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Natural Gas as Transportation Fuel: Solution to National Carbon Dioxide Reduction and Fuel Related Issues in Nigeria

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***Abstract*—This In this study, strategic substitution of natural gas (NG) as transportation fuel in place of gasoline and diesel has been proposed due to the volume of NG flared on daily basis and its negative impacts on the micro-environment. Data on the volumes of gas flared and quantities of gasoline and diesel distributed from 2000 to 2014 used in this work were sourced from bulletins published by Nigerian National Petroleum Corporation. Empirical formulae and standard conversions were employed to estimate variables (carbon dioxide and cost benefits) based on current price regimes and energy contents of the fuels. The strategic utilization of NG - scenario 1 - (33% to 1% of flared volume) and the baseline (actual situation in 2014) were the two scenarios considered. Findings from this study revealed that at 33% and 1% utilization of flared gas (11.30 x 10^9 m^3), CO_2 released were 2.5 x 10^7 tons and 3.43 x 10^7 tons, as against 3.46 x 10^7 (scenario 1) and 3.42 x 10^7 tons emitted for the baseline scenario, respectively. These values correspond to CO_2 reduction of 9.63 x 10^6 tons (27.79%) and 2.92 x 10^5 tons (0.84%), for 33% and 1% NG utilization, respectively. Based on energy contents of the fuels, NG as transport fuel is 60.7% and 62.5% cheaper than gasoline and diesel, respectively. The implementation of strategic NG substitution as transportation fuel proposed seems a lasting solution to gas flaring, and petroleum products and their associated problems in Nigeria.**

Keywords*— *Natural gas; Gas flaring; Diesel; Gasoline; Carbon dioxide; Nigeria; Strategic substitution

I. INTRODUCTION

One of the most fundamental issues for sustainable development is energy. Economic and technological development of a nation is strongly connected to energy. Energy security of a nation must be vigorously pursued with the ultimate aim of energy independence. In Nigeria, over 70% of the petroleum products used in the country are imported despite her being the 10th largest oil producer in the world [1]. In August, 2015, 376.02 x 10^6 litres and 6.54 x 10^6 litres of premium motor spirit (gasoline) and automotive gas oil (diesel), respectively, were distributed for consumption in the country [2]. The distribution of these fuels are oftentimes characterized with variation in their prices, long queues at fuel stations, scarcity of supply, increase in transport fare, injuries, ripple effect on prices of other commodities etc., especially for gasoline as its demand is more. The transport sub-sector is second to the largest contributor (gas flaring sub-sector) in the energy sector as reported in the year 2000 for national emission inventory [3]. Emissions from these sub-sectors translate to 40.3% and 18.4% (energy sector) and, 24% and 12.1% (total national emissions) for gas flaring (GF) and transport sub-sectors, respectively.

In context with the above, continuous GF activities (since inception of oil exploitation operations) in Nigeria have ranked the country second to Russia in the world in terms of the volume of GF [4]. Several attempts at putting a stop to this barbaric act of international concern have proved abortive and this singular action has been tagged globally as wastage of natural resource and a significant source of emission [5,6,]. Elvidge et al. [7] reported that the estimated amount of GF in Nigeria in 2008 was 15.1 billion cubic meter (bcm). The huge amount of money lost annually due to GF over a long period of time is incomparable to the devastating effect of this action on immediate environment and people in the vicinity of flare sites all over the Niger Delta region of Nigeria [4,6].

In light of this, the use of NG as transportation fuel to substitute gasoline and diesel has been suggested at different fora by several authors as a probable lasting solution to curb the notorious act of GF and the problems linked to it [5,6,8,9]. Among the reasons highlighted for the future use of NG in vehicles, especially in compressed form included; economic advantage, environmental friendliness, non-dependency on imported fuel, reduction of flared gas, increased domestic utilization of NG, low-carbon strategy and conservation of oil reserves. Owing to the fact that the country is blessed with more gas than oil with an estimated reserve of 187 trillion cubic meter, the strategic substitution of NG for gasoline and diesel is inevitable. In addition, the technology to this effect is not new as it has been in operation in other countries long before now. Nigeria is rich in NG but its use as transportation fuel in the form of compressed natural gas (CNG) is in its infancy with a pilot project inaugurated in 2010 in Edo State, which was promoted by the Nigerian Independent Petroleum Company in partnership with the Nigeria Gas Company [8].

