Journal of Emerging Trends in Engineering and Applied Sciences (JETEAS) 8(1): 1-6

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How to Use the CO_2 Ecological Footprint and Isolated Thermodynamic System Approach as a Tool for Achieving the UN 2030 Agenda for Sustainable Development: A Case Study of Nigeria

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Abstract
To meet the United Nations 2030 Agenda for Sustainable Development, there is need to have a way to measure the footprint of human activities, countries, regions, etc on the environment. For countries with mono-cultural economies, it is easier to estimate the impact of the main source of the country's foreign exchange on the environment. This research focuses on how to use Carbon (IV) Oxide (CO_2) Ecological Footprint (EF) and Isolated Thermodynamic System Approach for Oil and Gas producing countries as a tool for achieving the United Nations 2030 Agenda for Sustainable Development. Using the Nigerian Oil and Gas Industry as a case study, model for computing the CO_2 EF was developed with MATLAB 7.5.0 Software. In this research, Nigeria was viewed as an Isolated Thermodynamic system, hence, mass and energy cannot cross the Geographical boundary of Nigeria. This is a theoretical analysis as mass and energy can in reality cross the geographical boundary of any country. Viewing every country as an Isolated Thermodynamic system ensures that each country strives to live sustainably. This means the economic development of a country should be within the bio-capacity of its environment and should not be socially injurious at the same time. The Purpose of this research is to demonstrate how the CO_2 Ecological Footprint and the Isolated Thermodynamic system approach can be used as a tool for analyzing the sustainability of Oil and Gas Producing Countries. The United Nations 2030 Agenda for sustainable development can be easily achieved using this approach while ensuring the Oil and Gas Producing Countries whose economies benefit from the emission of CO_2 also bear some cost in accordance with the "Polluter Pays Principle"

Keywords: ecological footprint, isolated thermodynamic system, bio-capacity, sustainable development.

INTRODUCTION

Every country whose economic activity imposes impacts on the environment needs to pay some costs in line with the "polluter pays principle". As Oil and Gas Exporting countries generate economic benefits from the activity of their Oil and Gas industry, the impact of which transcends their national boundaries, there is need to provide a methods which prescribes what the countries should pay as a result of the impact on the environment. The payment could be in the form of developing facilities to sequester all the CO_2 emission that will result from the combustion of any barrel of Oil produced from any Oil producing country. Furthermore, it could be in the form of developing Forest reserves that will sequester all the released CO_2 by any Oil producing country. The view in this research is significantly different from what is currently obtainable with respect to CO_2 tax system, where the Oil and Gas producing counties are exempted from CO_2 tax on the Crude Oil and Gas that they export. The approach in this study will make each Oil and Gas producing country independently sustainable.

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. 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. With the launch of the UN 2030 Agenda for sustainable development (2015), the approach for combating the impact of CO_2 emission should be shifted to the source of Hydro-carbon generation rather than the Sink as it is currently being done. This study prescribes how the CO_2 EF of Oil and Gas Producing countries can be estimated and applied for sustainable development.

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.

Statement of the Problem

Oil and Gas Producing Countries currently get revenues from the Export of Oil and Gas without paying any corresponding cost on the pollution resulting from CO_2 emission. This approach needs to be reviewed in view of the need to meet the UN 2030 Agenda for sustainable development.

METHODOLOGY

This research uses Nigeria as a case study. Nigeria is viewed 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 green house gases without resulting in climate change. The CO_2 EF was computed based on the amount of Oil and Gas produced In Nigeria between 1961 and 2014 as shown in Appendix I and II. The cost of sequestering the emitted CO_2 based on the available technology for CO_2 sequestration as well as the size of the Forest was computed. The Methodology is summarized in figure 2

