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Modelling the CO_2 Ecological Footprint for an Oil and Gas Producing Country – A Case Study of Nigeria

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Abstract

The United Nations 2030 Agenda for Sustainable Development needs some metric to measure the progress of nations towards sustainability. The method for using the Carbon (IV) Oxide (CO_2) Ecological Footprint (EF) as a means for measuring the progress of a developing country towards sustainable development has been studied in this research. Using the Nigerian Oil and Gas Industry as a case study, models for computing the CO_2 EF and Bio-capacity of the Nigerian Environment were developed with MATLAB 7.5.0 Software. By comparing the CO_2 EF and the Biocapacity of Nigeria, the picture of the Nigerian oil and Gas Industry with respect to sustainability was painted and hence the progress towards sustainable development is now measurable. The study viewed Nigeria as an Isolated Thermodynamic system in space; hence, all the activities within the system must be sustainable, with the three dimensions of sustainability respected: Environmental, Social and Economic. Empirical analyses of data obtained with regard to CO_2 released during Oil and Gas production in Nigeria suggests that the CO_2 release by the Nigerian Oil and Gas Industry is unsustainable. To make oil and gas production sustainable in Nigeria, the Nigerian forest needs to be increased to be able to sequester the emitted CO_2 by the oil and gas industry.

Keywords: Ecological footprint, Oil and Gas Industry, Forest, Sequestration, Isolated Thermodynamic System

I. INTRODUCTION

The survival of human beings depends on the survival of the environment in which they live. The people in the world depend on the ecosystem for the resources, energy and also for the assimilation of the wastes resulting from the use of those resources. This is leading to questions such as "will this planet be able to meet or satisfy the needs of the future generations?", "Are we living within the earth's Carrying capacity?" The consumption of Oil and Gas resources will increase globally over the next fifty years. In order to meet the world's demand, Oil and Gas companies will increase and improve their prospecting efforts into very remote and unexplored areas of the earth some of which are protected or candidates for protection. As existing Oil, producing areas mature and produce less Oil, the Oil and Gas industry will explore new areas and new products. Exploration and production is already taking place in regions that are known for their bio-diversity and cultural importance, areas such as West Africa, Indonesia, the Caspian and the Andes. (Jaffe and Victor, 2004).

The Oil and gas Industry's exploration, production, transportation and the use of the oil itself have potential for a variety of impacts on the environment. Some of these impacts threaten the existence of humans and the environment in which they live. There is therefore need to estimate these impacts and whether these impacts can be considered sustainable or not. Sustainable development is a concept that was developed to capture the need of man to be responsive to the need of future generations. According the Word Commission on Environment and Development Report (1987), Sustainable development is one that satisfies the needs of the current generation without impairing the ability of coming or future generations to meet their own needs. In the same vein Meadows, et al., (1972) defined a sustainable society as one that can stay over generations, one that is fore-sighted enough, flexible enough and sensible enough, not to undermine its physical and social support systems. Sustainability therefore offers a means of balancing the gains of growth and human development with the potential unfavourable impacts of continued growth.

With increasing emphasis on sustainability and energy management, there is the need to estimate the ecological footprint due to exploitation, exploration, production, processing and transport of crude oil and natural gas. Most studies in our developing country context tend to focus only on oil spillages and the associated impact that may result in water contamination and loss of farming or fishing opportunities. However, there is need to measure the impact of the Oil and gas industry on the environment in terms of the Ecological footprint. The Ecological footprint can be measured using the metric of the released Carbon (IV) oxide (CO_2). The indicator (CO_2 emission) was selected because it is fundamental to Oil and gas production and it is always present as a by-product of Hydrocarbon combustion. The usual sink for the emitted CO_2 are broadly classified into three namely: The Ocean, the Atmosphere and the Terrestrial Biosphere. Using these three sinks, a theoretical model will be developed to provide a metric for characterizing the impact of the Oil and Gas industry on the Nigerian Environment. With the result of the model, it will be possible to communicate important policy decisions empirically as well as a means for measuring progress towards sustainable Oil and gas production.

II. STATEMENT OF THE PROBLEM

This article investigates, examines and assesses the sustainability of the Nigerian Oil and Gas industry. The Nigerian Oil and gas industry does not have a documented value of its CO_2 EF. Ambitious targets for Oil and Gas production needs to measure sustainability so as to respect the UN 2030 Agenda for Sustainable Development. Furthermore, there is no way to measure the progress that is being made by the Nigerian Oil and gas industry towards sustainable development. Currently, there is no consideration for the environmental cost impact in terms of sequestration of the released Carbon (iv) Oxide (CO_2). By being able to measure the Cost of CO_2 sequestration, policy makers and economists will be able to make more informed decision.