CNG is a fossil fuel substitute for gasoline, diesel, or propane (liquefied petroleum gas). It is a more environmentally clean alternative to those of other fossil fuels. The use of CNG in vehicles has a wide range of advantages over gasoline and diesel. CNG is used in traditional gasoline and diesel vehicles that have been converted into bi-fuel vehicles or dedicated vehicles. The primary purpose of this paper was to assess the possible use of strategic NG substitution for gasoline and diesel as transportation fuel in Nigeria. This is in order to reduce the volume of gas flared by increasing NG utilization beyond its present use. Consequently, this would mainly address the problems of gas flaring, national GHG emissions, supply, distribution and cost of gasoline and diesel in the country.

II. MATERIALS AND METHOD

A. Study Area

The Niger Delta region of Nigeria is currently the sole deposit of oil and gas which accounts for over 95% of export income and around 85% of national revenue [9]. This region is the second largest mangrove forest in the world and it is a renowned hotspot for biodiversity conservation [10]. The region‘s biodiversity is seriously threatened by the continuous degradation of the micro-environment as a result of oil and gas exploration activities.

B. Data Source, Collection and Analysis

The data utilized in this study were sourced from bulletins released by the national agency (Nigerian National Petroleum Corporation) overseeing oil and gas sector of the country. Information on the volume of gas produced, flared, percent flared and the quantity of gasoline and diesel distributed in Nigeria was collected for a period of 15 years (2000 to 2014). The volume of gas was in cubic meter while that of gasoline and diesel were in liters. Microsoft Excel (2013) was used as the statistical tool to calculate and analyze the data gathered. The correlation between the volume of gas produced, GF, gasoline and diesel was carried in addition to analysis of variance test at 95% confidence interval to check the significance of the data employed in this study. The cost benefits of utilizing NG as transportation fuel was also estimated and analyzed.

C. Calculations

Of the emissions discharged into the atmosphere from burning of diesel, gasoline and NG, CO_2 is prevalence and constitutes a major environmental footprint. The estimation of the amount of CO_2 emitted from the burning of the aforementioned fuels were carried out with using empirical formulars. The cost benefits of substituting NG for gasoline and diesel were also estimated. Basic conversions (Eqs. 1-7), empirical formular (Eqs. 10) and emission factors (in Eqs. 11-12) were obtained from literature [11,12] while mathematical expressions (Eqs. 8-9 and 11-16) were developed.

$$1\ ft^3 = 0.0283\ m^3 \quad (1)$$

$$126.67\ ft^3 = 1\ GGE = 4.5\ l \quad (2)$$

$$131.73\ ft^3 = 1\ DGE = 3.785\ l \quad (3)$$

$$1.14\ GGE = 1\ DGE \quad (4)$$

$$8.91\ kg\ of\ CO_2 = 1\ gallon\ of\ gasoline \quad (5)$$

$$10.15\ kg\ of\ CO_2 = 1\ gallon\ of\ diesel \quad (6)$$

$$0.0545\ kg\ of\ CO_2 = 1\ ft^3\ of\ NG \quad (7)$$

$$NG_{GE}\ (l) = ((\%GF\ (m^3)\ x\ GGE\ (l) \times Ratio_G))/(3.587\ m^3) \quad (8)$$

$$NG_{DE}\ (l) = ((\%GF\ (m^3)\ x\ DGE\ (l) \times Ratio_D))/(3.7279\ m^3) \quad (9)$$

$$CO_2\ (F)\ (tons) = (GF \times molar\ volume \times MW\ (CO_2) \times mass\ conversion \times (\sum(((mole\ Hydrocarbon)/(mole\ gas) \times (A\ mole\ C)/(mole\ Hydrocarbon) \times (0.98\ mole\ CO_2\ formed)/(mole\ C\ combusted))) + (B\ mole\ CO_2)/(mole\ gas)) \quad (10)$$

$$CO_2\ (G)\ (tons) = (V_G\ (l) \times \rho_G\ (kg/l) \times HHV_G\ (MJ/kg) \times EF_G\ (kg/TJ) \times 10^{-6}\ (tons)) \quad (11)$$

