits substantial amount of noise and heat pollution 0.5 km from the stack base making the flare zone too unlively for human habitation (Emam, 2016; Obi, *et al.*, 2021a; Abdulkareem, *et al.*, 2012). The exothermic combustion of associated gas releases significant amount of heat. Fishes as cold-blooded aquatic animals are sensitive to such water temperature rise. Reports (Abdulkareem, *et al.*, 2012), reveal premature hatching of fish eggs before their gestation period due to unusual temperature rise of the aquatic habitat and worse still, not hatching at all. In addition, the radiated heat around flare stacks have been noticed to be above tolerable limits for certain cash crops to survive, while (Abdulkareem, *et al.*, 2012), estimated a 10%, 45% and 100% reductions in crop yields for plants at 1 km, 0.6 km and 0.2 km from the flare stack respectively. With these regions as a heat sink to the flare stacks, plants have met stunted

growth and reduced propensity to pollination leading to dwindling agricultural productivity as well as diminishing wildlife and domestic biodiversity (Edino, *et al.*, 2010; Ana, 2011; Nwanya, 2011). No significant farm practice is currently going on at the Niger Delta mainly due to the flared gas effects (Adekomaya, *et al.*, 2016). Comparing the prehistoric Niger Delta residents who were fish and food crop farmers to the present-day residents (non-oil working class), it is obvious that they have been displaced without an effective program of rehabilitation. The water toxicity from acid rain and heating from the flare stacks has got the fishes extinct while the people eating the surviving intoxicated fishes in turn get poisoned since biological law has it that once a unit in a food chain is infected, its dependents will be affected. Acidified soil profile, (Anosike, 2010); Orimoogunje, 2010), coupled with anthropogenic photoperiodic effects due to the excessive light from flare stacks has led to reduced crop yields. It was observed in the infertility in okra and palm trees which lost their budding tendencies hence could not bear fruits while maize, yam and cassava have been warned not to be planted within 2 km from flare stacks if any crop yield is expected. Besides, cassava plants were reported with stunted growths and diminishing nutritive contents in starch, vitamin C and amino acids in the root tubers near flare zones, (Nwanya, 2011; Odjugo and Osemwenkhae, 2009). Worst still, to humans, much attention has not been given to the thermal energy released from the flare stacks having it in mind that this is a place some people call home, (Nwanya, 2011). Sunstroke due to prolonged and extreme exposure to UV rays above the heat-regulating mechanisms of the human body as well as skin disorders are eminent to Niger Delta residents.

Socioeconomic consequences and perceived injustice: Despite the huge income, the oil sector has not added significant value to the Nigeria economy looking at the 2% it offers as GDP in addition to its negative impacts to health and environment (Mafimisebi and Nkwunonwo, 2014). Regardless of the huge economic fortunes and developmental platforms from oil discovery in Nigeria, the environmental, health and socio-economic consequences of its upstream and downstream emissions are rather ubiquitous. In addition, the compromise of economic profits by the Nigerian government, the multinational oil companies and other stakeholders at the expense of standard livelihood of Niger Delta communities is an outright abuse of human dignity. Reacting to these, the restiveness and agitations for commensurate balance and remediation of the damages have taken dimensions that were not earlier envisaged. From another perspective, looking at the recorded 168 bcm

