International Journal of Development and Sustainability
ISSN: 2186-8662 – www.isdsnet.com/ijds
Volume 10 Number 5 (2021): Pages 182-199
ISDS Article ID: IJDS21072801

Impact of greenhouse gases emission on sustainable economic development of the Niger delta region

Endurance Oriakhi *

School of Law, Business and Social Science, Abertay University, Dundee, United Kingdom

Abstract

Continuous release of greenhouse gases (GHGs) from anthropogenic sources in the Niger Delta into the atmosphere adversely affects the social, economic and environmental well-being of the ecosystem. The primary objective of this study is to use data on flared gases obtained from emission inventory for the Niger Delta region (NGR) towards evaluating the impact of GHGs emissions on sustainable economic development of the NGR. Empirical formula, as well as emission factors collected from existing literature and secondary data sourced from the Nigeria National Petroleum Corporation, was used to estimate GHGs and black carbon inventory for the region. Out of 555.74 billion cubic metres of gas flared between 1990 and 2014, an estimated 1.80 × 109 tonnes of Carbon (IV) Oxide equivalent was released to the atmosphere. Emission uncertainty measured in relative terms was between –92.2% and 51.16%. The emission volumes reduced by 49.71% in 2014 to 3.61 × 107tCO_2 e relative to the volume of emission in 1990. The findings also demonstrate that the commendable success made by the country in reducing greenhouse and black carbon emissions has been driven by improved gas utilisation nationwide, which directly reduces the volume of gas flared amid oil companies' activities in the region.

Keywords: Greenhouse Gases; Black Carbon; Sustainable Economy; Niger Delta

Cite this article as: Oriakhi, E. (2021), "Impact of greenhouse gases emission on sustainable economic development of the Niger delta region", *International Journal of Development and Sustainability*, Vol. 10 No. 5, pp. 182-199.

* Corresponding author: *E-mail address: endurenosa@yahoo.com*

1. Introduction

Greenhouse gases (GHGs) are defined as gases capable of infrared absorption leading to atmospheric trapping of heat (Oguwuike et al., 2019). These gases directly increase atmospheric heat and are greatly responsible for greenhouse effect with results in global warming. The causes of greenhouse effect can be directly attributed to natural or biogeographical processes (such as respiration of living plants and animals) as well as anthropogenic processes or activities such as fossil fuel use, deforestation, synthetic fertiliser use, intensive farming and many industrial processes. Other causes are largely extraterrestrial factors such as solar radiation quantity (sunspot), solar radiation quality (ultraviolet radiation change), volcanic eruption and meteor. However, the largest source of GHGs emission from anthropogenic processes or activities is from burning fossil fuels for electricity, heat and transportation (Intergovernmental Panel on Climate Change, 2001). Another notable contributor is debris burning by subsistent and commercial farmers.

GHGs are capable of intercepting radiation and radiating them back to the earth's surface at different wavelengths. On the earth's surface, these GHGs are also responsible for regulating temperature. There are majorly exists five forcing GHGs (Carbon (IV)Oxide, Methane, Nitrous Oxide, Water vapour and Fluorinated gases) (Gray, 1990), all of which have natural and anthropogenic sources of emission, but anthropogenic sources outweigh natural sources in terms of emission (Intergovernmental Panel on Climate Change, 2011). The mean warming effect of GHGs is about 33°C (590F) (Intergovernmental Panel on Climate Change, 2007).

The greenhouse effect describes the process of absorption and emission of radiation from infrared rays by gases in the atmosphere leading to increasing levels of warmth in the atmosphere and on the earth surface (Odigure, 2003). Stated simply, it is basically maintaining the temperature of surface air by atmospheric components by absorbing radiation and inhibiting the escape of same in similitude to a glassed roof and greenhouse walls. However, scientists first used the phrase (Greenhouse effect) early in the 19^{th} century but were used to refer to natural occurrences related to atmospheric trace gases without any inclination towards a negative implication.

Later in the mid-1950s, the phrase was attributed to concerns over climate alteration, but in contemporary decades it became established to negative terms. These negative terms were related to concerns over the improved greenhouse effect, but it was undeniable that life-forms on earth would be inexistent without the greenhouse effect. Regarding the greenhouse effect, the surface type that solar radiation strikes are the most determining factor. These surfaces include vegetation (forests and grasslands), the surface of water bodies, deserts and ice caps, but they all radiate, reflect and absorb differently. Rays of light falling on a white or opaque glacial surface are strongly reflected back into space, the resultant effect being minimum surface heating while rays of light falling on dark desert soils become absorbed strongly and contribute significantly to surface heating and lower atmosphere. The contribution of cloud or cloud cover to the greenhouse effect is noteworthy as it reduces the amount of solar radiation directed towards the earth surface as well as the energy radiated back into space (Ni et al., 2013).

Carbon (IV) oxide, such as most GHGs, acts like a thick covering or blanket, holding infrared radiation and preventing its release into space. The aggregate effect is the continuous heating of the earth's surface and its atmosphere, leading to global warming. Recent results revealed that Methane has a greater global warming potential than anticipated or expected, especially when considering its indirect effects on aerosols. It is a somewhat strong GHG compare to Carbon (IV) Oxide but has a relatively short ambient domicile time hence, greater effect on global warming (Intergovernmental Panel on Climate Change, 2007).

The concentration of GHGs in the atmosphere directly influences greenhouse effect as increasing concentration increase the earth's insulation ability (Shires et al., 2009). Water vapour contributes between 36 and 70% to the greenhouse effect (excluding clouds); Carbon (IV) Oxide causes about 9–26%, attributed to Methane is 4–9%, while Ozone causes about 3–7% greenhouse effect Gogoi and Baruoh, 2002). Other gases such as Nitrous oxide (N_2O) contribute less significant fractions to the greenhouse effect. The concentration of N_2O increases as a result of agricultural or farming practices

Pearson and Palmer, 2000 reported that atmospheric concentrations of Carbon (IV) Oxide (CO_2) and Methane increased by 31% and 49% respectively during the period succeeding 1750, with these levels being higher than recorded or experienced during the last 650,000 years, as evident from data extracted from ice cores. Deductively, less direct geological evidence revealed that CO_2 had a higher contribution to global warming about 20 million years ago (Pearson and Palmer, 2000), with the burning of fuels containing fossils producing three quarters to this increase in the last two decades while the remainder is as a result of changes in land uses (especially deforestation) (Intergovernmental Panel on Climate Change, 2001).

The emission of GHGs has a resultant effect on the economic activities of developed and third-world countries (Twerefou, 2017). In Africa, the primary sources of emission include (but are not limited to) Lumbering activities or deforestation, domestic use of fuelwood and consumption of charcoal, production of electricity and activities such as transportation and changes in land use. Globally, the specific effect of increases in emission of GHGs is global warming, with other effects being acidification of oceans, pollution by smog, depletion of the ozone layer and stunting in the growth of plants (Shindell, 2009).

