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ASSESSMENT OF CARBON (IV) OXIDE (CO₂) EMISSION IN SOME SELECTED INDUSTRY AT AGBARA INDUSTRIAL ESTATE, OGUN STATE NIGERIA

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ABSTRACT

The Nigerian manufacturing industries represents a major contributor of the country's Carbon (IV) Oxide (CO₂) foot print and in spite of this, little has been done on the assessment of CO₂ emission in the Nigerian manufacturing industries with a view of discerning the nature of CO₂ emission in the sector in order to pave the way for its sustainable management. As a result, this study was aimed at contributing to the local and ultimately the global efforts directed at managing CO₂ emission by assessing the CO₂ emissions in the Nigerian manufacturing industries by means of some selected industries at Agbara Industrial Estate, Ogun State. The aim of the study was to determine the amount of CO₂ emitted from the stationery sources of some selected industries in the study area between the period of Twelve months (June 2015 to May 2016) and to compare this amount with the inclusion threshold i.e. the maximum allowable amount of CO₂ emission of various emission management programme around the world using documented emission factors in measuring CO₂ emission. Twelve months' fuel consumption records of each emission source from each selected industry was collated and examined, this were then used to calculate the CO₂ emission for each emission source by multiplying the monthly volume/mass (as the case may be) of the fossil fuel combusted with the appropriate emission factor. Results showed that the average CO₂ emission of the assessed industries is quite large and required to be reduced over time as they are found to be way beyond the inclusion threshold of many carbon management programmes around the world. The results also showed that Natural gas fuel and natural gas combusting stationery equipments were the major contributors of the CO₂ emitted in the assessed industries. The study concluded that a significant amount of CO₂ was emitted by the assessed industries and these were majorly contributed by natural gas fuel combustion. It is therefore recommended that the manufacturing industries should focus attention on natural gas combusting sources for emission management activities, environmental regulators should develop an emission standards/programme where a cap or a pre-determined maximum allowable amount of CO₂ should be allocated to industries.

INTRODUCTION

Warming of the climate system is an undisputable fact of the 21st century (Intergovernmental Panel on Climate Change IPCC, 2001). Warming of the climate system is unequivocal, as it is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level (IPCC, 2007). Each of the last three decades has been successively warmer at the earth's surface than any preceding decades since 1850, and the period from 1983 to 2012 was likely the warmest 30-year period of the last 1400 years in the Northern Hemisphere (IPCC, 2014). The globally averaged combined land and ocean surface temperature data as calculated by a linear trend show a warming of 0.85 [0.65 to 1.06] °C over the period 1880 to 2012 (IPCC, 2014).

This observed increase in global average temperatures and the associated climate change has been attributed with a very high level of confidence and strong scientific consensus to the increase in anthropogenic greenhouse gases concentrations which is largely due to fossil fuel combustion and to a smaller extent due to changes in land use and deforestation (United Nations, 2013). These gases have been proved to be capable of absorbing infrared radiation as it is reflected from the earth's surface, therefore acting like a blanket, trapping heat, and keeping the earth warm, a process known as the greenhouse effect (World Resource Institute WRI, 2006). The Kyoto protocol identified six of these gases as very important and which require to be urgently addressed, they include, carbon dioxide (CO₂) the most prevalent, followed by methane (CH₄), nitrous oxide (N₂O), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs) and Sulphur hexafluoride (SF₆) in a decreasing order of prevalence (WRI, 2006).

Anthropogenic emissions CO₂ constitute by far the largest part of the emissions of greenhouse gases accounting for one third of the total CO₂ emission. The main sources of greenhouse gases due to human activity are: burning of fossil fuel and deforestation leading to higher CO₂

concentration in air (Simmons, 2010). Since the beginning of the Industrial Revolution, the levels of Green House Gasses (GHGs) in the atmosphere have been observed to have grown rapidly as a result of human activities, particularly due to the burning of fossil fuels like coal, oil, and natural gas as an energy source (WRI, 2006). IPCC (2014) reported that between 1750 and 2011, the cumulative anthropogenic CO₂ emissions to the atmosphere were 2040 ± 310 GtCO₂ which by far exceed the natural range over the last 650,000 years and of which half of this emissions occurred in the last 40 years. It was revealed that total anthropogenic GHGs emissions continuously increase from 1970 to 2010 with larger absolute increase between 2000 and 2010. In Nigeria, according to the second national communication of the country GHGs inventory to the united nation framework convention on climate change in 2014 by the Federal Ministry of Environment, Nigeria contributes about 214.21 million tones of CO₂ to the atmosphere in the year 2000 and as expected, the energy sector (fuel combustion and fugitive emissions) contributed the largest proportion (53.6%) of these emissions (Federal Ministry of Environment, 2015). Within this sector, combustion of fossil for powering industrial processes was identified as a major contributor to the atmospheric CO₂.