(billion cubic meters) of gas flared globally per year, the Nigeria's Niger Delta contributes 13% which is about 23 bcm and are in surplus for both export and domestic demand. This amounts to an annual loss of \$2.5 billion to all Nigerians at the detriment of potential returns on natural gas investments (Giwa, *et al.*, 2014; Mafimisebi and Nkwunonwo, 2014; Ogolo and Onyekonwu, 2015; Edino, *et al.*, 2010; Giwa, *et al.*, 2016; Ite and Ibok, 2013; Olujobi, 2020; Anosike, 2010; Nkwocha and Pat-Mbano, 2010; Dung, 2008; Mrabure and Ohimor, 2020; Ighalo, *et al.*, 2020). A recent study, (Calel and Mahdavi, 2020), puts this figure at 16% of global flared gas with the economic annual loss still at \$2.5 billion meanwhile Nigeria remains among the poorest countries with more than half the populace living below US\$ 2.0 per day, (Maduka and Tobin-West, 2017). As at 2004, Nigeria alone contributed 14% of the 160 bcm of gas flared globally, making her the second behind Russia in gas flaring (Giwa, *et al.*, 2014; Ukala, 2010; Ogolo and Onyekonwu, 2015; Giwa, *et al.*, 2016; Osuji, and Avwiri, 2005; Anejionu, *et al.*, 2014; Onyejekwe, 2013). Instead of second position, other researchers (Mafimisebi and Nkwunonwo, 2014; Adoki, 2012; Emoyan, 2008; Ana, 2011; Inumidun, *et al.*, 2021), have placed Nigeria as the number one gas flare country contributing roughly 19.79% of the total global quantity and 46% of African flared gas per ton of produced petroleum crude oil. With Nigeria leading the flare table with 24.1 bcm behind Russia at 14.7 bcm, yet six out of the first 20 highest farers were African countries. It has been reported that, Nigeria flares 42.6% of her gas, Equatorial Guinea, Angola, Gabon, Congo and Algeria at 94.9, 80, 66.7, 16.9 and 2.3% respectively on same chart with the UK and USA at 1.7 and 0.4% respectively (Oni and Oyewo, 2011; Adekomaya, *et al.*, 2016). This also indicates that before 2004, Nigeria has already flared about 76% of her produced gas at the rate of about 70 million/m³ per day (Emoyan, 2008; Orimoogunje, 2010). This 42.6% lost as an asset daily is enough to meet the electric energy needs of the country with more to lend to neighbors. Despite the gas reserves enough to generate constant electric power supply, within massive industrialization and increasing socio-economic developments, the citizens were left with no option than self-auto-generation sets and electric power plants which also contribute to downstream emissions. Apart from gas flaring and private electric power generation, illicit refineries, oil spillage, pipeline leakages and explosions have also submitted their quota to the total anthropogenic emissions in this region without successful control measures. Worst still, the state of road network, presence of adulterated fuel and number of malfunctioning vehicles on the road as well as heavy road traffic and indiscriminate

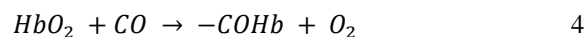
disposal of used vehicle oils have contributed immensely to pollutant saturated atmosphere (Ana, 2011; Osuji and Avwiri, 2005; Zitte, *et al.*, 2016; Marais, *et al.*, 2014). A report, (Zitte, *et al.*, 2016), showed that improper disposal of used oil can pose lethal effect than oil pollution as one gallon of it can contaminate one million gallons of fresh water. Apart from being a colossal waste, the natural gas meant to be put in useful values has turned the Niger Delta into civil unrest, socioeconomic devastations, ecological degradation as well as the global threats of climatic changes and global warming (Giwa, *et al.*, 2017). Although the opinions of previous studies have differed on the link of these effects with the political and security instability in the Niger Delta region, yet, it is imperative that socioeconomic and cultural heritage in the area have been adversely affected. While reports claim that it will take up to 30 years to detoxify the Ogoni area of the Niger Delta, (Uwagie-Ero, 2015), yet more anthropogenic emissions are introduced into the environment extending both the degree of damage and the hope of restoring normalcy. Pertaining to perceived injustice, human security is not restricted to an individual's freedom to movement. The Niger Delta residents are subjected to other severe human security threats like instabilities to daily routine life whether in their homes, source of income or as a community as well as threats of hunger, diseases and natural tragedies. Attention has been drawn to these threats to life as they can wipe out an entire community even more than war, genocide and terrorism put together, (Ololube, *et al.*, 2013). Therefore, there is an urgent need to rehabilitate the Niger Delta as the people have lost confidence in the leadership to the extent that even best intentions have always been misunderstood (Emoyan, 2008). This can be seen in a common practice where different sets of youthful groups demand royalties from contractors before commencement of any industrial activity believing that all projects in the area have political interests alone.