III. LITERATURE REVIEW

The exploration and recovery of Oil and gas from deposits and reserves has some ecological side effects and impacts. The broad environmental issues encountered during exploration and production of Oil and gas manifest both locally and globally. They include adverse effects on habitat and biodiversity, air emissions, marine and fresh water discharges, Oil spills and the resultant soil and ground water pollution. The challenge for the Oil and gas sector is to ensure that all operations conform to current good practice. (UNEPIE/PA, 1997).

The planet's human population, now estimated at over 7 billion, is expected to increase to 10 billion by 2050, and the footprint in terms of resource extraction and environmental effects on ecological cycles are matters of ongoing vibrant and intense debate. Cains (2004) argues that some indigenous communities have lived sustainably for many generations, while others with too many unsustainable practices have collapsed. Ewing et al., (2010) claim that ecological footprint creates global tensions with regard to food shortages, biological diversity loss, reduced fishes, soil degradation and lack of fresh water.

The earth which is the home of humanity is limited, it not infinite, its radius is defined, its surface area is known, so the human community cannot continue to deplete the resources of the earth as though it is infinite. The use of the resources of the earth has consequences on the well-being of humanity if it is not within the regenerative capacity of the earth as seen in the increase in the frequency of natural disasters, increasing surface temperature of the earth, floods, hurricanes, Typhoons, etc. According to Ewing et al (2010), "without a way of comparing the demand on resources to the capacity of the planet to supply those resources, policy makers could ignore the threat of overshoot, and remain entangled in discussion over the "affordability of sustainability".

Wackernagel and Rees (1996) introduced the concept of ecological footprint. Its basic theory is that every human being has real area of the Earth's surface dedicated to us for our survival: food to eat, land to build houses, garbage dump etc. According to Weidmann and Barrett (2010), ecological footprint is "an indicator that accounts for human demand on biological resources. It compares the available bio-productive land and Sea area with the level of consumption to see the possibility of exceeding the sustainability threshold. The concept of ecological footprint was developed to promote human progress and development without stifling the environment." The method of calculating the Ecological footprint proposed by Rees and Wackernagel (1996) has been criticised for being static and not a dynamic model. However, if the study is carried out for a given location over a period of time year in year out, the series of data obtained can be used as a form of time series which can then be used for dynamic modelling.

IV. METHODOLOGY

The study views Nigeria as an Isolated Thermodynamic system in space. An Isolated thermodynamic system is one in which no transfer of mass or energy occurs across its boundary. See figure 1. With Nigeria viewed as an isolated thermodynamic entity, all the activities within the system must be independently sustainable, with the three dimensions of sustainability respected: Environmental, Social and Economic. As the Oil and Gas industry is currently the main stay of the Nigerian economy, all the Carbon (IV) Oxide emission resulting from the economic activity (Oil and Gas Production) of Nigeria must be sequestered within the Bio-capacity of Nigeria. The Oceans, Forest and the atmosphere must take up the emitted greenhouse gases without resulting in climate change. Based on this view of each developing country as an Isolated Thermodynamic system, if the Bio-capacity of a country is low leading to its ability to sequester all the emitted Carbon (IV) Oxide as a result of its Oil and Gas production, the Bio-capacity needs to be expanded by planting more Forests, or Utilizing the new technologies available for CO_2 sequestration to take up any excess CO_2 oxide its Bio-capacity for CO_2 sequestration. Another way to attain Environmental sustainability will be to find another isolated thermodynamic entity (Another country with very high Bio-capacity) willing to accept the excess mass of CO_2 at a cost. This view of every Oil and gas producing country as an Isolated Thermodynamic system ensures that environmental sustainability is measured from the source of the Hydro-carbon generation and not at the sink. All countries whose economies benefit from Oil and Gas production will have to pay in line with the "polluter pays principle".