$$CO_2\ (D)\ (tons) = (V_D\ (l) \times \rho_D\ (kg/l) \times HHV_D\ (MJ/kg) \times EF_D\ (kg/TJ) \times 10^{-6}\ (tons)) \quad (12)$$

$$CO_2\ (NG_{ge})\ (tons) = 1.956 \times NG_{GE} \times Ratio_G \times ton/1000 \quad (13)$$

$$CO_2\ (NG_{de})\ (tons) = 2.668 \times NG_{DE} \times Ratio_D \times ton/1000 \quad (14)$$

$$CO_2\ (T)\ (tons) = CO_2\ (F) + CO_2\ (G) + CO_2\ (D) + CO_2\ (NG_{ge}) + CO_2\ (NG_{de}) \quad (15)$$

$$CO_2\ (S)_{(@\ X\%\ GF)}\ (tons) = CO_2\ (T)_{@\ 100\%\ GF)} - CO_2\ (T)_{@\ X\%\ GF\ utilized)} \quad (16)$$

Where:
ft^3= Cubic feet;
m^3 = Cubic meter;
l = Liter;
kg = Kilogram;
GF = Gas flared in m^3;
$Ratio_G$ = Ratio of fifteen years distribution of gasoline to diesel (0.857);
$Ratio_D$ = Ratio of fifteen years distribution of diesel to gasoline (0.143);
NG_{GE} = Natural gas gasoline equivalent in liter;
NG_{DE} = Natural gas diesel equivalent in liter;
GGE = Gallon gasoline equivalent;
DGE = Diesel gasoline equivalent;
CO_2 (F) = Carbon dioxide from flared gas in tonnes;
CO_2 (G) = Carbon dioxide from combustion of gasoline in tonnes;
CO_2 (D) = Carbon dioxide from combustion of gasoline in tonnes;
CO_2 (NG_{ge}) = Carbon dioxide from combustion of NG-based gasoline in tonnes;
CO_2 (NG_{de}) = Carbon dioxide from combustion of NG-based gasoline in tonnes;
CO_2 (T) = Total carbon dioxide in tonnes;
CO_2 (S) = Carbon dioxide saved (in tonnes) using strategic fuel substitution;
ρ_G = Density of gasoline (0.745 kg/l);
ρ_D = Density of diesel (0.832 kg/l);
V_G = Volume of gasoline in liters;
V_D = Volume of diesel in liters;
HHV_D = Higher heating value of diesel (45.77 MJ/kg);
HHV_G = Higher heating value of gasoline (46.54 MJ/kg);
EF_G = Emission factor of CO_2 for gasoline engine (69300 kg/TJ);
EF_D = Emission factor of CO_2 for diesel engine (74100 kg/TJ);
Molar volume = conversion from molar volume to mass (23.685 m^3/kgmole);
$MW_{(CO2)}$ = CO_2 molecular weight;
Mass conversion = tonne/1000 kg;
A = the number of moles of carbon for the particular hydrocarbon;
B = the moles of CO_2 present in the flared gas stream.

It is worth noting that the NG composition of Nigeria origin was engaged in this work as utilized and reported in literature [11].

A. Procedures

The procedures undertaken with some assumptions made in this study demand details. Also, the need to succinctly describe the procedures used in this work for proper understanding of the subject is paramount. The procedures include:

i. Fifteen year data as earlier stated were used in order to probe back in terms of the key input parameters (volume of gas produced, GF, gasoline and diesel) used in the study. Since the data for the year 2015 were not complete as at the time of this work, 2014 was used as baseline year.

ii. The total volume of GF in 2014 was assumed to be utilized as transportation fuel in vehicles, hence converted to gasoline and diesel equivalents in terms of energy content. The average ratio of distribution of gasoline and diesel for 15 years as obtained from NNPC was used in rationing the NG-sourced gasoline and diesel. These involved Eqs. (1-4 and 8-9).