Health Implications: In the Niger Delta region, residents have been striving with the flaring of crude oil associated gas which is heavily laden with CO, CO₂, SO₂, NO₂, soot enriched with Black Carbon (BC), hydrocarbons and polycyclic aromatic hydrocarbon (PAH) alongside noise and heat (Emam, 2016; Giwa, *et al.*, 2017; Nwosisi, 2021; Fawole, *et al.*, 2019; McEwen and Johnson, 2012), which are all detrimental to the ecosystem. Records (Nwosisi, *et al.*, 2019; Obi, *et al.*, 2021a; Giwa, *et al.*, 2017) show that short time human exposure to NO₂ can cause breathing complications, increased exacerbation of asthma and other respiratory morbidities. Residents exposed to other gas flare pollutants are noticed to suffer different

levels of hematological, skin and eye deteriorations. Other health issues associated with flared gas which have been reported in Niger Delta includes blindness, aggravated Asthma, Chronic Bronchitis, Cancer, Leukemia, reduced lung function, Pneumonia, impotency, miscarriages, stillbirths and other reproductive disorders as well as dysfunctional immune system (Mafimisebi and Nkwunonwo, 2014; Oni and Oyewo, 2011; Emam, 2016; Ana, 2011; Anosike, 2010; Osuoha and Fakutiju, 2017). The noise and heat have become major causes of insomnia and heat rashes respectively in addition to disruption of wake-sleep rhythm of residents especially those at close proximity to flare facilities (Ekpoh and Obia, 2010). In addition to gas flaring, oil spillage causes bioaccumulation of trace metals and the health effects of consuming intoxicated seafoods can lead to severe poisoning, nephrotoxicity and neurotoxicity, (Zabbey, and Babatunde, 2015). Gas flaring has been suspected to affect the unborn children (Adekomaya, *et al.*, 2016), through transferred toxicities. Even in the US, Unconventional oil and gas practices has been linked to adverse effects on fetal development and neonates (Cushing, *et al.*, 2021). In unborn and newly born babies, apart from child malnutrition and premature births, epidemiologic evidence indicates that newborn babies from pregnant mothers with moderate doses of Carbon monoxide (CO) were at higher chances of underweight and higher risks of premature death. This was due to fetal toxicity of CO occurring even when maternal absorption of CO was still at low doses. Death of Neonates has been placed at a child mortality of 16,000 babies dying within the first month after birth while adult life expectancy in the Niger Delta has been cut down to 45 years or even less, (Stork, 2014; Ratcliffe, 2019) against the national average of 55 years (Ebeku, 2020). Fetal toxicity of CO was evident (Payne-James, 2016) as confusion, cerebral edema, excessive heartbeat (tachycardia), unusual fast breathing, (tachypnea) and bluish skin due to insufficient oxygen in the blood (cyanosis) in the unborn baby. It was also linked to personality and behavioral deficits in young people with maternal CO toxicity. Diseases and organ failures attributed to gas flaring in the Niger Delta includes kidney failure, diabetes as well as Alzheimer's and Parkinson's diseases (Ratcliffe, 2019).

Epidemiology of oxides of carbon inhalation: The toxicokinetic of Carbon monoxide inhalation which is one of the dominant gas flaring emissions shows that when the gas exchange region of the respiratory track absorbs inhaled Carbon monoxide, a part of it is bound to myoglobin. Significant amount of CO bound to myoglobin reduces the oxygen carrying capacity of the blood, muscular hypoxia, tissue oxygenation to the

heart and myocardial destruction. However, more of the inhaled CO are reversibly distributed to hemoglobin (Hb) in the red blood cells as (Payne-James, 2016):



Since the relative affinity of CO for Hb is higher by 200 to 250 times than that of Oxygen, it can easily displace Oxygen in the blood to form Carboxyhemoglobin (COHb), (Stork, 2014; Payne-James, 2016). Consequently, this ends up in hypoxemia, tissue hypoxia and when the COHb is circulated within the body it causes Asphyxia. CO poisoning targets mostly organs with high oxygen demand such as the heart and central nervous system leading to dizziness, loss of coordination and headache as well as delayed neuropsychiatric sequelae (Stork, 2014; Payne-James, 2016; Lee and Bye, 2019; Betterman and Patel, 2014). Since CO health problems are dose dependent, the inhalation at low concentrations can cause fatigue even in healthy people while at higher quantities it can lead to reduce blood supply to the heart (myocardial Ischemia), irregular rhythm of the heart (cardiac dysrhythmia), lethargy (physical and mental dullness) due to carbon monoxide induced fatigue (Stork, 2014; Payne-James, 2016; Lee and Bye, 2019; Betterman and Patel, 2014). In addition, spasm (seizures), coma and death as well as visual, auditory and memory losses mainly due to the destruction of the hippocampus has also been linked to Carbon monoxide poisoning. The challenging part of COHb formation according to Fawole, *et al.*, (2019), lies in the body's difficulty of early detection and the complexities of its clinical diagnosis since it has similar coloration with the host (red blood cells) (Stork, 2014; Payne-James, 2016; Lee and Bye, 2019; Betterman and Patel, 2014).