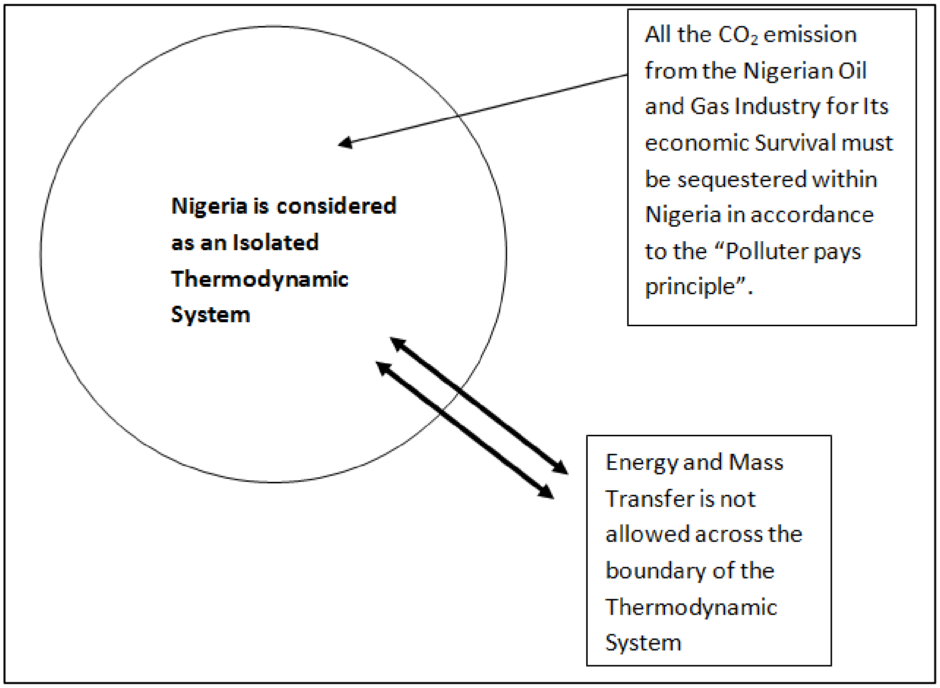

Fig. 1: Nigeria as an Isolated Thermodynamic System

The study carried out empirical analysis of Carbon (IV) Oxide emitted as a result of the production of oil and gas in a developing country location. Oil and gas production data of Nigeria was obtained from 1961 to 2014; this was converted to the equivalent quantity of CO_2 generated as a result of combustion in air. The CO_2 released into the environment is normally sequestered by the Ocean, terrestrial Biosphere and the atmosphere. The amount of CO_2 sequestered naturally by the Ocean was deducted, thereafter; the rate of sequestration by the terrestrial Biosphere (Forests) was used to compute the ecological footprint of the Nigerian Oil and gas industry. The deforestation was taken into account during the computation. After the CO_2 ecological footprint was calculated, the Bio-capacity of the Nigerian forest was calculated. By comparing the CO_2 ecological footprint and the Bio-capacity, the sustainability of the Nigerian Oil and gas industry was determined. The summary of the methodology is presented in figure 2.

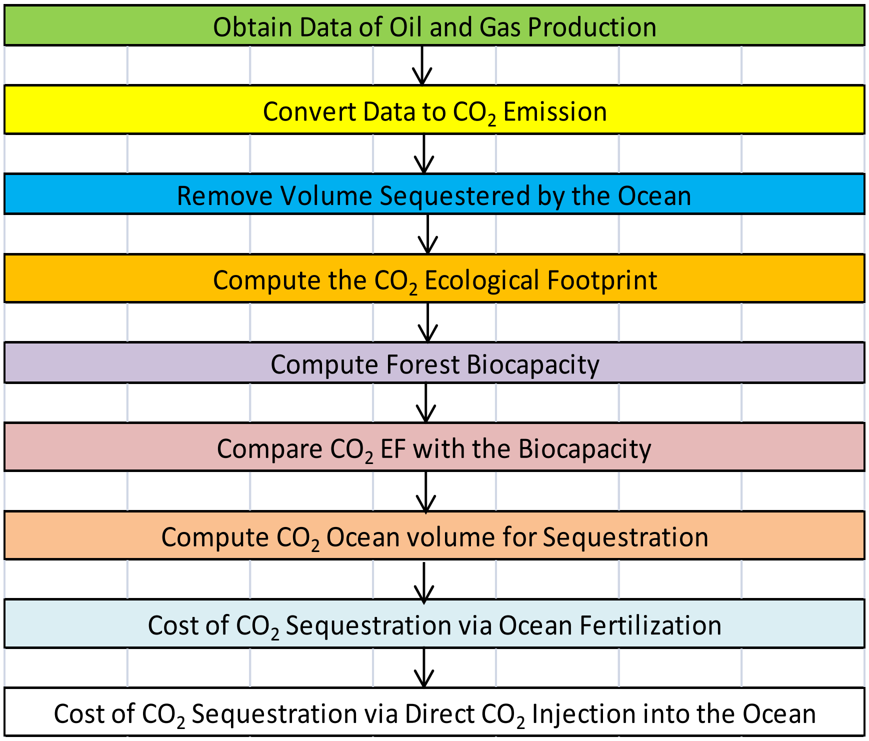

Fig. 2: Flow chart for Ecological Footprint and Bio-capacity Estimation

The assumptions in this model development are as follows: the statistics of the suite of variables that was used to indicate/measure ecological footprint conforms to that of an ergodic ensemble. In the second instance, it is assumed that the release of CO_2 as a result of exploration and production of Oil and gas is a sensitive and useful indicator of ecological footprint. Thus, we focus attention on empirical analysis of CO_2 release into the Nigerian environment attributable to Oil and gas exploration and production activities. The third assumption is that for a complete combustion, a barrel of crude Oil produces 388kg of CO_2. The fourth assumption was that the available forest sequesters CO_2 at the rate 3.46 tonne/hectare/year. (Chambers et al, 2004). The data used consists of Oil and gas production data for Nigeria between 1961 and 2014. The ecological footprint of the emitted CO_2 was calculated as follows as per Ewing et al., (2010):

$$EF = \frac{P}{Y_N} \times Y_F \times EQF \quad (1.0)$$

Where P is the amount of CO_2 emitted in million tonnes per year (Mt/yr); Y_N is the national average forest sequestration rate for CO_2 in tonnes per hectare per year (T/H/yr) yield. Y_F is the yield factor and EQF is the equivalence factor (Global hectare/hectare) for the Forest land.