Energy-related activities have the dominant share of GHGs emissions in Nigeria and industrial activities have been identified as major contributor of the GHGs emissions (Federal Ministry of Environment, 2014). For example, the energy sector (fuel combustion and fugitive emissions) contributed the largest proportion (70%) to direct GHGs emissions in Nigeria in the year 2000 (latest year for which data were submitted to the UNFCCC as part of the national GHGs inventory communication) of which CO₂ was the largest contributor (74%) of the total energy sector emissions. The manufacturing and construction sub-sector accounted for 12.6% of the energy emissions in the same year after gas flaring and transportation subsector (Federal Ministry of Environment, 2014).

Meanwhile, Nigeria's vision for the industrial sector is a technologically driven and globally competitive sector, it is expected that this sector will account for a larger percentage of the fossil fuel energy demand in the nearest future. Consequently, this will have serious implication for climate change in the very near future. Thus, this sector should be a major focus towards sustainable management of future GHGs emissions in Nigeria. Since the assessment of the level of GHGs, particularly CO₂ emissions is an essential first step towards managing GHGs induced global warming, there is need for detailed, systematic and regular assessment of CO₂ emission in this sector of the economy, so that the best emission reduction opportunities could be identified. However, empirical studies on this observation are few to non existence as most of the studies on CO₂ emission are not related to the Nigeria manufacturing industry. Most studies that have been conducted emphasize oil industry pollution as a result of gas flaring (Nwaichi and Uzazobona , 2011), other studies are in relation to the construction industry (Edeoja and Edeoja, 2015), while other studies focus on the health implications of the magnitude of the problem of air pollution from road transportation (Okhimamhe and Okelola, 2013). The idea of this study is to fill this gap in research. This study therefore seeks to contribute to the efforts directed at managing GHGs emission by assessing the CO₂ emissions in the Nigerian manufacturing sector by means of some selected industries at Agbara industrial Estate, Ogun State. The information derived from the result of the study will first and foremost enable the likes of the selected manufacturing industries to identify opportunities to reduce emissions and draw up

a long-term plan to manage their company's impact on climate change. The result of the study will also be useful in the development of emission abatement policies aimed at accelerating energy efficiency improvement in the industrial sector in Nigeria. Furthermore, it is expected that the results will serve as a pilot for developing a more comprehensive database for future comparative analyses of CO₂ emission levels in the Nigeria manufacturing industry.

MATERIALS AND METHODS

Description of the study area

Agbara Industrial Estate is a model integrated town developed on 454.1 hectares of land and it is being managed by Agbara Estate Property Services Limited, a subsidiary of Lawson's Corporation Nigeria Limited. It is situated approximately 31 kilometers west of Lagos on the Lagos-Badagry expressway on high ground above the Owo River and derives its name from the neighboring Agbara Village (Fig. 1). The estate lies at the boundary of Ogun State and located between latitude 6°27' and 6°45' North and longitude 3°23' and 3°49' East (Agbara Estate Limited AEL, 2008).

Agbara Estate is on a laterite outcrop in an area of lowland behind the swamp forest of the Ologe Lagoon. It is fairly flat and approximately 50 feet above sea level, gently sloping into River Owo and the swamp areas to the south and east while gently undulating to the north and west. Few valleys dissect the site which is in an area of recent geological deposits with sandbanks and creeks behind the coast and a laterite outcrop to the north of the Badagry laterite 200mm - 250mm in depth with a low humus content and low pH level (AEL, 2008).