Correlation between GHGs and global warming: There is a direct link between GHGs and global warming. When the sun emits solar radiations through light and heat energies into the earth as visible, ultraviolet and infrared rays, parts of these rays are reflected back into space by the ozone layer to protect the earth. The part of the rays penetrating the earth surface are meant to be partly absorbed and partly reflected back into space but a gaseous blanket of GHGs traps some of the reflected rays and remit it into the earth to maintain warmth until the next sunshine. Without this, extreme cold and freezing would set in especially at night. These gases were named greenhouse gas similar to the horticultural technology where a glass house was used to transmit light but reserve heat energy from the sun for plants to grow in otherwise cold environment. This greenhouse effect

has been altered by anthropogenic GHGs in which their concentration has exceeded the natural greenhouse gas budget leading to excessive gaseous blanket that absorbs and emits more than required. This higher heat balance of the earth is causing extreme warming called global warming (Kaladumo and Ideriah, 2014; Abdulkareem, *et al.*, 2012). Global warming has caused globally detrimental effects like climatic alterations, excessive storms and flooding, significant melting of snow and ice into water that consequently increase sea level and temperature. Projected impacts suggest loss of biodiversity and sinking of shoreline human habitats (Emoyan, 2008), in which Niger Delta as a coastal region is a potential candidate. Apart from reducing the emission of GHGs, planting of trees which absorbs CO₂ as a major component of the greenhouse gas is another approach of controlling global warming. However, gas flaring systems displaces forest trees and releases GHGs into the atmosphere which are two fundamental causes of the greenhouse blanket enrichment leading to global warming. It has been warned (Rahimpour, *et al.*, 2011), that GHG emissions will certainly increase the more, looking at the rate of global population growth and industrialization that raises downstream emissions. Release of anthropogenic GHGs from both burnt and residual flared gas byproducts such as CH₄, CO_x, SO_x and NO_x raise the GHGs concentration above the natural budget which mankind is currently paying for as global warming. This global pandemic has led to undue melting of Greenland and Antarctic ice consequently leading to global changes of ocean levels and circulation as well as sea-surface temperature and acidity (Abdulkareem, *et al.*, 2012; Nwanya, 2011; Uwagie-Ero, 2015).

Effect of gas flaring facilities' proximity: Several health challenges have been reported from people living in close proximity to flare stations. For instance, it was observed in (Maduka and Tobin-West, 2017), that there is 1.75 likelihood for hypertension in residents living in the communities hosting gas flare stacks than those living in communities further away. Typical morbidities in form of skin outgrowths, respiratory disorders and diseases were statistically significant among residents surveyed in a highly industrialized community *viz a vis* air polluted area relative to a less industrial neighborhood. Same way, the effect of close proximity to flare stacks was evident from the study by (Ana, 2011). when the flared gas contents were recorded at Port Harcourt Refinery as PM₁₀ of 130.3 g/m³ which is higher than the stipulated 100µg/m³ limit from Federal Ministry of Environment while there was 81.3 g/m³ at the Eleme Petrochemical complex within the same city. Also, the heavy metal (Pb and Ni) levels were at 0.20 mg/m³ and 0.86 mg/m³

respectively at Port Harcourt Refinery with 0.16 mg/m³ and 0.05 mg/m³ at the Eleme Petrochemical complex. This shows the concentration of emissions closer to the flare zone relative to distances further away. Similarly, as the flared gas contents are proven carcinogens (Edino, *et al.*, 2010), such as Benzopyrene and dioxin (Anosike, 2010), study by (Nkwocha and Pat-Mbano, 2010), within the vicinity of flare stacks, highlighted higher health cases like 8 cancer cases, 49 untimely deaths and 120,000 hits of Asthma. In addition, microclimatic condition stimulated by proximity to gas flaring sites affects soil fertility and was evidenced in (Odjugo and Osemwenkhae, 2009). Their study noticed a reduced maize yield by 58.2%, 70.2% and 76.4% as distance from flare stack reduced from 2Kilometer (km), 1km and 0.5km respectively. This agrees with previous recommendation (Osuoha and Fakutiju, 2017), prohibiting maize cultivation near the bund wall of flare sites within 2 kilometers radius. Besides, as the heat energy generated and the acid rain showers affects soil moisture content to a great extent, findings, (Onyejekwe, 2013; Nwaugo, 2006), indicate a severe ecological and bacterial spectra alteration. Their findings demonstrated a reduced Total Coliform Count (TCC), Petroleum Degrading Bacterial Count (PDBC) and Total Heterotrophic Bacterial Count (THBC) towards the bund walls of flare sites.