The Forest land Bio-capacity as per Ewing et al (2010) is estimated as follows:

$$BC = NF_L \times Y_F \times EQF \quad (2.0)$$

Where BC is bio-capacity, NF_L is available forest land for CO_2 sequestration; Y_F is the yield factor and EQF is the equivalence factor.

The daily Oil and gas production figures used in this research were obtained from the Nigerian national petroleum Corporation annual statistical bulletins. See appendix I and II for the data used for modelling. Based on the data presented in appendices I and II, models were developed from the data using the MATLAB 7.5.0 software. The co-efficient of determination for the models are between 0.95 and 1.

V. Results and Discussion

The result of the study is presented from the analysis carried out using the method described above. The details of the calculations are presented in appendix III. The total CO_2 production from the Nigerian Oil and gas industry is obtained by summing the CO_2 production from Oil and gas combustion.

$$\text{Mass of } CO_2 \text{ from Oil and Gas combustion (Kg)} = 0.58289\, \rho_o \left(\frac{Kg}{m^3}\right) * V_o\,(bbl) + 1.9386 V_{CH4}(m^3) \quad (3.0)$$

Expressing the above equation in terms of Gas Oil Ratio (GOR), we have:

$$\text{Mass } CO_2 \text{ from Oil and Gas combustion (Kg)} = V_o\,(\text{bbl})\left(0.58289\, \rho_o \left(\frac{\text{Kg}}{\text{m}^3}\right) + 12.2 * \text{GOR}\left(\frac{\text{Sm}^3}{\text{Sm}^3}\right)\right) \quad (4.0)$$

The CO_2 EF of the Nigerian Oil and gas industry was calculated based on the equation below:

$$CO_2\ \text{EF} = \frac{0.58289\, \rho_o\left(\frac{\text{kg}^3}{\text{m}}\right) * V_o\,(\text{bbl}) + 1.9386 V_{CH4}(\text{m}^3)}{1000 * Y_N} \times Y_F \times \text{EQF} \quad (5.0)$$

Using the data in appendix I and II and MATLAB 7.5.0 software, the models for the CO_2 EF of the Nigerian Oil and gas industry are as follows:

At lower values of CO_2 emission (<250 Mtonnes):

$$EF_{CO_2} = P_1 * x^3 + P_2 * x^2 + P_3 * x + P_4 \quad (6.0)$$

Where $EF_{CO_2}\ (Mgha)$ is the Ecological footprint of CO_2 production by the Nigerian Oil and gas industry and x is the quantity of CO_2 (Mtonnes) produced by the Nigerian Oil and Gas industry.The coefficients within 95% confidence bounds are:

$$p_1 = 1.3 * e^{-006}; p_2 = -0.0003187; p_3 = 0.3339; p_4 = -0.5325$$

The coefficient of determination, $R^2 = 0.9732$

Higher values of CO_2 production (> 250 MTonnes) are better modelled by the power equation:

$$EF_{CO_2} = a * x^b \quad (7.0)$$

The coefficients within 95% confidence bounds are:

$$a = 0.07579; b = 1.272$$

The coefficient of determination $R^2 = 0.971$

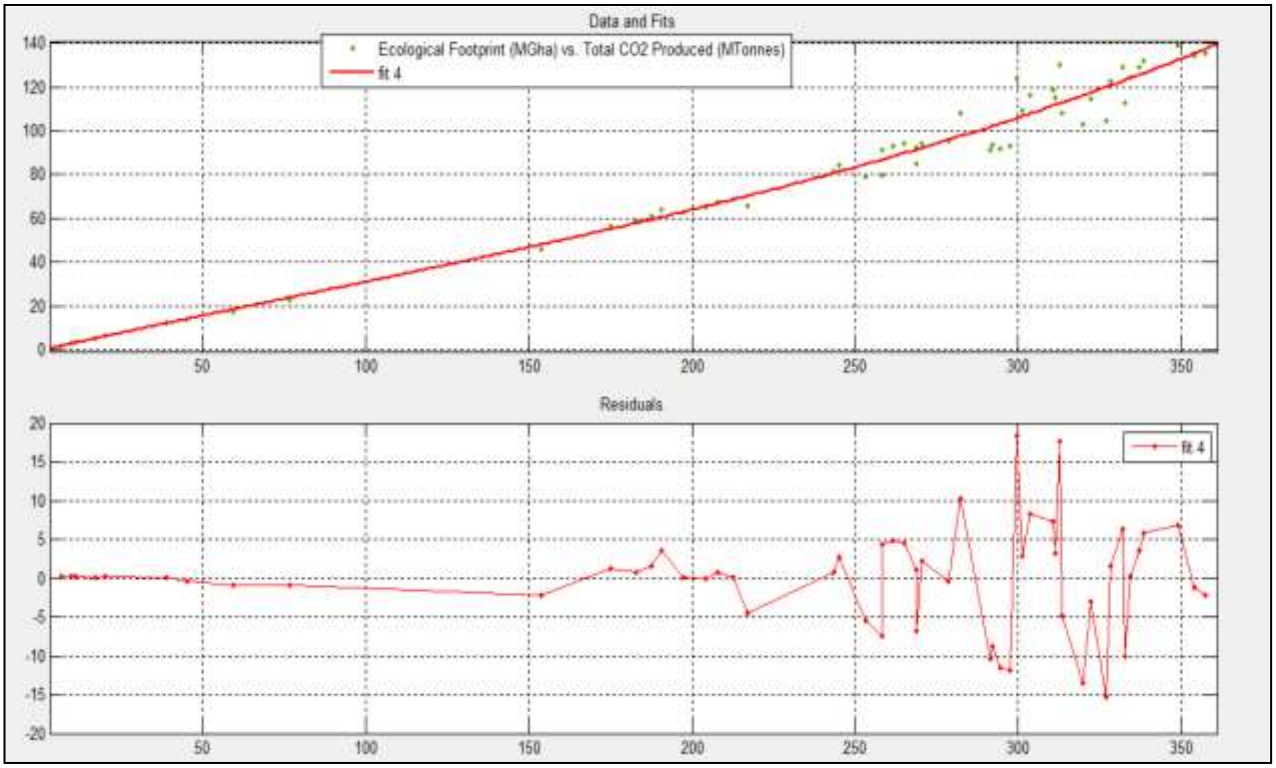

Fig. 3: CO_2 EF (Mgha) for the Nigerian Oil and Gas Industry with CO_2 emission (Mtonnes). (x<250 Mtonnes)