In Nigeria, the prevalent use of hydrocarbon as an energy source has unquantifiable implications on socioeconomic activities and the biodiversity of life forms. Sustainable development in the economy is that which fulfils the desires of future generations and the current generations independently (Abubakar, 2013). The concept of sustainable development must be precise and concise and entails strategies as philosophy (which encapsulates vision about future societies and its nature), giving regard to basic needs of man, driving towards equity and justice of present and subsequent generations, putting economic and environmental factors into consideration and integrating both, attaining self-empowerment of humans and avoiding biodiversity loss (Dearden and Mitchell, 2009). Sustainable development can also be described as a product and as such ensures that economic, social and environmental aspects are synchronised and put into consideration, and gaps existing between economic, social and environmental systems are met, addressed, transparent and visible to all affected parties.

The process of improving the opportunity range of opportunities with the aim of enabling individuals and communities towards achieving their goals, expectations and maximum ability in a manner that nurture's assets for future generations. Every economy functions in an (eco) system, and this provides productive factors for fuelling economic growth. However, the manner and extent of exploiting or exploring these resources as well as the resultant pollution attributed to these processes make long-lasting changes of landscape and life-forms in the Niger Delta, causing harm and slowing or deterring the process of achieving sustainability (Nwilo and Badejo, 2008; Olaolu, 2008).

Despite these negative effects of the exploitation and exploration of resources in the Niger Delta region (NGR), the burden of these activities is rarely borne by individuals or corporate bodies responsible (Al Mamun et al., 2014), leading to the concept of a negative externality. Therefore, patterns that are unsustainable related to production and/or consumption of resources should be discarded as they ultimately culminate in an increase in natural disasters around the world, degradation in the environment and global warming (Onuoha, 2007).

The activities of the Multinational Oil Companies in the region, which have caused severe climate alteration, justified the selection of the region by this study. The Delta region is enriched with human, atmospheric, water, mineral and vegetative resources (Chinago, 2017), and the selective exploitation and/or exploitation of these resources have considerable economic gain that is capable of supporting human activities adequately. Without this selective exploration and exploitation, reduced yield, soil degradation and pollution become imminent as a result of continuous emission of GHGs through gas flaring, haulage of wastes into rivers, as well as increased social vices among residents of the NDR. Niger-Delta oil fields in Nigeria occupy roughly 70,000 square kilometres and are one of the world's largest wetlands, containing the country's known gas reserves, which are estimated to be 120 trillion cubic feet (Uyigue and Agho, 2005; Onyiah, 2005). While oil production and exploration have brought some fortunes to Nigeria and helped the country's economic and technological growth, the socioeconomic and environmental consequences have remained an issue in the Niger-Delta region (Akpan, 2009). The residents hold oil-producing companies operating in the region oil fields responsible for polluting the environment through continuous gas flaring and venting, heat radiation, noise radiation, oil spillage, water pollution, site clearing, deforestation and breakdown of flora and fauna, and ecosystem disturbances in the 70,000 square kilometre area (Ifeanyichukwu, 2002; Abdulkareem et al., 2010). This study, therefore, investigates the impact of greenhouse gas emissions on sustainable economic development of the NGR of Nigeria.

2. Review of literature

2.1. Theoretical framework

2.1.1. Neoclassical economic theory

Neoclassical economics is an economical approach focusing on the determination of goods, output or product and income distribution in markets through demand and supply mechanisms. This determination is often mediated through a hypothesised maximisation of utility or satisfaction subject to income constraints by individuals and profit constraints by firms (Weintraub, 1985).

2.1.1.1. Assumptions of neoclassical economics

There are many branches that use different approaches under neoclassical economics. All of the approaches are based on three central assumptions:

1. People are rational in making choices between identifiable and value-associated outcomes
2. An individual's purpose is to maximise utility, as a company's purpose is to maximise profits
3. People act independently on perfect (full and relevant) information.

With the fundamental assumptions above, various studies and approaches have been developed. For example, utility maximisation can explain the demand for a product or service. The interaction of demand and supply explains the pricing, and thus the distribution of production factors (Weintraub, 1985).

2.1.1.2. Key concepts of neoclassical economics

Neoclassical economics primarily concerns the efficient allocation of limited productive resources. It also considers the growth of the resources in the long-term. The growth will allow for expanding the production of goods and services. It emphasises that market equilibrium is the key to an efficient allocation of resources. Thus, market equilibrium should be one of the primary economic priorities of a government.

2.1.1.3. Neoclassical economic theory and sustainable economic development

Resource scarcity, resource allocation and optimal welfare are the cornerstones of environmental, economic analysis. Neo-classical economists interpret environmental degradation as a problem of allocation, and this has been a constant cause of debates and discussions over two decades. This reflects through continuous emphasis externalities and (optimum) welfare, optimal resource allocation and optimal growth or development, which gives an inclination that environmental problems such as emission of GHGs in the NGR are primarily examined within the framework of market equilibrium and externalities, with attention devoted to providing answers to the question "how a social optimum can be realised in a market economy with externalities."

At the heart of the neoclassical approach to environmental economics is the aim to turn the environment into a commodity that can be analysed such as any other commodity. The preliminary exercise is to break down the environment into its constituent goods and services. For example, wetlands provide a range of goods (such as fish, water and wood) and services (water filtration, water transport and climatic regulation). Once defined in commodity terms, the environment can be brought into the market economy by constructing supply and demand curves for environmental goods and services and inputting market prices. As a result, neoclassical economic theory is fundamentally unconcerned about the processes ensuring the reproduction of the environmental and material circumstances necessary for human existence (Luzzati, 2005). Economists, usually with an institutionalist background, who are interested in proposing alternative interpretations of economic action and questioning the paradigm of homo oeconomicus, have strongly criticised the neoclassical economic approach to environmental harm. Environmental degradation poses a theoretical issue for neoclassical economics, which has been openly accepted and researched (Martinez-Alier, 1987).

2.1.2. Empirical review

The decline of agricultural yield was examined by Obioma (1985) in Rivers State. Results revealed that warmth emanating from gas flares attracts swarms of insects from the woods at night, leading to the loss of vegetation by the insects. Ukegbu and Okeke (1987) considered the impact of gas flaring on growth, yield and productivity of chosen plants in the Izombe flow terminal in Imo State. Results obtained show that crops cultivated 200 metres from the flare sites experienced total crop loss; 45% crop loss was experienced in farm sites located 600 m from the flare, while at farm sites located 1000 metres from flares records only 10% loss in crop yield. Deductively, crop loss declined with increasing distance from flare sites.