Millennium development goals (MDGs) and gas flaring: All of the eight (8) Millennium Developmental Goals (MDGs) (Giwa, *et al.*, 2016), affect the Niger Delta which ranged from poverty, quality education, human capital empowerment, child mortality, health, disease control, environmental sustainability and global development. These have been significantly desecrated by the upstream and downstream crude oil exploitation and effects of pollutant gas emissions in particular. Despite the impressive impact of gas utilization at the Niger Delta on the amount of flared gas in response to MDG goals especially the environmental sustainability initiatives, there are still threatening concerns as gas flaring with its effects are still in progress. These calls for relentless efforts to continue the zero-carbon emission global campaign. Even as the Global Gas Flaring Reduction Partnership (GGFR) of the World Bank (The World Bank, 2020a), sets "raising awareness" as one of the measures to identify solutions to routine flaring of natural gas. This study joins the anti-flare campaign by contributing to the continuous sensitization of the gas flare status and the harm done so far.

From Willink commission to NDDC, failed measures to environmental sustainability: The agitations for environmental sustainability, *inter alia*, socioeconomic and infrastructural development in the

Niger Delta in both peaceful and militant confrontations dates back from colonial to democratic Nigeria. Historically, (Efebeh, 2017; Otega, 2015; Omotola, 2007; Okolo, 2014), this started in 1956 when Harold Dappa-Biriye was sent by the Rivers Chiefs and Peoples Conference to present the need for an Oil Rivers State to the pre-Independence Constitutional Conferences in London. The presentation led to the colonists establishing the Henry Willink's Minorities Commission of Enquiry which confirmed that the region was actually impoverished, undeveloped and disregarded in Nigeria. The Harold's struggle and Willink Commission's recommendation led to the 1959 creation of the Niger Delta Basin Development Authority (NDBDA). More (Ehirim and Abbey, 2016) river basin development authorities, (RBDAs) were launched in 1978 by the General Obasanjo's military government with less funding of the NDBDA. Apart from funding, political interests among other factors ruined the agencies' mandates until the civil war led to reduction of the 50% derivation to 20% before a total withdrawal of the derivation leading to its final collapse. Next intervention through President Shagari's democratic dispensation brought the Revenue Act with a Presidential Task Force to manage a 1.5% derivation to the development of the Niger Delta, (Ogundiya, 2009). The agitations remained due to unfruitful impact attributed to low funding and wide distance between the people and the administrative office at Lagos. The funding was raised to 3% in 1993 by the General Babangida's military government with the establishment of the Oil Mineral Producing Areas Development Commission (OMPADEC). The OMPADEC had laudable mandates to remediate and rehabilitate the ecologically dilapidated region due to gas flaring, oil pollution and spillages with projects mutually consented between the agency and Niger Delta communities. The persistent failures of the commission led to creation of the Niger Delta Development Commission (NDDC) by the President Obasanjo's democratic tenure in 2000. Instead of a lasting solution, the NDDC still became a shadow of itself.

In fact, it can be seen that these interventionist measures in different platforms of colonial, military and civilian governments right from Willink's Commission to NDDC have failed to address the agitations for environmental sustainability, socioeconomic and infrastructural development in the Niger Delta from 1956 until today, (Omotola, 2007). It is widely reported that the NDDC in particular has grossly failed like its predecessors (Ebeku, 2020; Okolo, 2014; Isidiho and Sabran, 2015; Ebeku, 2008; Eni, *et al.*, 2017), making it a mere change in