iii. The percent of the total amount of GF approximately equals to the volume of gasoline and diesel distributed for the baseline year subject to the ratio mentioned in (ii) was determined. Maximum of 33% of total GF in 2014 gave approximately the volume of both gasoline and diesel for the baseline year. Therefore, this informed the choice of NG utilization (from 33, 30, 25, 20, 15, 10, 5, 3, 1 and 100%) of the total GF for this work. This is termed scenario 1, which involved the strategic NG substitution. The second scenario is termed baseline scenario, where the actual values of the amount of gasoline and diesel distributed as sourced from NNPC in the year 2014 was used. The 100% in scenario 1 and the baseline scenario are for comparison purposes.

iv. For scenario 1 at 33% utilization of the total GF, no gasoline and diesel was utilized since the entire NG equivalent of gasoline and diesel were used. At less than 33% use of the flared gas as fuel, gasoline and diesel were utilized to complement the total fuel distributed for use. This provides for flexibility in the quantity (% flared gas) that can be used as fuel from 33% to 1%.

v. The amounts of CO_2 from the volume of GF, volume of NG equivalent of gasoline and diesel and volume of gasoline and diesel consumed were estimated depending on the percent of flared gas utilized as transportation fuel (scenario 1). Eqs. (5-7, 10-14) were used for estimation of the amounts of CO_2 from the fuels (flared gas, NG-sourced gasoline and diesel, diesel and gasoline).

vi. Estimated total CO_2 released via this work was the sum of CO_2 from all the fuels (Eq. (15)) while estimated total CO_2 saved at specific percent utilization of flared gas was estimated as total CO_2 at 100% flaring of gas minus estimated total CO_2 at the same specific percent utilization of flared gas (Eq. (16)).

vii. Energy contents of the fuels and the current local prices were used to evaluate the cost benefits of using NG as fuel substitute for gasoline and diesel. The payback period was also estimated based on the price of NG and the cost of engine retrofitting.

viii. The exchange rate used was Nigerian Naira (N) 197 to US$1. The price of N86.50 per liter (gasoline), N120 per liter (diesel) and $2.5 per 1,000 ft^3 (N17.32 per m^3) was used in this work. Energy contents of 1 gallon of gasoline and diesel, and NG were taken as 125,000 BTU (British thermal unit), 139,200 BTU and 1,050 BTU. Engine retrofitting cost was N150,000.

III. RESULTS AND DISCUSSION

A. Gas Flaring and Pretroleum Consumption

A.1 Gas Flaring

GF is a wasteful and destructive act which has been on in the country for more than five decades. The irremediable and immeasurable implication of this notorious action lives with us as a nation and it is hugely bore by the inhabitants of the micro-environment of the Niger Delta region. Domestically, this act has left indelible footprint of environmental degradation, ecological destruction, socio-economic problems and serious health concerns. National and global effects of gas flaring as to do with the colossal damage on the atmosphere due to the discharge of obnoxious gases and particles [13]. Though GF flaring activities in the country is on the decline due to fair increase in the utilization of NG domestically and as export commodity, internationally. As seen in Table 1, percent GF has decreased from 56.76% in 2000 to 15.28% in 2014. Apparently, this shows a considerable reduction in the volume of GF yet the quantity of gas produced signifies that the quantity flared is still much and this needs to be addressed urgently. CO_2 from the flaring of gas contributes to global warming and this source is nationally important as it contributes to 24% of total national emission in the year 2000 [3].

TABLE 1. GAS FLARING (MILLION CUBIC METER) AND, GASOLINE AND DIESEL (000 LITERS) DISTRIBUTION IN NIGERIA

Year	GP	GF	%GF	Gasoline	Diesel
2000	42,732	24,255	56.76	4,761,073	1,985,639
2001	52,453	26,759	51.02	7,142,715	2,664,542
2002	48,192	24,836	51.53	8,687,595	2,645,976
2003	51,766	23,943	46.25	8,725,938	2,375,711
2004	58,964	25,091	42.55	8,676,810	1,916,000
2005	59,285	23,003	38.80	8,644,260	2,368,000
2006	82,037	28,584	34.84	8,306,985	1,649,749
2007	84,707	27,307	32.24	8,859,802	1,384,956
2008	80,604	21,811	27.06	7,206,729	1,273,203
2009	64,883	17,988	27.72	6,876,577	648,417
2010	67,758	16,468	24.30	6,353,518	879,368
2011	60,720	12,318	20.29	5,688,450	977,892
2012	64,695	11,279	17.43	5,017,535	676,728
2013	61,642	12,701	20.60	3,816,267	733,822
2014	72,962	11,269	15.28	3,969,710	397,898