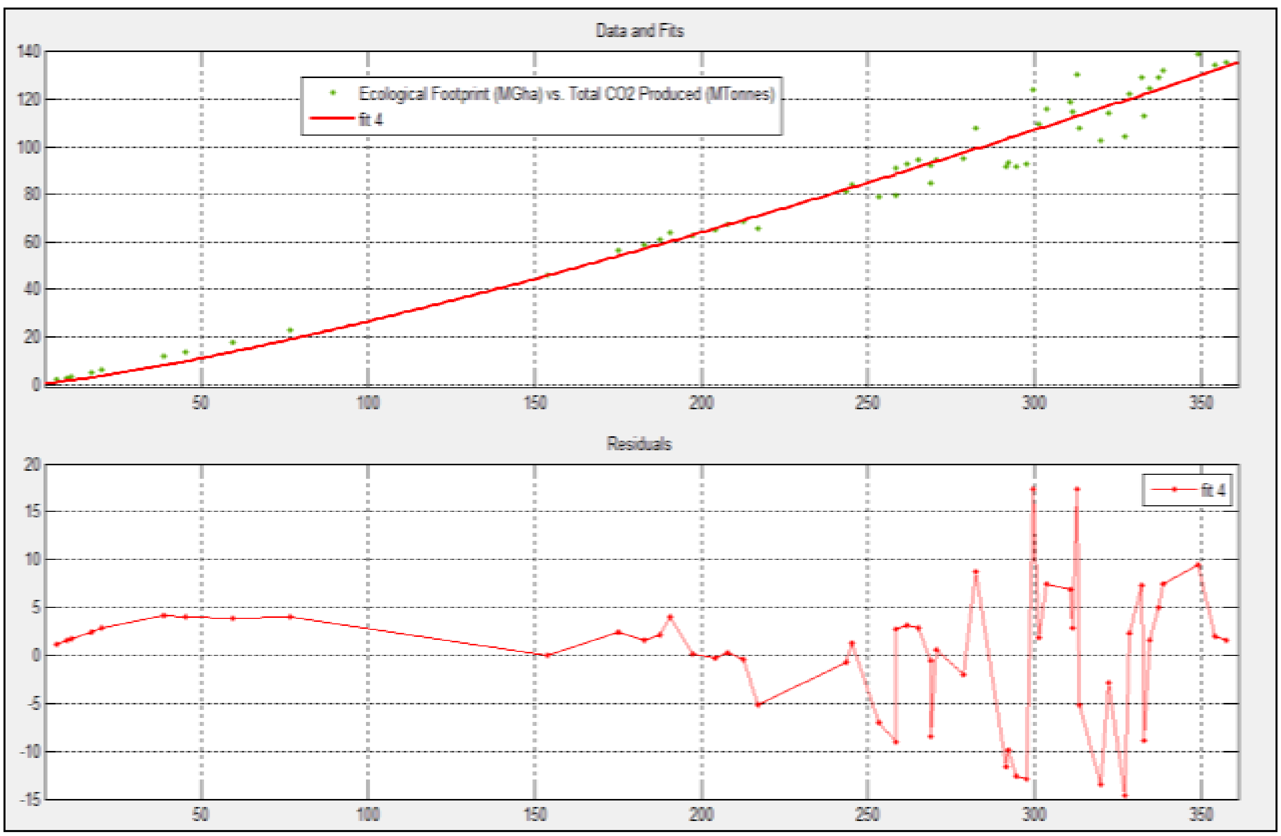

Fig. 4: MATLAB modelling of the Ecological footprint (Mgha) of the Nigerian Oil and Gas Industry with CO_2 emission (Mtonnes). (x>250 Mtonnes)

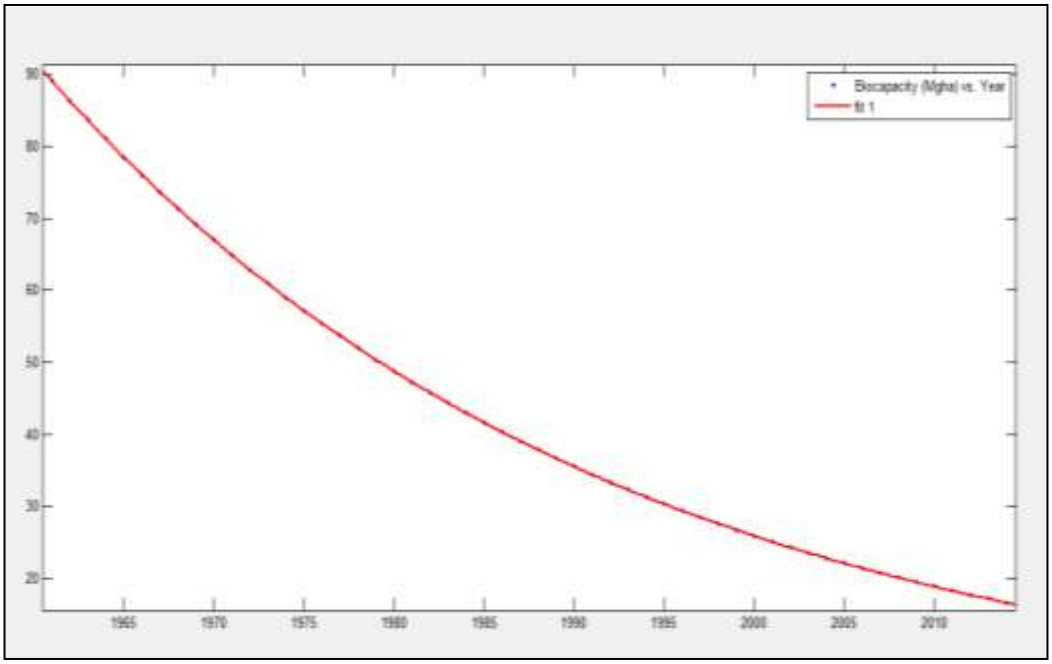

Figure 5: MATLAB modelling of the available Bio-capacity (Mgha) for sequestering CO_2 in Nigeria from 1961 to 2014.

The bio-capacity available for sequestering the CO_2 released by the Nigerian Oil and Gas industry can be modelled by the exponential equation below:

$$BC = a * e^{b*x} \quad (8.0)$$

Where BC $(Mgha)$ is the Bio-capacity of Nigeria available for CO_2 sequestration and x is the year under consideration. The coefficients within 95% confidence bounds are:

$$a = 38.48 \quad ; b = -0.4987$$

The coefficient of determination for the model $R^2 = 1.0$

By comparing the CO_2 EF and the Forest Bio-capacity of Nigeria, we have the plot shown in figure 6 below.