nomenclature to its failed defunct pioneers (Efebeh, 2017). Hence, there is no hope that another change of name will be different since the major problems of the Niger Delta region being gas flaring, oil spillage, *inter alia*, negligence remained without any recorded success (Ebeku, 2020; Eni, *et al.*, 2017). Questions have been raised that why the speed used to develop Lagos and Abuja cannot be deployed to develop the Niger Delta. The factors that configured the NDDC for failures includes no community participation in project conceptualization and execution making the projects absolutely useless to the people it is meant for (Uwagie-Ero, 2015; Omotola, 2007). Others are deficient political will to develop the Niger Delta, corruption, conflict of interest, lack of adherence to its master plan, few cases of environmentally sustainable projects instead of being major emphasis, use of incompetent contractors, lack of adequate project monitoring and evaluation, political dominance on the agencies, inflated overhead costs, misappropriation and mismanagement of funds (Ebeku, 2020; Isidiho and Sabran, 2015; Ebeku, 2008). To show that the NDDC was built to fail, the people at community and state levels have no power to appoint a member of the NDDC leadership which forces the board members into political patronage without objections leaving behind their statutory obligations and fast deteriorating status of the region (Ebeku, 2020). In reply to the NDDC's claims of underfunding, President Buhari's response "*You just cannot say you spent so much (sic) billions and when the place is visited, one cannot see the structures that have been done*". In addition, the SPDC's claimed huge remittals were not contested by the NDDC leading to the President Buhari's order for a forensic audit of NDDC from 2001 to 2019 (Ebeku, 2020).

Constraints to realistic anti-flare deadlines: Nigeria flares the largest quantity of natural gas globally (Oni and Oyewo, 2011) with all measures aimed at harnessing this natural resource for electricity and other forms of utility values facing several constraints. Legislation has been driving the stop-flare campaign as gas flare was declared illegal since 1984 emanating from the first zero-flare target date enshrined in the Associated Re-Injection Act of 1979. Despite that gas flaring reduction is economically practicable, certain exemptions and the insignificant levy charged as penalty (US\$0.003 per million cubic feet as at 1984 and US\$ 3.5 per 1000 standard cubic feet in 2008) have encouraged corporate defaulters to flare with minimal remorse (Ukala, 2010; Olujobi, 2020; Osuoha and Fakutiju, 2017; Maduka and Tobin-West, 2017). Like in the USA, unregulated practice is a major cause of flare hazards since the reported data is usually less than actual records (Cushing, *et al.*, 2021). In the

Nigerian case, there is an uncertainty on the actual quantity of oil and gas produced annually due to wide margins between produced and announced figures (Efebeh, 2017; Akpomovie, 2011). This has been linked to corruption to the advantage of some stakeholders. Based on this, the realities of reducing the carbon debt accumulated over the years has been elusive.

Another root cause of the delayed abatement of gas flaring can be traced to deficient political will of the government to enforce the anti-flare deadlines in addition to suspected conspiracies with the multinational oil companies to give precedence to economic profit over environmental sustainability (Oni and Oyewo, 2011).

In addition, the role of the court has been faulted over a long time which can be linked to their lack of autonomy from other influences. Jules Lobel's Model (Ukala, 2010) sees the court as a forum for protest and a tool for social change permitting the court to be an unbiased arbitrator on social justice like ecological status of the environment. However, the absence of judicial independency has led to shortcomings of this mandate with a typical example being the Mr Jonah Gbemre lawsuit of 2005 to stop gas flaring. This report, (Ukala, 2010), shows that as immediate as one of the major oil companies violated the anti-flare court orders, the trial judge over the case was transferred out of the judicial district and the case file was reported lost. This was likely a strategy to suspend the case followed by the military detention of the plaintiff, Mr Jonah Gbemre.

Technically, the top five countries in gas flaring Russia, Nigeria, Iran, Iraq and Algeria are also top-rated in political instability and corruption, (Calel and Mahdavi, 2020), making anti-flaring policies difficult to regulate and implement. The Nigerian government has actually instituted policies at different occasions to extinguish the gas flaring without realistic results making the exactitude that government's priority of economic proceeds over quality life at the Niger Delta more factual than indicting. If this is contested, why can't the same strategies used to increase oil production not being deployed to reduce flaring or better still used to diversify gas utilization. Despite government's negligence on the human integrity at the creeks, the dishonesty among operating oil companies in the region is another hinderance to prospective end to gas flaring (Oni and Oyewo, 2011; Udoekem, 2013; Osuoha and Fakutiju, 2017). Despite these waste gas recovery projects with operative gas master plans for a sustainable energy mix for Nigerians, bureaucratic bottlenecks on policymaking, regulations, enforcements and flare-out deadlines have

created a gap between the expectations and realities. Even as more gas is flared in Nigeria than any other place in the world (Ogbe, *et al.*, 2011; Akpomovie, 2011; Oni and Oyewo, 2011; Tawari and Abowei, 2012; Anosike, 2010; Nwanya, 2011) showing her enriched natural gas reserves and potential benefits yet the country is among the 30 poorest nations with more than average of her citizens living below poverty line (Ukala, 2010; Nwanya, 2011).