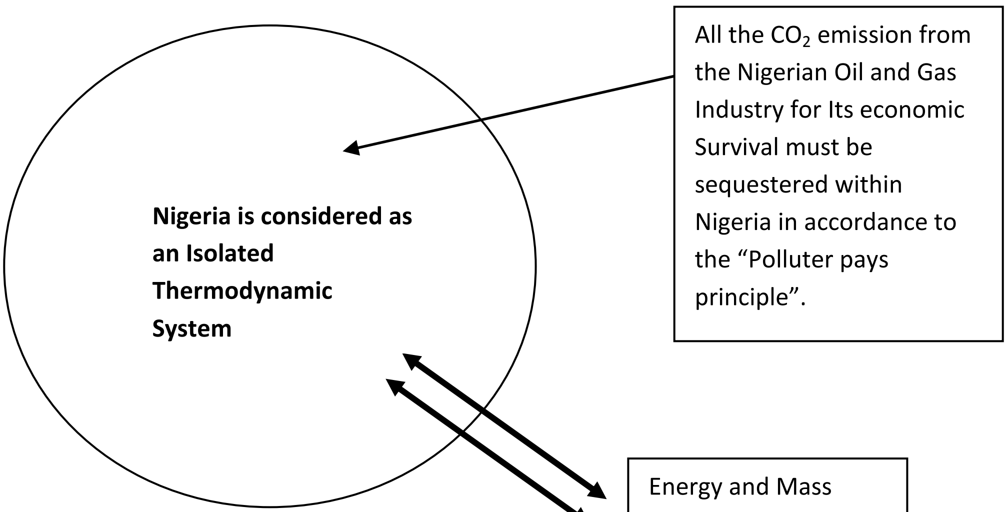

Figure 1: Nigeria as an Isolated Thermodynamic System

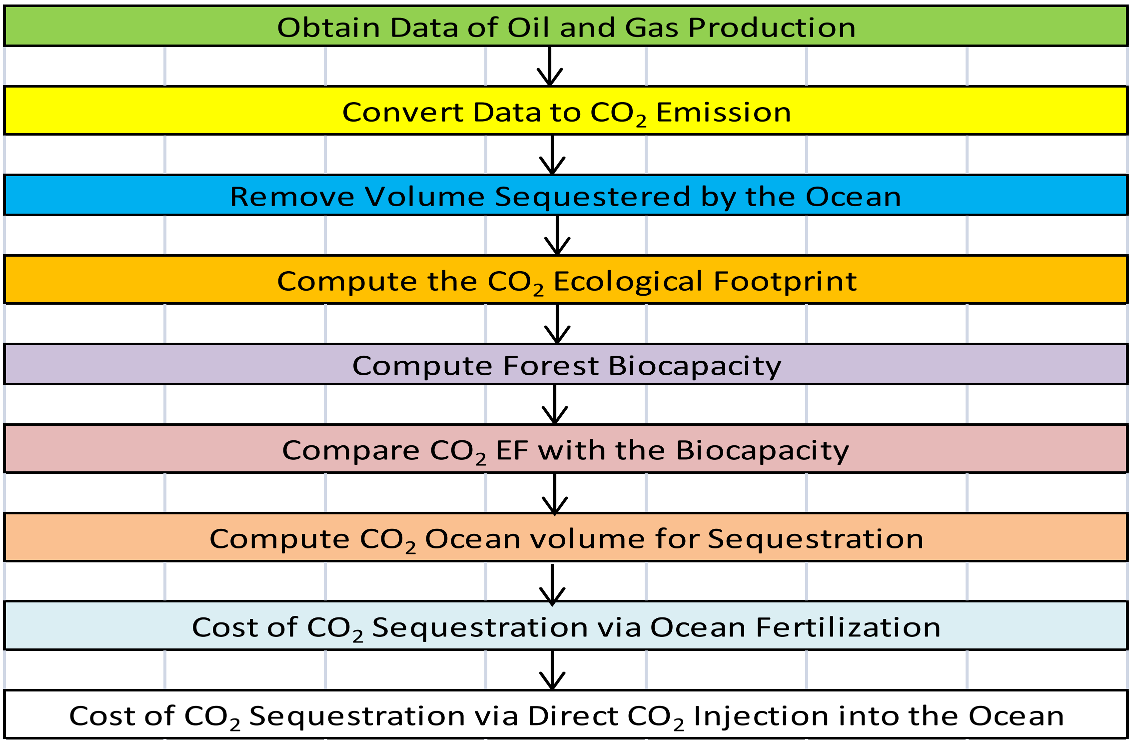

Figure 2: Flow chart for Ecological Footprint and Bio-capacity Estimation

The ecological footprint of the emitted CO_2 was calculated as follows as per Ewing et al., (2010):

$$EF = \frac{P}{Y_N} \times Y_F \times EQF \quad (1)$$

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 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.

RESULTS AND DISCUSSION

This research work agrees with the "polluter pays principle". Based on this study, two methods are presented for introduction of Carbon tax on the Oil and Gas Producing countries.

Tax based on the cost of available technology for CO_2 sequestration

This approach will impose penalty on the polluting country based on the quantity of CO_2 released into the environment. The methods of CO_2 sequestration considered for this costing is the direct injection of CO_2 to a depth above 3000m and the option of Ocean fertilization with highly enriched nutrients. In this methodology, the average cost of using the two methods was used for imposing the tax on the polluting Country based on the quantity of CO_2 emitted to the environment. The cost can be adjusted for different years based on the consumer price index for the year under consideration. The costing is based on the works of Williams and Druffel (1987) for Ocean fertilization and Akai et al (2004) for Ocean storage.

$$C_{Ocean\ injection}(US\$) = p_{01} * x^3 + p_{02} * x^2 + p_{03} * x + p_{04} \quad (2)$$