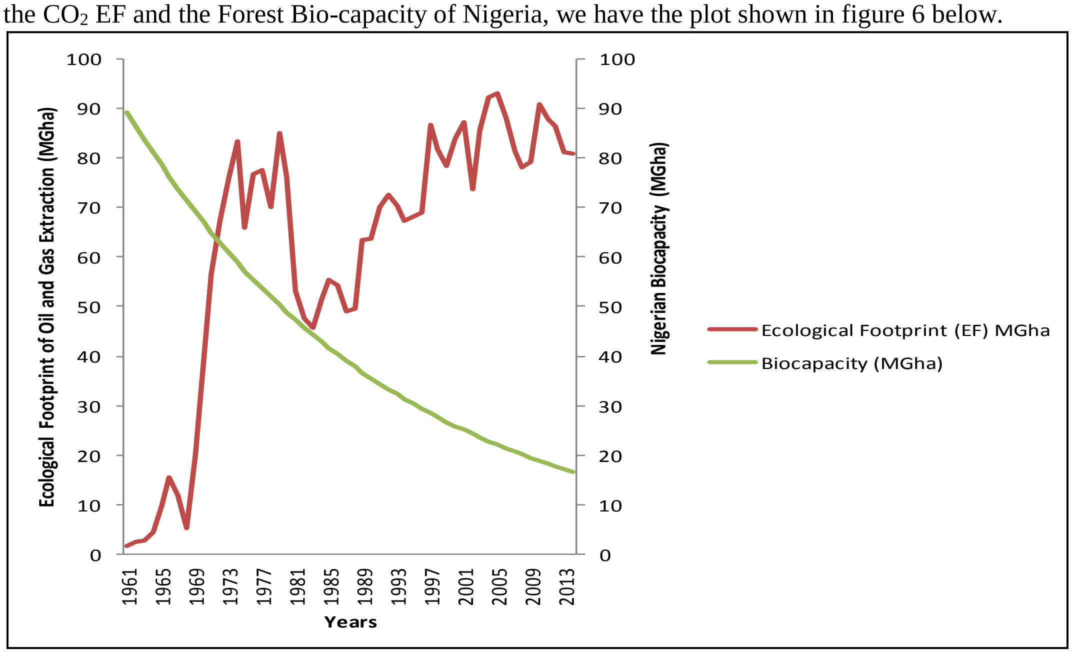

Fig. 6: Plot of Bio-capacity and Ecological footprint of CO_2 released by the Nigeria Oil and Gas Industry between 1961 and 2014

From figure 6, it can be seen that by plotting the Ecological footprint and Bio-capacity on the same graph, it is easy to see the period during which Oil and gas production by Nigerian was sustainable. This was between 1961 and 1970. However, beyond 1970, the effect of increase in Oil production coupled with desertification and deforestation has made the activity of the Nigerian oil and gas industry unsustainable. Nigeria is currently producing more carbon (IV) oxide than its forest resource can sequester.

VI. Conclusion

The study of the Ecological Footprint of the Nigerian Oil and Gas Industry while considering Nigeria as an Isolated Thermodynamic system is critical in view of the need to meet the UN 2030 Agenda for sustainable development. From the study carried out, the CO_2 EF of the Nigerian Oil and Gas Industry ranges from 1.7 Mgha to 93.13. MGha between 1961 and 2014. The forest Bio-capacity of Nigeria decreased from 89.14 Mgha to 16.61 Mgha between 1961 to 2014. The ratio of the mean CO_2 EF to the mean Biocapacity of Nigeria is 1.42. This shows that the CO_2 emission by the Nigerian Oil and Gas industry is unsustainable. CO_2 Ecological footprint can be used as a communication tool in Nigeria based on the findings of this study. The use of the concept of the Isolated Thermodynamic system is very essential because for proper accounting of all Carbon (IV) Oxide emissions, it focuses on the Source rather than on the sink and considers the world as a global village.

Appendix – 1

Nigerian Oil Production from 1961 to 2014.

S/NO	Year	Annual Production (bbl/Year)	Daily Production (bbl/Day)
1	1961	16801896	46032.6
2	1962	24623691	67462.2
3	1963	27913479	76,475.30
4	1964	43,996,895	120,210.10
5	1965	99,353,794	272,202.20
6	1966	152,428,168	417,611.40
7	1967	116,553,292	319,324.10
8	1968	51,907,304	141,823.20
9	1969	197,204,486	540,286.30
10	1970	395,835,825	1,084,481.70
11	1971	558,878,882	1,531,175.00
12	1972	665,283,111	1,817,713.40
13	1973	750,452,286	2,056,033.70
14	1974	823,320,724	2,255,673.20
15	1975	651,509,039	1,784,956.30
16	1976	758,058,376	2,071,197.70
17	1977	766,053,944	2,098,777.90
18	1978	692,269,111	1,896,627.70
19	1979	841,226,770	2,304,730.90
20	1980	752,223,285	2,055,254.90
21	1981	525,500,562	1,439,727.60
22	1982	470,687,221	1,289,554.00
23	1983	450,974,545	1,235,546.70
24	1984	507,998,997	1,387,975.40
25	1985	547,089,595	1,498,875.60
26	1986	535,296,671	1,466,566.20
27	1987	482,886,071	1,322,975.50
28	1988	490,440,000	1,340,000.00
29	1989	626,449,500	1,716,300.00
30	1990	630,245,500	1,726,700.00
31	1991	690,981,500	1,893,100.00
32	1992	716,262,000	1,957,000.00
33	1993	695,398,000	1,905,200.00
34	1994	664,628,500	1,820,900.00
35	1995	672,549,000	1,842,600.00
36	1996	681,894,600	1,863,100.00
37	1997	855,736,287	2,344,483.00
38	1998	806,443,999	2,209,435.60
39	1999	774,703,222	2,122,474.60
40	2000	828,198,163	2,262,836.50
41	2001	859,627,242	2,348,708.30
42	2002	725,859,986	1,983,224.00
43	2003	844,150,929	2312742.271
44	2004	910,156,486	2493579.414
45	2005	918,660,619	2516878.408
46	2006	869,196,506	2381360.29
47	2007	803,000,708	2200001.94
48	2008	768,745,932	2106153.238
49	2009	780,347,940	2137939.562
50	2010	896,043,406	2454913.441
51	2011	866,245,232	2373274.608
52	2012	852,776,653	2336374.392
53	2013	800,488,096	2193118.071
54	2014	798,541,589	2187785.175