Note: GP = Gas Produced; GF = Gas Flared. Source: [16 -23]

A.2 Petroleum Products Consumption

The volume of gasoline and diesel distributed from 2000 to 2014 is presented in Table 1. A reduction in the quantities distributed in the country was observed from 2007 to 2013. This may be due to increased utilization of renewable energies and NG for electricity generation by some companies in the country. From Table 1, it was observed that more of gasoline was distributed compared to diesel. This increase is in multiple of five to seven and can be attributed to the demand and applications of gasoline as fuel to that of diesel. The average ratio of distribution of gasoline to diesel was 7:1 (Table 1). Combustion of these fuels in internal combustion engines, especially in the transport sector can lead to release of pollutants (majorly CO_2) into the atmosphere which contributes to global warming and climate change. Nationally, the transport sector has been reported to contribute 12.1% of total emissions in the country [3]. This value reflects 18.4% of the total national emissions from the energy sector.

TABLE 2. CARBON DIOXIDE (TONS) FROM GAS FLARING AND CONVENTIONAL FUELS (GASOLINE AND DIESEL)

Year	CO_2 (GF)	CO_2 (Gasoline)	CO_2 (Diesel)	CO_2 (Total)
2000	50,598,437	11,439,860	5,603,027	67,641,325
2001	55,822,040	17,162,447	7,518,739	80,503,226
2002	51,809,587	20,874,470	7,466,350	80,150,407
2003	49,947,635	20,966,600	6,703,723	77,617,958
2004	52,342,232	20,848,556	5,406,522	78,597,309
2005	47,986,030	20,770,345	6,681,964	75,438,340
2006	59,629,992	19,959,944	4,655,221	84,245,157
2007	56,965,495	21,288,247	3,908,036	82,161,778
2008	45,500,000	17,316,258	3,592,693	66,408,952
2009	37,523,972	16,522,973	1,829,687	55,876,631
2010	34,354,326	15,266,172	2,481,378	52,101,875
2011	25,696,162	13,668,152	2,759,391	42,123,705
2012	23,528,117	12,056,085	1,909,574	37,493,775
2013	26,494,764	9,169,690	2,070,681	37,735,135
2014	23,509,175	9,538,380	1,122,779	34,170,334

B. Carbon Dioxide from Gas Flaring and Petroleum Products Consumption

Table 2 shows the quantity of CO_2 released through the flaring of NG and consumption of gasoline and diesel. Estimated total CO_2 from GF, gasoline and diesel were 7.41 x 10^7 tons, 2.10 x 10^7 tons and 6.73 x 10^6 tons, respectively, for the 15-year consideration (Table 2). For the baseline year, 2.35 x 10^7 tons, 9.54 x 10^6 tons and 1.12 x 10^6 tons of CO_2 were estimated for GF, gasoline and diesel. For the duo of petroleum products a sum of 1.07 x 10^7 tons of CO_2 were discharged into the environment (Table 2). Obviously, the amount of CO_2 released via gas flaring (2.35 x 10^7 tons) is significantly higher (1.78 x 10^7 tons) than the combined CO_2 emitted through gasoline and diesel. This is corroborated by the fact provided in the national emission inventory that the total emissions from gas flaring (24%) is more than total emissions from transport (12.1%), as the transport section of the nation uses mainly gasoline and diesel as fuel.

In this context, the two main contributors to the amount of CO_2 released from the energy sector (responsible for 53.6% of total CO_2 emission and 70.4% of national total GHG emission (1.55 x 10^8 CO_2 e)); gas flaring and transport sub-sectors can be harnessed as sources of CO_2 reduction on national scale. The carbon and environmental footprints as presented by both the current study and national emission inventory show the urgency to addressing the amounts of CO_2 released to the environment as a country. In addition, the global clamour to cut down CO_2 emissions by nations of the world (Nigeria inclusive) and the global drive to curb global warming and climate change, this nation is under compulsion to seek ways and technologies to reduce CO_2 emission. Furthermore, in consonance with the international outcry for sustainable development in terms of sustainable energy development and sustainable environment, the large quantity of CO_2 from these two sources needs prompt attention.