Dosunmu and Amadi (1996) studied the gas flaring effect on the environment, and the result revealed stunted growth in maise planted in the direction of the flare. Results also revealed that a significant reduction was recorded in soybeans yield as distance to flare site increased. Gogoi and Baruoh (2002) considered the effects of natural gas flare on growth, flowering and rice yield close to an oil installation. Growth, flowering and yield were inhibited within 45 metres to glass flare points, and damage to rice was also intense with 30 metres from flare points, as revealed by results of the study.

Matthew et al. (2018) used autoregressive distribution lag to examine the effect of GHG on health outcomes in Nigeria using data obtained within 1985-2016. Results indicated that a unit percentage increase in GHG emission reduces life expectancy by 0.04%, leading to a 146.6% increase in mortality rate. Osabohien et al. (2019) studied the effect of GHG emissions on crops produced in West Africa using panel data obtained from 14 Economic Community of West African States member countries. From the econometric model constructed, the results of the analysis showed that crop production was reduced by GHG emissions at 0.13% as a result of lower crop yields.

Manasseh et al. (2019) used annual time series data covering the period between 1981 and 2014 and multiple regression analysis to investigate the impact of fluctuating oil prices and oil revenue on wellbeing in Nigeria. Exogenic variables for the regression model include exchange rate (nominal), consumer index growth rate and inflation lag period. Results indicated that fluctuations in oil prices do not significantly influence well-being while oil revenue has a significant direct effect on well-being. However, a long-run relationship exists between fluctuation in oil prices and well-being, as further revealed by the Johnson cointegration test.

Environmental pollution has transcended natural boundaries; stratospheric ozone depletion, global warming, the greenhouse effect, deforestation, acid rain and mega-disaster are some of the various environmental problems attributed to pollution (Nugraha and Osman, 2019). The potential effects of global pollution have necessitated global cooperation to secure and maintain a liveable global environment (Odjugo, 2010). It has been reported that pollutants emitted from one country can easily cross political boundaries. People are beginning to recognise that pollutants can affect not just a region but the entire planet. Modern industrial society creates far more Carbon (IV) Oxide (CO2) than what the planet vegetation can consume (Odigure and Abdulkareem, 2001). As the excess CO2 rises into the atmosphere, it acts as an absorptive body, which traps heat reflected from the earth surface. The most of the literature (Obioma, 1985; Gogoi and Baruoh, 2002; Manasseh et al., 2019) on climate change and GHGs emission focuses most of its attention on the decline of agricultural yield, impact of gas flaring on growth, yield and productivity of chosen plants, gas flaring effect on the environment and the effect of GHG on health outcomes in Nigeria, with little attention on the economic sustainability of the inhabitants of oil-exploring and production regions in Nigeria, this study filled the gap in the literature by exploring the direct impact of greenhouse gas emission on sustainable economic development of the NGR.

3. Methodology

3.1. Study area

The delta of River Niger (Niger Delta) sits directly on the Gulf of Guinea on the Atlantic Ocean in Nigeria. Extending over more than 2000 square miles, it makes up about 7.5% of Nigeria's landmass. The Delta of River Niger is located within nine coastal Southern States, including all states in the South-South geopolitical zone, Ondo State from the South-West geopolitical zone and Abia and the Imo States in the South-East geopolitical zone, with Akwa Ibom state being the only non-oil producing state. The NGR till 2000 previously consisted of Bayelsa, Delta and Rivers States, but subsequently, Bayelsa, Delta and Rivers States were added to the NDR.

Being Nigeria's largest wetland, ranked as the third-largest wetland in the world and having the world's second-largest mangrove forest, NDR has a population of over 40 million people (23% of Nigeria's total population) (National Population Commission, 2006). The population density of NDR is one of the highest in the world, with about 265 individuals per square kilometre. The NDR also encompasses major ecological zones such as freshwater, swamp, mangrove, creeks and estuaries.

3.2. Source and type of data

Press releases published on the Nigerian National Petroleum Commission (NNPC) website were used to gather data on the output of gas, flared gas and per cent flared gas in Nigeria (NBS, 2013; NNPC, 2010; NNPC, 2011; NNPC, 2012; NNPC, 2013; NNPC, 2014). Data on the amount of flared and produced gas were collected for 25 years (between 1990 and 2014), and the data were converted to million cubic metres (mcm) from million standard cubic feet (mscf), while the collected data were analysed with the use of Microsoft Excel (2013). For the 25-year period under analysis, the correlation coefficient indicating the relationship between gas produced and gas flared was estimated as well as the mean yearly volume for the flared and produced gas.

3.3. GHGs and black carbon emission reports

Emission factors and activity data were used to estimate pollutant emissions from their inventories (Zhou et al., 2014). Records of emission quantities into the atmosphere as a result of gas flaring activities are grossly inadequate in Nigeria, and this forms an integral element of the purpose of this paper. Hence, information gathered from the aforementioned bulletins for a period of 25 years was used in estimating the volume of CO_2, Methane, N_2O and black carbon emitted with the aim of indicating the country's progress regarding the environmental sustainability of the NDR. The volume of each GHG emitted was estimated using reported empirical methods by the Association of Petroleum Institute (API) for the oil and gas industry (Odukoya, 2006), while the volume of black carbon emitted was estimated using gas emission factor for flaring gas related to the heating volume of natural gas of Nigerian origin (McEwen and Johnson, 2012).

The system equations used for estimating emissions from gas flares are:

$$ECO_2 = (GF \times MW_{CO2} \times mass\ conversion \times (\Sigma\left(\frac{mole\ Hydrocarbon}{mole\ gas} \times \frac{A\ mole\ C}{mole\ Hydrocarbon} \times \frac{0.98\ mole\ CO^2\ formed}{mole\ of\ C\ combusted}\right) + \frac{B\ mole\ CO_2}{mole\ gas}) \qquad (A)$$

$$ECH_4 = GF \times CH_4\ mole\ fraction \times \%\ residual\ CH_4 \times \frac{1}{molar\ volume} \times MW\ CH_4 \qquad (B)$$

$$EN_2O = GP \times EFN_2O \qquad (C)$$

$$GHG\ emission = ((1 \times CO_2\ emission) + (21 \times CH_4\ emission)) + (310 \times N_2O\ emission) \qquad (D)$$