Role of government in abatement of the gas flaring:

The strategic measures to stop-flare deadlines have been following gradual processes since strict regulations to flaring can drive the oil companies into unintended venting. Venting must be avoided because the intricacies of detecting gas venting is high compared to flaring. On the other hand, the lethal consequence of venting is so ruthless that in every metric ton of methane vented there is an equivalent global warming tendency of up to 20 years spread of 86 metric tons of CO₂ (Calel and Mahdavi, 2020; McEwen and Johnson, 2012). The only way Nigeria has been recuperating from this colossal loss due to flaring of a supposedly valuable gas is by converting the associated gas into products of benefit (Fagbami, *et al.*, 2015). In modern technology which Nigeria has been taking part in, petroleum crude oil's associated gas is recovered for several uses such as for electric power generation, conversion into Liquified Natural Gas (LNG), production of byproducts like plastics for petrochemicals, fertilizer for agriculture, fabrics for textile and feedstock for allied companies. Also, the recent sequestration technology has been used in Carbon Capture and Storage (CCS) where the associated gas can be mineralized by isolating and compressing it before it is injecting into geological formations like saline aquifers, deep coal beds, oil and gas reservoirs for future recovery when needed. Hence, gas flaring can only be allowed as a safety measure to dispose associated gas or to relieve built up pressure during emergency, testing or equipment failure (Emam, 2016; Edino, *et al.*, 2010; Chang, *et al.*, 2017; Fagbami, *et al.*, 2015).

Apart from encouraging the LNG project, alternative technological approaches like gas turbine commercialization for electric power generation and/or improved oil recovery through sequestration have been suggested by several studies (Emam, 2016; Edino, *et al.*, 2010; Anosike, 2010; Orimoogunje, 2010). Much credit has been awarded to the several efforts to diversify Nigerian gas to products of value. For instance, the Bonny Liquified Natural Gas (LNG), Brass LNG, Olokola LNG, OSO NGL project, Extravos Gas Project, Extravos Gas to Liquid (GTL), Belema Gas injection project, Trans-Sahara Gas

project, Gbaran-Ubie Integrated oil and power, Afam Integrated Gas and power project as well as the Ajaokuta-Abuja-Kaduna and Aba-Enugu-Gboko Pipeline networks to distribute domestic consumption of natural gas for power generation (Ogbe, *et al.*, 2011). Despite the failures of the established interventionist agencies like the NDDC, (Emoyan, 2008), the statutory obligations of such agencies have raised the Niger Delta's level of social inclusion and human capacity development. Though some researchers (Ogolo and Onyekonwu, 2015), have expressed doubt to the possibility of gas flaring eventual phase out based on the inconsistencies to Nigeria's carbon footprints, between 2010 to 2013, the Nigerian government recorded reductions in flared gas with 540 bcf (billion cubic feet) and 428bcf in 2013, (Maduka and Tobin-West, 2017). Also, despite about 91.13% increment in the volume of natural gas production between 2001 and 2016, further reduction in volume of gas flared has been recorded at 38.06%, (Ighalo, *et al.*, 2020). An additional reduction from 7.31 bcm in 2016 to 7.83 bcm in 2019 shows a remarkable 7.11% reduction in gas flaring volume. Also, recently, out of the 150 bcm of global gas flared in 2019, Nigeria flared 7.83bcm while the former contender Russia flared 23.21 bcm. This has placed Nigeria at the 7th position behind Algeria, Venezuela, Iran, the United States, Iraq and Russia in the increasing order of volume of gas flared in 2019. knowing that oil and gas exploitation of this riverine countryside has caused rapid depreciation of its environmental qualities especially by turning arable land and fishing waters unproductive as well as the atmosphere that has received up to 350 million tons of CO₂ as at 2018 (Akinwumiju, *et al.*, 2020; Ozigis, *et al.*, 2019; Edegbene, *et al.*, 2021; Motte, *et al.*, 2021), then, the rising hope from the above achievements has to be sustained. In fact, there are signs of hope for further reductions in volume of gas flared as the billion cubic meters flared in the first quarter of 2020 has already fallen by 10% across the first 30 oil producing countries with Nigeria inclusive, (The World Bank, 2020b). This is a welcomed development that must be both encouraged and sustained which can be attributed to commercialization of the Nigerian flared gas, reduced air pollution and job creation in the Niger Delta.