$p_{01} = 7.87e^{-8}$; $p_{02} = -1.924e^{-5}$;
$p_{03} = 0.02016$; $p_{04} = -0.03215$

$$C_{Ocean\ fertilization}(US\$) = p_{F1} * x^3 + p_{F2} * x^2 + \quad (3)$$

$p_{F1} = 1.334e^{-8}$; $p_{F2} = -3.27e^{-6}$;
$p_{F3} = 0.003426$; $p_{F4} = -0.005464$

Carbon (IV) Oxide Emission Tax (US$)
=

$$0.5 * [(p_{01}+p_{F1})x^3 + (p_{02}+p_{F2})x^2 + (p_{03}+p_{F3})x + p_{04} + p_{F4}] * [\frac{CPI(year) - 177.1}{177.1}] \quad (4)$$

Where x is Mass of CO_2 (Mtonnes) released by the country under consideration, $C_{Ocean\ injection}$ and $C_{Ocean\ fertilization}$ are the cost of CO_2 sequestration by Ocean Injection and Ocean Fertilization technologies respectively.

The mass of CO_2 (Kg) can be calculated as follows:

$$X\,(Kg) = 0.58289\,\rho_o\left(\frac{Kg}{m^3}\right) * V_o\,(bbl) + 1.9386V_{CH4}(m^3) \quad (5)$$

or in terms of Gas-Oil Ratio (GOR (Sm^3/Sm^3)) as follows:

$$X\,(Kg) = V_o\,(bbl)\left(0.58289\,\rho_o\left(\frac{Kg}{m^3}\right) + 12.2 * GOR\left(\frac{Sm^3}{Sm^3}\right)\right) \quad (6)$$

Where:

$\rho_o\left(\frac{Kg}{m^3}\right)$ *is the density of the Crude Oil*, $V_o\,(bbl)$ *is the volume of crude oil produced and* $V_{CH4}(m^3)$ *is the volume of natural gas produced.*

Use of Forest Plantation

The Second approach that can be used for sustainability of an Oil and Gas producing Country is to ensure the CO_2 ecological footprint resulting from Oil and Gas production is equal to the Bio-capacity of the Country under consideration. In this method, the Oil and Gas Company will maintain a size of forest which is equivalent to its ecological footprint in terms of bio-capacity for CO_2 sequestration. The ecological footprint based on Carbon (IV) oxide production is computed as follows for Nigeria:

$$EF_{CO_2} = P_1 * x + P_2 \quad (7)$$

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:

$p_1 = 0.2605; p_2 = 1.084 * e^{-014}$

The coefficient of determination for the model

$R^2 = 1.0.$

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

$$BC = NF_L \times Y_F \times EQF = EF_{CO_2} \quad (8)$$

$$NF_L = \frac{EF_{CO_2}}{Y_F \times EQF} = \frac{(P_1 * x + P_2)}{Y_F \times EQF} \quad (9)$$

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

CONCLUSION

The use of the Isolated Thermodynamic system approach for attaining the UN 2030 Agenda for sustainable development is a novel approach. This approach holds the Oil and Gas producing countries accountable for CO_2 emission as their economies benefit from the unfavorable impact of Oil and Gas production. This is in agreement with the "polluter pays principle". The method for estimating the cost to be imposed on Oil and Gas Producing countries has been presented in this study using the Nigerian Oil and Gas Industry as a case study. An alternative solution uses the CO_2 ecological footprint of an Oil and Gas producing Country to estimate the size of the Forest to be maintained to ensure all the emitted CO_2 due to the Combustion of a Country's Oil and Gas production are sequestered.

Contribution to Knowledge

This paper has demonstrated how the CO_2 EF and the concept of Isolated Thermodynamic System can be used to ensure the sustainability of the environment by imposing some Penalty on the Oil and Gas producing countries whose economies benefit from CO_2 emission. New models have been developed in this study. Focus has been shifted to the Source (Producers) of Hydrocarbon rather than the sink (consumers). Model for the size of Forest for CO_2 sequestration for environmental management has also been developed.

Limitations of the Study

The following are the limitations of the research done: The existing methods of computing the Ecological footprint can be narrowed down to CO_2 and are applicable to the Nigerian situation.

The reliance on available government data who are an interested party.

The release of CO_2 as a result of the activities of Oil and Gas Industry has been assumed to be a sensitive indicator of ecological footprint.

The developed models like all models are necessarily simplified and cannot include all interactions.

RECOMMENDATIONS FOR FURTHER STUDY

The United Nations Organisation should study the possibility of Inter-country trading Scheme for Carbon (IV) Oxide emission based on the Isolated Thermodynamic system approach for CO_2 emission from Oil and Gas Producing countries.

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Appendix I: Nigerian Oil Production from 1961 to 2014.

APPENDIX

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 II: 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