C. Strategic NG Utilization

The substitution of NG for conventional fuels (gasoline and diesel) using various percent of total volume of GF (from 33% to 1%) is presented in Table 3. The strategy herein is that different percent of the volume of GF can be employed at any point in time to displace the use of gasoline and diesel distributed for consumption. For this study, the strategy is that at 33% utilization of flared gas as fuel substitute for gasoline and diesel, 3.72 x 10^9 m^3 of NG is available, which translate to 39.98 x 10^8 l of gasoline and 53.99 x 10^7 l of diesel equivalent in energy terms (Table 3). As these volumes of NG equivalent of gasoline and diesel correspond to the total volume of gasoline and diesel distributed in the year 2014, the supply is sufficient and there is no need for gasoline and diesel fuel for use. At less than 33% utilization of GF, there is need to use gasoline and diesel to complement the supply as there will be shortfall in supply of the petroleum products. It can be seen in Table 3 that the more the volume of NG used as substitute to gasoline and diesel, the less of these products are consumed and vice versa.

TABLE 3. SUBSTITUTION OF NATURAL GAS FOR CONVENTIONAL FUELS

GF utilized (%)	NG (10^7 m^3)	NG_{GE} (10^7 liter)	NG_{DE} (10^7 liter)	Gasoline (10^8 liter)	Diesel (10^7 liter)
33	371.88	399.82	53.99	0	0
30	338.07	363.47	49.08	3.63	4.91
25	281.73	302.89	40.90	9.69	13.09
20	225.38	242.31	32.73	15.75	21.27
15	169.04	181.74	24.54	21.81	29.45
10	112.69	121.16	16.36	27.87	37.63
5	56.35	60.58	8.18	33.92	45.81
3	33.81	36.35	4.91	36.35	49.08
1	11.27	12.12	1.64	38.77	52.36

D. Carbon Dioxide Reduction by Strategic NG Utilization

The amounts of CO_2 emitted under the fuel substitution strategy are illustrated in Figure 1. From Table 3, the volumes of fuels used for the strategic NG substitution were given while in Figure 1, the CO_2 released from these fuels are shown. It can be observed that increase in NG substitution via percent of GF utilized (33% to 1%) results in reduction in CO_2 released in burning the fuels (see Figure 1). Comparing the substitution strategy with the 100% flaring of NG (inclusive of total volume of petroleum products), reduction in the quantity of CO_2 was noticed. In addition, the more the volume of fuels substituted (less volume of NG-equivalent diesel and gasoline), the more the amount of CO_2 emitted from gas flaring and consumption of diesel and gasoline. At 100% gas flared (0% NG utilization), CO_2 released is the sum of CO_2 from flaring and combustion of total volume of gasoline and diesel (under scenario 1). The latter is similar to the baseline scenario where 100% actual total volume of gas is flared and 100% actual total volume of gasoline and diesel are burnt.

The aforementioned reduction in the amounts of CO_2 due to the fuel substitution strategy is clearly illustrated in Figure 1. Based on the strategic NG substitution involving the two scenarios, the same trend is observed for total CO_2, volume of GF, CO_2 from GF and combustion of gasoline and diesel (Figure 1). This trend is indicative of the fact that there is a gradual decrease in the aforementioned variables as shown in Figure 1 as the NG substitution strategy is increasingly applied. That is, as the percent NG utilized is increasing with the corresponding substitution of gasoline and diesel, the volume of GF, total CO_2 and CO_2 from GF, and gasoline-diesel consumption are decreasing. This also applies to the 100% gas flaring situation in scenario 1 and the baseline scenario.