$$Emission\ factor\ (BC) = 0.0578(HV) - 2.09 \qquad (E)$$

$$E_{BC} = Emission\ factor\ (kg\ of\ BC/10^3 m^3)\ GF\ (m^3) \qquad (F)$$

$$E_{BC}\,(tCO_2e) = E_{BC} \times 900 \quad (G)$$

$$\text{Total Emission} = \text{GHG emission} + E_{BC}\,(tCO_2e) \quad (H)$$

Where E_{CO_2} = Carbon (IV) oxide emission in Kilograms
E_{CH4} = Methane emission in Kilograms
E_{N2O} = Nitrous Oxide emission in Kilograms
GF = Gas flared in Kilograms
EB = Black carbon emission in Kilograms
EB (tCO_2e) = Black carbon emission (tonnes of Carbon (IV) Oxide equivalent)
GHG Emission = Greenhouse gas emission (tonnes of Carbon (IV) Oxide equivalent)
Molar volume = Converted from molar volume to mass (23.685 m^3/kg/mole)
MW = Molecular weight of Carbon (IV) Oxide
Mass conversion = tonnes/1000 kilograms
A = representing the moles of carbon for the particular hydrocarbon
B = Carbon (IV) Oxide present in the flared gas stream (in moles)
% residual CH_4 = Noncombusted fraction of flared stream
MW = Molecular weight of methane; EF = Emission factor of Nitrous Oxide
GP = Gas produced in cubic metres; HV = Heating volume of natural gas

The formulation of crude oil reported from Nigerian origin established in literature was employed with heating capacity of natural gas from Nigeria origin being 52.46 MJ/m^3 (computed through heating amount of 37.23 MJ/kg) (Rahmouni et al., 2003).

3.4. Quantitative uncertainty analysis: Its procedure and methodologies

3.4.1. Procedures for uncertainty analysis

To estimate the uncertainty associated with total greenhouse gas emissions through gas flaring in the Niger Delta, data comparison or aggregation of the GP and GF volumes for output (Carbon (IV) Oxide, Methane, Nitrous Oxide, black carbon, GHGs and total greenhouse gas emissions) is the first step.

Establishing the model is the second step, and it involves empirical formulae use, such as provided in the set of equations provided above. Relevant parameters are selected, with some assumed to be fixed and having less uncertainty. To fit input, data for gas produced and gas flared into the reasonable probability distribution function, EasyFit® 5.6 (evaluation version) was used, and uncertainty in the emission estimate was modelled using Analytica® (4.5) software. Therefore, the models of the probability distribution of the input parameters (gas flared and gas produced) were established as inputs in the model. Probability distribution functions might be both empirical and parametric or either.

In summary, the technique encompasses establishing input models for produced and flared gases, propagating uncertainty from input parameters to model output estimated with either Monte Carlo simulation (MCS) or Latin hypercube sampling - a Tier 2 method suggested in 2006 Instructions for National Greenhouse Gas Inventories (Marland et al., 2014). Ultimately, quantitative estimates of the uncertainty associated with GHGs, black carbon emissions and aggregate emissions emanating from gas flaring should be made known.

3.5. Simulating uncertainty propagation methods

Latin hypercube simulation was adopted in this study for propagating probability distributions for all inputs by adopting a model based on a random sampling procedure. MCS method and Latin hypercube simulation method are the most common numerical methods for simulation (Giwa et al., 2016). The MCS method involves running a model multiple times employing dissimilar values for each uncertain input parameter per period. For each uncertain input parameter, values are randomly generated based on the probability distribution of the parameters. In the light of this study, Analytica® was used and minimal standard (the configuration technique was implemented as the random number generator. Advantages accruing to the use of the MCS method include but are not limited to its ability to afford laudable approximation of output distribution using representative sample size. A major drawback is the necessity of the MCS method is that it oftentimes becomes a necessity on using huge sizes of samples to produce a smooth or perfect estimation of the probability distribution function.

Contrastingly, for the Latin hypercube simulation method, values for each uncertain input are not generated randomly; rather, the probability distribution is firstly separated into an equal range of probabilities and afterwards, a sample is selected from each range (Lu et al., 2013). Lu et al., 2013 explained that for some applications for a specific simulation sample size, the Latin hypercube simulation method gives more precise numerical simulation than the MCS method. In the Analytica®, Due to its high precision, the median Latin hypercube is more common and is the reason why it is set as the standardised sampling method for this research.

3.6. Sensitivity analysis

Identifying the key causes of uncertainty in the developed model, sensitivity analysis was used. The results of this analysis would help decision-makers invalidating the primary influencers to uncertainty in the model outcome, and it would also help to decide whether additional data needs to be collected to reduce uncertainty in the model input. However, sensitivity analysis was employed in this research to confirm parameters that significantly affect greenhouse gas emissions through gas flaring in the input models.

4. Results and discussion

4.1. Generated and flared gas analysis

At the beginning of 1990, the volume of gas produced was 28.43 billion cubic metres (bcm), and it steadily rose to 59.28 billion cubic metres in 2005 (well over double its 1990 value). Around 2005 and 2007, substantial rises in the amount of gas output were also noted (84.71bcm), being the peak production year for the 25-year period. Gas production, however, declined considerably between 2007 and 2009 to (64.88 bcm) and slightly further decreased to 61.64bcm in 2013; a steep increase was reported in gas production in 2014 to 72.96 bcm. Over the period considered, a mean average of 52.02 bcm was reported.

With respect to gas flared, the volume for 1990 was reported to be 22.40bcm, increased steadily between 1999 and 2006 to 22.36 bcm and 25.58 bcm, respectively. The highest amount of gas flared was recorded in

2006, while 2014 had the lowest volume of flared gas (about 11.27 bcm), implying that a sharp decline was recorded between 2006 and 2014. The difference between the volume of gas flared in 1990 and 2014 was estimated to be 11.14 bcm, with the period between both years recording an average volume of 22.23 bcm of flared gases which have an adverse effect on the economic sustenance of the NDR.

Respectively, the aggregate of gas flared and gas produced for the total period under consideration in this study was 555.74 bcm and 1.30 trillion cubic metres. This indicates that indeed 57.26% of the produced gas was indeed flared, and in monetary units, annual gas flared amounts to about $2.36 Billion with $58.91 Billion ($3/1000 Standard Cubic Feet $0.106/cm) being the amount wiped up gas or gas flared in the 25-years under consideration.

By simple extrapolation, the observed difference between the volumes of produced and flared gas represents a measure of the utilised volume of gas. Considering the entire period under review, the peak volume of gas utilised was recorded for 2014, and it also documented the least volume of gas flared in contemporary memory. Pearson product-moment correlation coefficient estimated for data obtained for gas produced and gas flared was weak and negative (–0.36), indicating an inverse relationship between gas produced and gas flared. Deductively, as the volume of gas produced increases, the volume of gas flared decreases and vice versa. Furthermore, (ANOVA test) analysis of variance test performed on the data collected for gas produced and gas flared indicates that they are not statistically equal with (F-critical [4.052] being lesser than F-observed [70.982]), and a P-value of 0.001 at 95% confidence interval.