Source: Nigerian National Petroleum Corporation Annual Statistical Bulletins, 2010- 2014

Appendix – 2
Nigerian Gas Production from 1961 to 2014.

S/NO	Year	Gas Produced (MCM/Year)
1	1961	310
2	1962	486
3	1963	626
4	1964	1029
5	1965	2849
6	1966	2908
7	1967	2634
8	1968	1462
9	1969	4126
10	1970	8068
11	1971	12996
12	1972	17122
13	1973	21882
14	1974	27170
15	1975	18656
16	1976	21274
17	1977	21815
18	1978	20486
19	1979	27450
20	1980	24551
21	1981	17113
22	1982	15382
23	1983	15192
24	1984	16251
25	1985	18569
26	1986	18738
27	1987	17170
28	1988	20250
29	1989	25129
30	1990	28430
31	1991	31460
32	1992	32084
33	1993	33680
34	1994	33680
35	1995	35100
36	1996	35450
37	1997	37150
38	1998	37039
39	1999	43636
40	2000	42732
41	2001	52453
42	2002	48192
43	2003	51818
44	2004	59009
45	2005	59331
46	2006	61847
47	2007	68456
48	2008	64826
49	2009	52066
50	2010	67810
51	2011	58050.12
52	2012	59895.04
53	2013	47712.33
54	2014	53195.52

Source: Nigerian National Petroleum Corporation Annual Statistical Bulletins, 2010-2014.

Appendix 3: Calculation Details

The total CO_2 production from the Nigerian Oil and gas industry is obtained by summing the CO_2 production from Oil and gas combustion. The CO_2 from Oil production is computed as follows:

$C + O_2 \rightarrow CO_2$

1 mole of C produces 1 mole of CO_2

12kg of C produces 44 kg of CO_2

1 US gallon = 3.785 litres

1 barrel = 42 US gallons = 42 * 3.785 = 158.97 litres = 0.15897 m^3

Mass of CO_2 from combustion of 1 barrel of crude oil =

Density of Oil (kg/m^3) * Volume of Oil(m^3) * 44 kg/12kg

The CO_2 associated with gas combustion is computed as follows:

Chemistry of combustion for Methane is as follows:

$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

1 mole of CH_4 produces 1 mole of CO_2

16 kg of CH_4 produces 44kg of CO_2

Mass of CO_2(kg/m^3) from associated gas

$$= \frac{\text{Absolute Pressure } (N/m^2) * \text{ Molecular Weight of } CH_4}{(\text{Universal gas Constant } * \text{ Absolute temperature})} * \text{Volume of } CH_4(m^3) * \frac{44 \text{ kg}}{16 \text{ kg}}$$

The above equations can be combined to obtain the equation for the total CO_2 released by Oil and Gas production:

$$\text{Mass } CO_2 \text{ from Oil and Gas combustion (Kg)} = 0.58289\, \rho_o \left(\frac{Kg}{m^3}\right) * V_o \text{ (bbl)} + 1.9386 V_{CH4}(m^3)$$

Expressing the above equation in terms of Gas Oil Ratio (GOR), we have:

$$\text{Mass } CO_2 \text{ from Oil and Gas combustion (Kg)} = V_o \text{ (bbl)}\left(0.58289\, \rho_o \left(\frac{Kg}{m^3}\right) + 12.2 * GOR \left(\frac{Sm^3}{Sm^3}\right)\right)$$

VII. Recommendations for Further Study

The study of ecological footprint of the Oil and Gas Industry of Developing countries should be extended to the Produced Water. Furthermore, the United Nations Organisation should study the possibility of Inter-country trading Scheme for Carbon (IV) Oxide emission.

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