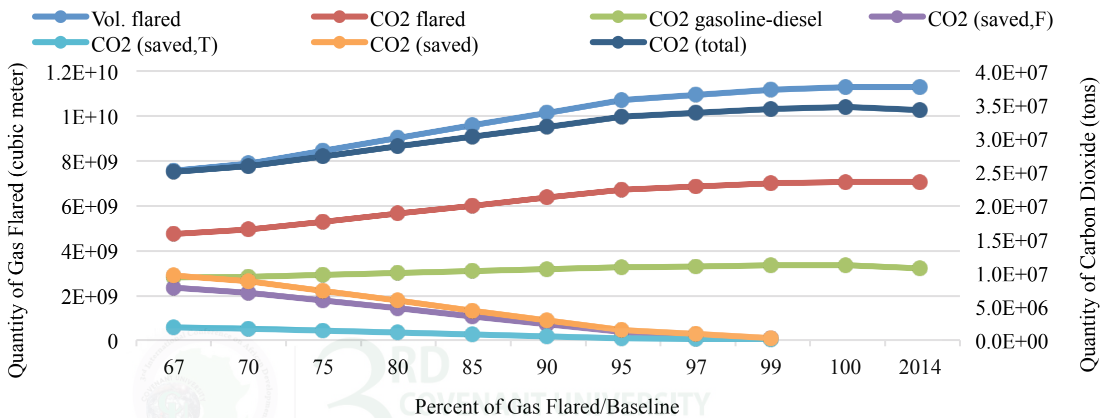

Fig. 1. Carbon dioxide reduction via strategic NG substitution

Since two main sources of CO_2 (gas flaring and transportation) are involved in this study using strategic NG substitution, CO_2 reduction is to be achieved at both sources. As observed in Figure 1, CO_2 saved from GF, transportation and total CO_2 from these sources follow the same pattern. The increase in the strategic substitution of NG for gasoline and diesel has impacted positively on reducing CO_2 from these sources. With a gradual increase in percent of flared gas used as NG substitute, an increase in the amount of CO_2 saved from these sources is observed in Figure 1. At 33% utilization of the total volume of GF, total CO_2 was 2.5×10^7 tons, which implies that 9.63×10^6 tons (27.79%) of CO_2 were saved using the strategic fuel substitution as against 3.46×10^7 tons and 3.42×10^7 tons at 100% flaring situation and baseline scenario, respectively. Also, at the least volume of GF (1%) utilized for fuel substitution, 0.84% (2.9×10^5 tons) of CO_2 (3.43×10^7 tons) was saved. This demonstrates that the percent reduction of CO_2 possible from the two sources subject to the strategic fuel substitution (33% to 1%) is between 27.79% and 0.84%. By deduction, the more the volume of GF available for fuel substitution, the more the amount of CO_2 saved.

E. Statistical Analysis Result

In this present study, correlation coefficients of -0.0463, 0.0856, -0.5301, 0.7888, 0.7904 and 0.6610 were obtained as relationships between GF and gas produced, gasoline and gas produced, diesel and gas produced, gasoline and GF, diesel and GF, and diesel and gasoline, respectively. Of all these, moderately strong and positive relationships exist between gasoline and GF, diesel and GF, and diesel and gasoline while negative and fairly strong correlation exists between diesel and gas produced. For GF and gas produced, and gasoline and gas produced, very weak and negative, and very weak and positive relationship exist, respectively. In addition, the ANOVA test carried out on all the data used in this work showed that the data were statistically not the same as indicated by $F_{critical}$ (2.7694) < $F_{observed}$ (159.1). With P-value << 0.00001 at 95% confidence interval, the data obtained and employed in this study were significant.

F. Cost Benefits

F.1 Based on Energy Content

For the development of strategic NG substitution to be viable, each segment of the chain must be feasible in its own right. For this reason, the economics of NG supply is considered solely. GGE is the amount of alternative fuel equal to the energy content of one gallon of petrol. GGE allows consumers to compare the cost of competing other fuels against gasoline. In the light of the above, NG (₦1,213/mmBTU) is clearly of lower cost compared to gasoline (₦3,114/mmBTU) and diesel (₦3,270/mmBTU) in terms of energy content. The economic benefit of NG as a substitute fuel shows 61.0% and 62.9% cost reduction for gasoline and diesel, respectively. This result is in agreement with previous study which reported that NG is at least 30% cheaper than gasoline [14].