4.2. Emissions assessment from flared gas

The volume of GHGs and black carbon emissions through gas flaring operations in the NGR of Nigeria, which has gradually impeded the economic sustenance of its inhabitant, was calculated for the period under consideration. The volume of greenhouse gas emissions was calculated using the first four equations (A-D) specified above, while the volume of black carbon emissions was estimated using equations (E-G). The emission factor for black carbon was estimated to be 0.943 kilograms of black carbon per 103 cubic metres for gas flaring operations published in the literature (McEwen and Johnson, 2012), and this valuation is pertinently and particularly for this research paper.

4.2.1. Emissions of GHGs

From data showing the volume of distinct GHGs emitted from 1990 till 2014, gas flared indicates similar patterns for Carbon (IV) Oxide releases in the NDR. It is attributed to the positive relationship existing between the amount of flared gases and the volume of emitted Carbon (IV) Oxide (expressed in equation A). The volume of Carbon (IV) Oxide emitted was estimated to be 4.67 × 107 tonnes and 2.35 × 107 tonnes in 1990 and 2014, respectively, with 2006 having the maximum volume of 2.35 × 107 tons emission (5.96 × 107 tonnes). The total volume of CO_2 flared in the NGR was 1.16 × 109 tonnes between 1990 and2014. There exists a considerable reduction in CO_2 emissions by 60% from its peak volume in 2006 to its least value of 2.35 × 107 tonnes in 2014.

The result further shows that methane emissions occur in similitude to CO_2 emissions while the emissions of Nitrous Oxide for the considered period is dissimilar. The unique pattern indicated for N_2O emanates from Equation (C), which include estimating the gas produced parameter against gas flared for Carbon (IV) Oxide and Methane emissions provided in Equation (A and B). The volume of Methane (CH_4) flared in the NDR in 1990, 2006 and 2014 was 2.74 × 105, 3.49 × 105 and 1.38 × 105 tonnes, respectively. Considering Nitrous Oxide and the volume released 0.65 tonnes was released in 1990, it increasing to 1.95 tonnes in 2007 and gradually declined to a volume of 1.68 tonnes in 2014. 6.79 × 106 tonnes and 29.91 tonnes of Methane and nitrous oxide was the total emission recorded over the 25-year period.

The total volume of GHGs (1.16 × 109 tonnes of CO_2, 6.79 × 106 tonnes of CH_4 and 29.91 tonnes of N_2O) released in the NGR for the 25-year era was 1.33 × 109 tonnes of CO_2 precursor (t CO_2 e). The financial consequence of flaring 555.74 billion cubic metres of gas in the NGR in contexts of greenhouse gas emission levels was $19.94 billion (estimated $15/ton carbon credit tax), and the cumulated volume of GHGs as well showed a similar trend to the gas flared as well as other emissions reliant on the gas volume flared.

4.2.2. Emissions of black carbon

Due to the fact that the estimation of black carbon emissions largely relies on the amount of flared as shown in Equation F and for both volumes of black carbon emitted and volume of gas flared, similar patterns were observed. In 1990, about 2.11 × 104 tonnes of black carbon was flared into the atmosphere, with the peak volume recorded in 2006, and 1.06 × 104 tonnes was recorded in 2014. Emission of black carbon in total in the study area under the period considered was about 5.24 × 105 tonnes, translating into 4.71 × 108 tCO_2 e. Using a carbon tax credit of $15 for a ton of black carbon emitted, the financial estimate of the total volume of emissions was found to be $7.07 Billion.

4.3. Total estimated emission

Total black carbon and greenhouse gas emission along with gas flaring operations in the study area during the 25-year duration amounted to 1.80 × 109 tCO2 e from flaring 555.74 bcm of gas. The pattern of total emissions from 1990 to 2014 is similar to those of black carbon and GHGs emission. The emission of GHGs has an estimated cost of $19.94 Billion, while black carbon emissions were estimated to be about $7.07 Billion. Over the total period considered for this study, emission of GHGs and black carbon both have economic costs totalling $85.92 Billion (a value consisting cost of flared gas ($58.91 Billion) and the value of emission levels ($27.01 Billion) discharged into the air of the study area). All of these have had negative effects on vegetation growth, animal life and ecological equilibrium in the NGR. The finding was in consonant with Ojimba and Iyagba (2012), who revealed that the emission of GHGs and black carbon had detrimental and negative effects on the area of farmland cultivated, horticultural crops output produced and hence farmers' income. They noted that the reduction in income of farmers was because of low harvest resulting from retarded crop growth. However, the retardation in growth was due to air-borne pollutants released into the environment during gas flaring.

4.4. Uncertainty analysis

4.4.1. Quantitative uncertainty analysis for the mean of total emissions

Two of the approaches recommended for developing quantitative estimates (Tier 1 and 2) related to uncertainty in individual source categories; Tier 2 is more versatile and consistent than Tier 1 (Marland et al., 2014). Another reason necessitating the use of Tier 2 is the ratio of the standard deviation to the mean (coefficient of variation) associated with input variables.

The coefficient of variance (ratio of the standard deviation to the mean) correlated with the input variables that were more than 0.3 (0.52) and the non-normal distribution of the input variables are other factors that prompted the selection of the Tier 2 method for this analysis. Goodness-of-fit tests (Kolmogorov- Smirnov test, Chi-Squared test, and Anderson-Darling test) run on the input parameters (GP and GF) employing Easy Fit® allocated beta and triangle distribution to GP and GF, respectively. Finally, premised on this distribution, the scope of the mean of the cumulative emission levels (GHGs and BC) at 95% confidence was generated by running the algorithm that included both the input and output designs on Analytica®.

The effect diagram created to model the calculation of the uncertainty associated with this analysis using Analytica® is given in Figure 1. Taking the same sample size as the initial observed data collection, each sample was collected, and then the mean was measured. This implies it explains the distribution of probability for statistics from which ranges of probability have been deduced. The mean (simulated), comparative uncertainty of the mean, lower and upper confidence levels of the mean for the quantity of GHGs, BC and overall emissions emitted to the atmosphere of the Niger Delta due to gas flaring are shown in Table 1. It was observed that the approximate mean of GHGs, BC and overall emissions collected prior to quantifying the corresponding uncertainties was relatively higher than that observed for the virtual mean in Table 1. This disparity in the mean of GHGs, BC and overall emissions might well be due to the existence and statistical distribution by the oil firms operating in the region, who are the sole providers of such data, of the input data, of the data collection and of the data collection methods.

It is interesting to note that 250, 500, 1000 and 2000 iterations were used in the execution of the mathematical models. The simulation of 2000 iterations was examined to provide the best possible outcome for the emission model performance for this work. The median LH was used to achieve all of this.