Suggestions for substantial sustainability of the Niger Delta: As the need for a sustainable environment at the Niger Delta attract increasing global concern, there will be a climatic justice and zero-carbon footprint in the region if the following recovery measures are considered:

1. The government as the chief custodian of the national economy should diversify into alternative

energy resources so as to decongest the overdependence on fossilized fuel that raises the carbon debt.

2. There should be maximum commercialization of the natural gas with a national grid that spreads across the country to meet both domestic and industrial energy demands.

3. An investment in export potentials of natural gas as a means of foreign exchange should be extended to the global market in full capacity.

4. It will make economic sense and provide employment opportunities if attention will be devoted to science and technological advancement of the natural gas utilization and sequestration.

5. Bilateral relations with countries in need of the natural gas in exchange of basic needs of Nigerians should be established for shared prosperity within the global community.

6. There is also the need for economic empowerment and environmental rehabilitation of this region for agriculture and fishery so as to foster self-reliance of the Niger Delta residents.

7. It is also a necessity to promote peace, social inclusion and political stability in the Niger Delta which will proffer effective governance to the grassroots for sustainable environment.

8. To offset the constraints facing effective realization of anti-flare deadlines, a need to redesign the policies into enforceable and practicable dimensions should be embarked on.

9. The government should also desist from monetizing the violations as fines and carbon tax rather stringent measures like confiscation of operating licenses should be considered.

10. Global partnership in line with the MDGs should be reviewed for practicability towards the targeted beneficiaries cutting across the biotic and abiotic components of the environment.

11. Global climate treaties that address eco-friendly best practices to the grassroots of emission sources and enforcement of existing ones should be embarked on in the Niger Delta.

12. The court and enforcement agencies should be granted autonomy and their recommendations should be acted on without bias, undue influences and selfish interests.

13. Downstream emissions should also be monitored and reduced by encouraging the reuse, recycle and reduction of wastes in industrial production lines that pose environmental threats.

14. There should be a focus on the reduction of downstream pollution levels from vehicles, industry and domestic burning of timber to permissible levels. This can be done as a federal road safety regulation where annual testing of motor vehicles' emissions

should be considered as a part of road worthiness and for issuing or renewal of driving license.

15. Pollution and GHG monitoring stations should be established especially close to the point of emissions in the Niger Delta equipped with state-of-the-art devices for acquiring primary data for environmental protection policy making.

16. Policy makers should handle with caution the data they use in simulating ecological protection models as some of the data may have been biased hence are not be true reflections of reality.

17. Partnership with the academia in research and development is highly recommended. Empirical analysis and pilot testing at laboratory scales to these alternative energy sources are needed.

18. The national university commission should mandate all universities in the Niger Delta to run courses on environmental protection and engineering up to accredited standards.

19. In a computerized generation, the use of modelling and simulations should be intensified in researching into the solutions to gas flaring and reduction of Nigeria's carbon footprint.

20. Environmental quality assessment and studies have focused mainly on urban centers, there is need for baseline studies at the remote and underdeveloped areas of the Niger Delta. With these, the outcry of perceived injustice and marginalization that led to restiveness, terrorism and kidnapping for ransom will be withdrawn.

Conclusion: This study focused on the environmental sustainability of the Niger Delta region. Detrimental effects linked to the thermal, acoustic, and photogenic and GHG emissions from the flared gases comprised global warming, wildlife extinction, loss of biodiversity, infertile soil, intoxicated aquatic life, acidified rain, seawater and coastal aquifer as well as corrosion of roofing sheets and chronic human health challenges. The reasons why anti-flare policies failed their objectives were discussed with highlights of the recent achievements of the MDGs and LNG master plans.

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