F.2 Based on Mileage and Payback Period

For this study, cost per millage of N5.5/km for NG in car (gasoline engine) and N7.5/km for NG in bus (diesel engine) as against N14/km and N20/km, for gasoline and diesel respectively, was adopted [14]. It was observed that the percent cost reductions (60.7%, gasoline; 62.5%, diesel) based on energy content reported was similar to the values estimated in this study. Thus, this informed the choice of the cost per millage. Since this work is similar to a previous study in this regard, it can be reported here that profits of N850/day (N8.50/km) and N1250/day (N14/km) for a distance of 100 km are obtained. A payback period of 6 months is also reported for initial cost of N150,000 in retrofitting the engine [14].

G. Implication of Strategic Fuel Substitution on Sustainable Development

Millennium development goals (MDGs) gave birth to sustainable development goals (SDGs) on September 25, 2015 as countries of the world adopted a set of goals to end poverty, protect the planet and ensure prosperity for all [15]. In order to achieve the said milestones in the next 15 years, 17 goals with specific targets were highlighted. As Nigeria is a signatory to this global treaty, the onus is on the country to fashion out policies, plans and strategies to implementing the SDGs. This can go a long way in addressing the issue of SD in both the Niger Delta region (gas flaring activities) and the whole country (gasoline and diesel consumption in the transport sector and gas flaring operations) as it relates to this present study.

The fact that gas flaring and transportation are majorly significant sources of emission is corroborated by the national emission inventory [3]. In Nigeria, the indiscriminate flaring of NG and unsustainable consumption of gasoline and diesel which affect both energy and environmental sustainability could be solved via the strategic substitution of fuel using NG. In view of the findings of this study, the strategy of fuel substitution seems a potential way of abating CO_2 emissions from the two sources under focus, which by extension reduces the national emission of CO_2 in the country. This assertion is supported by a previous study on the assessment of millennium development goal 7 in the Niger Delta region of Nigeria via emissions inventory of flared gas that considerably progress has been achieved through increased NG utilization that has significantly reduced gas flaring [11]. In similar way, the strategic fuel substitution presented in this work could assist in achieving the SDGs, especially goals 7 (ensuring access to affordable, reliable and sustainable energy) and 13 (urgent action to combat climate change and its impacts).

NG substitution strategy is not rocket science but a long existing technology that can be tapped into to ameliorate or solve completely the protracted fuel supply and distribution related problems in the country. The political will-power of the government serving as the driving force towards achieving the aforementioned and unending list of merits attached to it is fundamental.

H. Conclusion

This study proposed strategic substitution of NG as transportation fuel in place of gasoline and diesel. The results obtained from this work showed that at 33% and 1% utilization of flared gas, CO_2 released were estimated as 2.5 x10^7 tons and 3.43 x 10^7 tons, compared to 3.46 x 10^7 tons (scenario 1) and 3.42 x10^7 tons released for the baseline scenario, respectively. These results correspond to CO_2 decrease by 9.63 x 10^6 tons (27.79%) and 2.92 x 10^5 tons (0.84%), for 33% and 1% NG utilization, respectively. Based on energy contents of the fuels, CNG use as transport fuel is 60.7% and 61.0% cheaper than gasoline and diesel, respectively, with six months of payback period on engine retrofitting. The results revealed the possible positive impact of this work on SDGs.

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Appendix

From Eq. (2), the cost per energy content of gasoline is given as:

1 gallon of gasoline = 125000 BTU and 1 gallon of gasoline = 4.5 l

1 l (gasoline) = 27,778 BTU

At the current pump price of gasoline in Nigeria = ₦86.50/liter

This implies that 1 l (gasoline) = ₦86.50/27,778 BTU = ₦3,114/mmBTU.

Also, using Eq.(3) to estimate the cost per energy content of diesel:

Energy content of 1 gallon of diesel =139,200 BTU and 1 gallon of diesel = 3.785 l

1 l (diesel) = 36,777 BTU

At the current pump price of diesel (Nigeria) = ₦120/l

This gives 1 l of diesel = ₦120/36777 BTU = ₦3,270/mmBTU

For cost per energy content of NG,1 ft^3 of NG = 1,050 BTU

1 m^3 of NG = 35.34 ft^3 = 35.34 x 1050 BTU = 37,102 BTU

At the current pump price of CNG in Nigeria = ₦45/m^3

This implies 1 l of NG = ₦45/37,102 BTU = ₦1,213/mmBTU.