4.5. Estimating model performance uncertainty

Considering the model for emission (output), gas production and gas flaring uncertainties were examined to estimate the volumes of black carbon, Methane, Nitrous Oxide, black carbon, GHGs, as well as total emissions based on the set of equations entered into the model. Samples were randomly generated with the use of the Latin Hypercube method, and the mean value of Carbon (IV) Oxide was 3.93× 107 tonnes, Methane was 2.30 × 105 tonnes, Nitrous oxide was 1.209 tonnes, black carbon was 1.78× 107 t CO_2 e, GHGs was 4.51 × 107 t CO_2 e, and Total emissions was 6.28 × 107 t CO_2 e.

Furthermore, the emission range of GHGs was estimated to be between 6.45 × 106 tonnes - 6.65 × 107 tonnes at 5% level of significance, which correlates to -92.20 and 51.16% relative uncertainty values. The relative uncertainties associated with CO_2, CH_4, N_2O and black carbon emissions are also compared, and the Comparison reveals that what has been formerly published (± 75% for CO_2 and CH_4; -10% to 1000% for N_2O) in the literature indicates that the lower CO_2, CH_4 and N_2O limits are marginally outside the stated values, while the upper limits are far below the specified limit, particularly for N_2O (API, 2009).

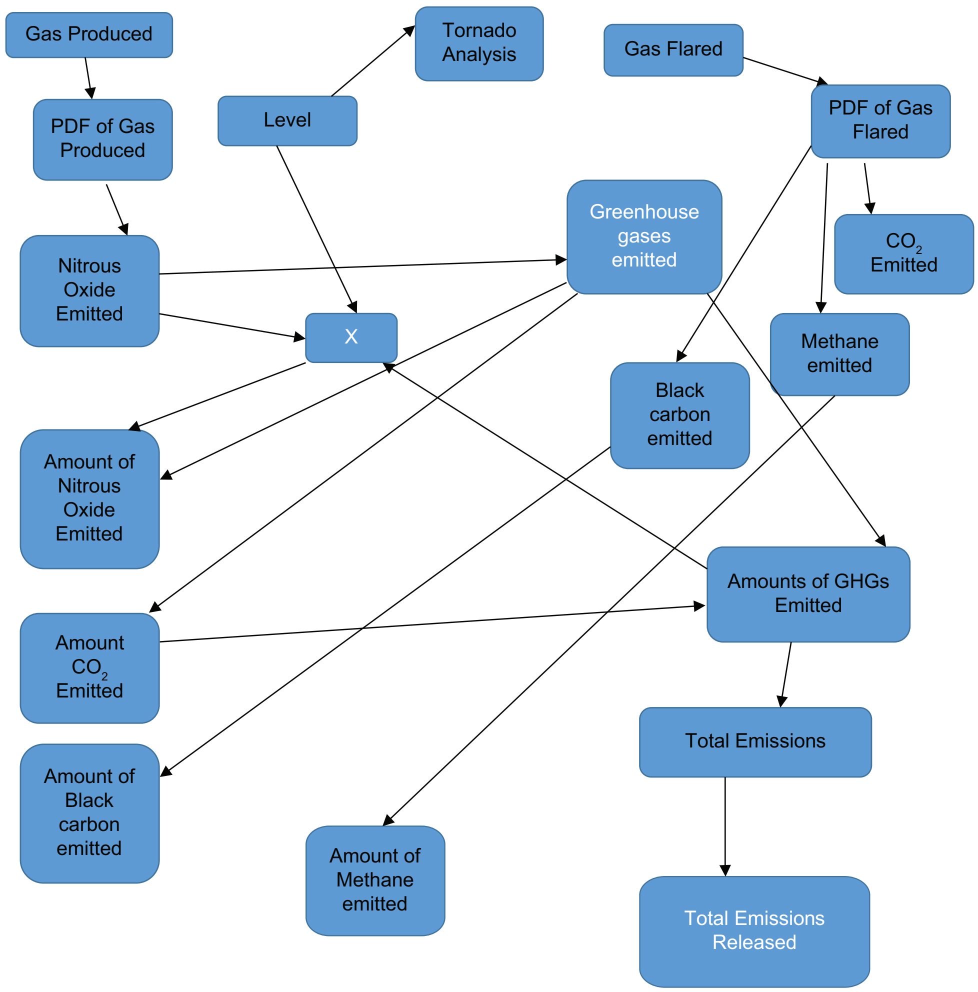

Figure 1. Showing the Diagram of impact used to model the Uncertainty Statistics

4.6. Sensitivity analysis on gas flaring emissions practices

It was observed that gas flared is more influenced by the uncertainty of total emissions in contrast to gas produced. Sensitivity analysis reveals that the most efficient method to minimise uncertainty if the overall emissions estimated would be to minimise total uncertainty of flared gases and using more accurate data collection while using contemporary instruments of measurements and analysis. In 1990 and 2014, the volume of emission into the environment was calculated to be 7.26 × 107 and 3.65 × 107 t CO_2 e, respectively, indicating significant reduction in emission by 50% that is, 3.61 × 107 t CO_2 e. 2.66 × 107 and 9.44 × 106 t CO_2 e was also recorded for greenhouse gas emissions and black carbon emissions, a volume which corresponds to 49.71% and 49.67% decrease, respectively. Result obtained is a pointer to the movement towards under-achieving economic sustainability in the study area, as the results showed that flares have negative effects on vegetation growth, animal life and ecological equilibrium in the Niger Delta area.

The results were in disparity to the report from the Atlas of sustainable development goal (SDGs) 2017 that global emissions of carbon dioxide, major greenhouse gas and driver of climate change, increased from 22.4 billion metric tons in 1990 to 35.8 billion in 2013, a rise of 60%. The increase in CO_2 emissions and other

Table 1. Gas flaring pollution uncertainties (1990-2014) in the 2000 trials in the NDR of Nigeria

Emission indicator	Min (2.5th CL)	Mean simulated	Max (97.5th CL)	Attributable uncertainty (%)		Mean estimated
N_2O	0.654	1.209	1.948	–46.81	61.12	1.125
CO_2	3.070 M	38.51 M	58.61 M	–91.30	51.16	42.43 M
GHHs	3.505 M	44.65 M	67.52 M	–91.30	51.18	44.71 M
CH_4	17.932 K	228.1 K	350.8 K	–91.30	51.15	233.1 K
BC	1.377 M	18.01 M	27.04 M	–91.30	51.12	19.16 M
Total	4.876 M	63.75 M	95.66 M	–91.30	51.16	65.56 M

GHGs has contributed to a rise of about 0.8 degrees Celsius in mean global temperature above pre-industrial times.

Some research, on the other hand, implies that Cdeg.2 emissions can be lowered at “zero” cost. That is, when these opportunities are appraised at the right social shadow prices, the costs of reducing GHGs are less than the benefits. Activities that generate GHGs and have other environmental externalities are one set of examples. In another instance, the use of CFCs is contributing to ozone depletion. Steps to safeguard the ozone layer by phasing out CFCs would also have the added benefit of reducing greenhouse gas emissions. Other areas are less clear from an economic standpoint, yet they could still be considered negative-cost activities. Subsidies to energy prices, for example, result in far greater levels of energy use in many nations than would be the case if prices reflected true market pricing or world prices. Capital markets, electric utilities and capital goods acquisitions are all alleged to have market defects or informational shortcomings. The scope of negative-cost possibilities is debatable, but the main challenge from a policy standpoint may not be the presence of negative-cost opportunities but rather the difficulty in identifying tools to exploit them.

5. Conclusion

This study investigated the impact of GHGs emission on sustainable economic development of the NGR of Nigeria. In this context, the term “sustainability” refers to taking into account man’s basic needs, striving for equity and justice for current and future generations, taking economic and environmental factors into account and integrating them, achieving human self-empowerment and avoiding biodiversity loss.

Ecosystem degradation is largely responsible for many decades of persistent gas flaring in the Niger River Delta, environmental degradation, low life expectance, multi-dimensional poverty, unrest, erosion and floods, critical and terminal health problems, as well as climate change and its effects. Results of empirical analysis show that emission quantity of GHGs and black carbon discharged into the Niger Delta environment due to gas flaring activity has declined by half its previous volume in 2014 compared to emission volumes in 1990. This may be as a result of continuous or sustained gas utilisation by the government of the Federal Republic of Nigeria to reduce and ultimately curb flaring of gases irrespective of increasing gas production. Although, there exists no agreed or recommendation to measure the success or otherwise of one of the SDGs in 2015 (Goal 8 – target 3), which aims to foster development-oriented policies that promote productive practices, the production of decent jobs, creativity, ingenuity and innovation and promote the formalisation and growth of micro, small and medium-sized businesses, along with financial intermediation., seems to be progressing compared to 1990.

Considering the region's unique nature and richness, ensuring environmental sustainability in this part of the country is critical. Above all, environmental sustainability in the NDR, as defined by MDG 7, will have a positive impact on the livelihood and wellbeing of the region's roughly 30 million people. To this end, Nigeria must either fully halt or drastically reduce gas flaring, which can be accomplished through the creation of a local market and gas infrastructure that encourages more natural gas consumption. In the best interests of the region, public decision-making procedures on environmental issues must be designed to incorporate multiple perspectives on not only the required knowledge basis for decision-making but also the basic definition of what constitutes an ecosystem fair or unfair.

References

Abdulkareem, A.S., Odigure, J.O. and Abenege, S. (2010), "A predictive model for pollutant dispersion from gas flaring: A case study of the oil-producing area in Nigeria", *Journal of Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, Vol. 32 No. 12, pp. 1004-1015.

Abubakar, A. (2013), "Education and sustainable national development in Nigeria: Challenges and way forward", *International Letters of Social and Humanistic Sciences*, Vol. 14, pp. 65-72.

Akpan, S. (2009), "The production and utilisation of natural gas resources in Nigeria: A review", in: *Proceedings of Annual International Conference and Exhibition of the Nigerian Society of Petroleum Engineers, Abuja, Nigeria*.

Al Mamun, M., Sohag, K., Mia, M., Uddin, G. and Ozturk, I. (2014), "Regional differences in the dynamic linkage between carbon dioxide emissions, sectoral output and economic growth", *Renewable and Sustainable Energy Reviews*, Vol. 38, No C, pp. 1-11.

Chinago, A. (2017), "Sustainable development in fragile Niger Delta region: A task for environmentalists", *International Journal of Development and Sustainability*, Vol. 6 No. 15, pp. 1293-1304.

Dearden, P. and Mitchell, B. (2009), *Environmental Change and Challenge*, Oxford University Press, Oxford, United Kingdom.

Dosunmu, A. and Amadi, B. (1996), "Evaluation of the effect of gas flares on the environment", in: *Proceedings of the 20th Annual International Conference the Society of Petroleum Engineers, Nigeria Council*, pp. 45-49.

Giwa, S., Nwaokocha, C. and Layeni, A. (2016), "Assessment of millennium development goal 7 in the Niger Delta region of Nigeria via emissions inventory of flared gas", *Nigerian Journal of Technology*, Vol. 35 No. 2, pp. 349-359.

Gogoi, N. and Baruoh, K. (2002), "Effects of Natural Gas Flare on Growth, Flowering and Yield of Rice", available at: http://www.envfor.nic.in/paryaabs/v19n12/plant.html. [Last accessed on 2021 Jul 12].

Gray, K.R. (1990), "Human rights principles and climate change", in: Carlarne, C., Gray, K.R. and Tarasofsky, R. (Ed.s), *Oxford Handbook of International Climate Change Law*, Oxford University Press, Oxford, UK, pp. 213-238.

Intergovernmental Panel on Climate Change (2000), “Climate change: The scientific basis”, Contribution of Working Group 1 to the 3rd assessment report of the intergovernmental panel on climate change, summary for policymakers.

Intergovernmental Panel on Climate Change (2007), “IPCC 4th Assessment Report (AR4)”, Working Group 1, the Physical Science Basis, available at: http://www.ipcc.ch/publications_and_data/ar4/wg1/en/contents.html. [Last accessed on 2021 Jul 12].

Lu, Y., Huang, Z. and Zhang, T. (2013), “Method and case study of quantitative uncertainty analysis in building energy consumption inventories”, *Energy and Buildings*, Vol. 57, pp. 193-198.

Luzzati, T. (2005), in Leggere Karl William Kapp (1910-1976), “Per una visione unitaria di economia, società e ambiente”, Discussion Papers del Dipartimento di Scienze Economiche Università di Pisa, Vol. 56, pp. 1-30.

Manasseh, C., Abada, C., Ogbuabor, J., Okoro, E., Ebeke, A. and Ozuzu, K.C. (2019), “Oil price fluctuation, oil revenue and wellbeing in Nigeria”, *International Journal of Energy Economics and Policy*, Vol. 9 No. 1, pp. 346-355.

Marland, E., Cantrell, J., Kiser, K., Marland, G. and Shirley, K. (2014), “Valuing uncertainty part I: The impact of uncertainty in GHG accounting”, *Carbon Management*, Vol. 5 No. 1, pp. 35-42.

Martinez-Alier, J. (1987), *Ecological Economics: Energy, Environment and Society*, Blackwell, Oxford, UK.

Matthew, O., Osabohien, R., Fagbeminiyi, F. and Fasina, A. (2018), “Greenhouse gas emissions and health outcomes in Nigeria: Empirical insight from auto-regressive distribution lag technique”, *International Journal of Energy Economics and Policy*, Vol. 8 No. 3, pp. 43-50.

McEwen, J. and Johnson, M. (2012), “Black carbon particulate matter emission factors for buoyancy-driven associated gas flares”, *Journal of Air Waste Management Association*, Vol. 62 No. 3, pp. 307-321.

National Bureau of Statistics, NBS (2013), “Millennium Development Goals Performance Tracking Survey Report 2012”, National Bureau of Statistics, China.

National Population Commission. (2006), *Nigerian Population Census Report 2006*. National Population Commission, Nigeria.

Ni, B., Yuan, Z., Chandran, K., Vanrolleghem, P. and Murthy, S. (2013), “Evaluating four mathematical models for nitrous oxide production by autotrophic ammonia oxidising bacteria”, *Biotechnology and Bioengineering*, Vol. 110 No. 1, pp. 153-163.

Nigerian National Petroleum Corporation, NNPC (2010), “Annual statistical bulletin”, Corporate Planning and Development Division (CPDD) January-December 2010.

Nigerian National Petroleum Corporation, NNPC (2011), “Annual statistical bulletin”, Corporate Planning and Development Division (CPDD) January-December 2011.

Nigerian National Petroleum Corporation, NNPC (2012), “Annual statistical bulletin”, Corporate Planning and Development Division (CPDD) January-December 2012.

Nigerian National Petroleum Corporation, NNPC (2013), “Annual statistical bulletin”, Corporate Planning and Development Division (CPDD) January-December 2013.

Nigerian National Petroleum Corporation, NNPC (2014), "Annual statistical bulletin", Corporate Planning and Development Division (CPDD) January-December 2014.

Nugraha, A. and Osman, N. (2019), "Carbon-dioxide emissions, economic growth, energy consumption, and household expenditure for Indonesia: Evidence from co-integration and vector error correction model", *International Journal of Energy Economics and Polic*y, Vol. 9 No 1, pp. 291-298.

Nwilo, P. and Badejo, O. (2008), "Oil dispersion and trajectories on Nigerian open sea", in: *Conference Proceedings of the International Conference on the Nigeria State, Oil Industry and the Niger Delta*, pp. 164-192.

Obioma, B. (1985), "An enquiry into lack of investment in agriculture by the Oil Communities: The Case of Ogba-Egbema and Oguta Communities", Seminar on Energy, University of Port-Harcourt, Port-Harcourt.

Odigure, J.O., Abdulkareem, A.S. and Adeniyi, O.D. (2003), "Computer simulation of soil temperature due to heat radiation from gas flaring", Association for the Advancement of Modelling and Simulation in Enterprises, Lyon France, Vol. 72 No 6, pp. 1-10.

Odjugo, A.O.P. (2010), "Regional evidence of climate change in Nigeria," *Journal of Geography and Regional Planning*, Vol. 3 No. 6, pp. 142-150.

Odukoya, O. (2006), "Oil and sustainable development in Nigeria: A case study of the Niger Delta", *Journal of Human Ecology*, Vol. 20, pp. 249-258.

Oguwuike, M., Lasbrey A., Tobechi, A., Iyke, U., Uma K., Kelvin O., Sunday, A. and Ikwor, O. (2019), "Oil exploration and exploitation in Nigeria and the challenge of sustainable development: An assessment of the Niger Delta", *International Journal of Energy Economics and Polic*y, Vol. 9 No. 4, pp. 369-380.

Ojimba, T.P. and Iyagba, A.G. (2012), "Effects of crude oil pollution on horticultural crops in rivers state, Nigeria", *Global Journal of Science Frontier Research Agriculture and Biology*, Vol. 12 No. 4, pp. 37-44.

Olaolu, A. (2008), "MNCs and Sustainable Environmental Development: An Assessment of the Niger Delta and Texas", *International Conference on the Nigerian State, Oil Industry and the Niger Delta: Conference Proceeding*s.

Onuoha, C. (2007), *Bioethics Across Borders. An African Perspective*. Upsala Studies in Social Ethics, Upsala Universitet, Upsala, p.14.

Onyiah, I.M. (2005), "Modification and verification of Milton equation for measuring gaseous pollutant concentration", Postgraduate diploma thesis, Department of Chemical Engineering, Federal University of Technology, Minna, Nigeria (unpublished), pp. 1-63.

Osabohien, R., Oluwatoyin, M., Aderounmu, B. and Olawande, T. (2019), "Greenhouse gas emissions and crop production in West Africa: Examining the mitigating potential of social protection", *International Journal of Energy Economics and Policy*, Vol. 9 No. 1, pp. 57-66.

Pearson, P. and Palmer, M. (2000), "Atmospheric carbon dioxide concentrations over the past 60 million years", *Nature*, Vol. 406 No. 6797, pp. 695-699.

Rahmouni, C., Tazerout, M. and Corre, O. (2003), "Determination of the combustion properties of natural gases by pseudo-constituents", *Fuel*, Vol. 82, pp. 1399-1409.

Shindell, D., Faluvegi, G., Koch, D., Schmidt, A., Unger, N. and Bauer, S. (2009), "Improved attribution of climate forcing to emissions", *Science*, Vol. 326, pp. 716-718.

Shires, T., Loughran, C., Jones, S. and Hopkins, E. (2009), "Compendium of greenhouse gas emissions methodologies for the oil and natural gas industry", Prepared by URS Corporation for the American Petroleum Institute (API), Washington, DC.

Twerefou, D.K., Danso-Mensah, K. and Bokpin, G.A. (2017), "The environmental effects of economic growth and globalisation in Sub-Saharan Africa: A general panel method of moments approach", *Research in International Business and Finance*, Vol. 42 No. C, pp. 939-949.

Ukegbu, D. and Okeke, A. (1987), "Flaring of associated gas in oil and gas industry: Impact on growth, productivity and yield of selected farm crops in the petroleum industry and the Nigeria environment", in: *Proceedings of 1987 Seminar, NNPC, Lagos*.

Uyigue, E. and Agu, M. (2007), "Coping with climate change and environmental degradation in the Niger Delta of Southern Nigeria", Report of Community Research and Development Centre (CREDC), Lagos, Nigeria, pp. 1-31.

Weintraub, E.R. (1985), *General Equilibrium Analysis: Studies in Appraisal*, University of Michigan Press, Ann Arbor, Michigan.

Zhou, Y., Cheng, S., Chen, D., Land, J., Zhao, B. and Wei, W. (2014), "A new statistical approach for establishing a high-resolution emission inventory of primary gaseous air pollutants", *Atmospheric Environment*, Vol. 94, pp. 392-401.