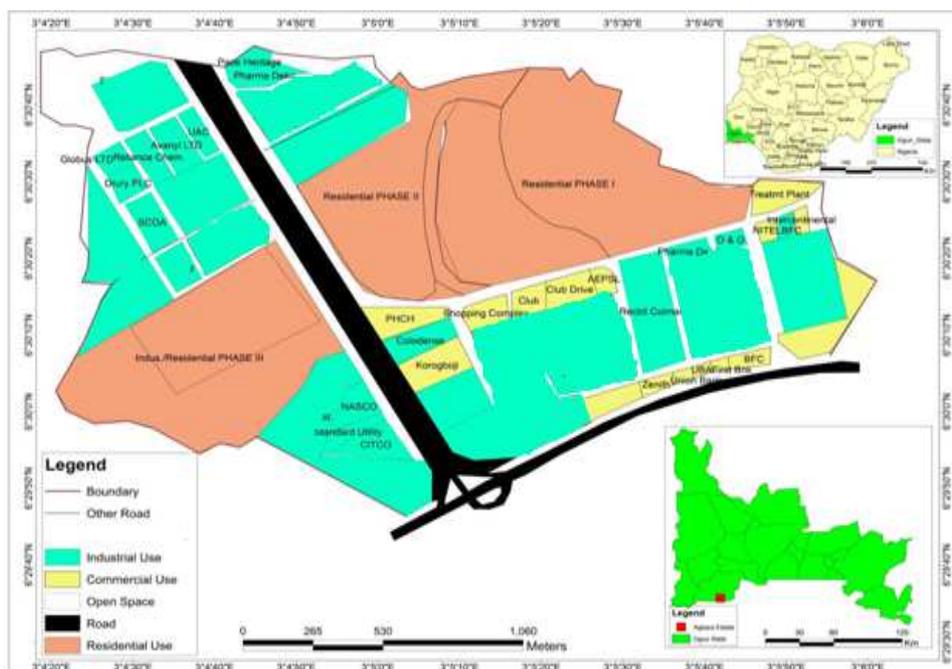


Fig 1: Agbara Industrial Estate, Ogun State, Nigeria

The Agbara Industrial Estate consists of industrial, commercial, residential and recreational sectors. The industrial sector constitutes 41.55% (188.2 hectares) of the whole Estate. The industrial area provides sites for a number of industrial, many of which are members of multinational conglomerates operating some of their most modern purpose built factories in the country (AEL, 2008). The study area is also an excellent mix of various types of manufacturing industries which fall into different sectoral groups according to the Manufacturers Association of Nigeria (MAN) industrial classification. These motives essentially informed why the study area was preferred for the study.

Scope of the study

The study covered CO₂ emissions from five MAN Industrial sectoral group: Food and Beverages and Tobacco, Chemical and Pharmaceutical, Domestic, Rubber and Plastic, Non-metallic Mineral Product and Metal, Iron and Steel industries. The study focused on emission that

come from stationary combustion i.e. combustion of fossil fuels in stationary equipment such as boilers, furnaces, generators, burners, turbines, heaters, incinerators, engines, flares, etc. and the emission estimation for a period of 12 months (June 2015-May 2016).

Industries selection

There are seventeen operational industries in the study areas at the time of the study and a total of five industries were selected for this study. The names of these industries were not used directly in this research for security purposes. A disproportionate stratified random sampling method was adopted for the industries selection. The stratification of the industries was based on the MAN industrial classification. All the industries in the study area fall into five MAN industrial strata as shown in Table 1. One industry from each sectoral group was randomly picked using dip in the basket method of random selection as shown in Table 1.

Table 1: Selection of industries

MAN industrial sectoral groups	Industries within each sectoral group	Selected industries for the study using dip in the basket
Food, beverages and tobacco sectoral group	Industry A Industry B Industry C Industry D Industry E	Industry D
Chemical and pharmaceutical sectoral group	Industry F Industry G Industry H Industry I Industry J Industry K Industry L Industry M	Industry G
Domestic and industrial plastic product, rubber and foam sectoral group	Industry N Industry O	Industry N
Nonmetallic mineral product sectoral group	Industry P	Industry P
Basic metal, iron and steel and fabricated metal products sectoral group	Industry Q	Industry Q

CO₂ emission and measurement

The use of documented emission factors in measuring CO₂ emission was adopted for this research and this method was selected because it is the recognized method of GHGs measurement by the United Nation Framework Convention on Climate Change (UNFCCC). The Emission Factor is the only method that realistically estimates the CO₂ emission in the study area due to the temporal scope of the study, the diversity of the emission sources and available resources. In this regard, a 12 months (June 2015-May 2016) fuel consumption records of each emission source (stationary equipment

that combust fossil fuel) from each selected industry was collated and examined. This provided the required information on the nature (type, volume and mass as the case may be) of the fossil fuel combusted in each emission source for the period under consideration. The CO₂ emitted from each source were then calculated by multiplying the monthly volume/mass (as the case may be) of the fossil fuel combusted during the studied period with the appropriate Emission Factor. The equation for estimating CO₂ emission from the stationary combustions was given in equation 1.

$$\text{Emission}_{\text{CO}_2, \text{fuel}} = \text{Fuel consumption}_{\text{fuel}} \times \text{Emission factor}_{\text{CO}_2, \text{fuel}} \dots \dots \dots \text{Eq. 1}$$

Where:

- a. Emission_{CO₂, fuel} = Emissions of CO₂ by type of fuel (in metric tons of CO₂)
- b. Fuel consumption_{fuel} = Activity data that quantify the CO₂ emission, in this case it was the volume (in liters or m³) or mass (tones) of the fossil fuel combusted in each emission source (as the case may be) for the period is considered.
- c. Emission factor_{CO₂, fuel} = Default emission factor of CO₂ by type of fuel (tones CO₂/liter, tones CO₂/m³ or tones CO₂/tones). IPCC's default emission factors were used because of the absence of country-specific (Nigeria) factors.

Emissions from all the selected industries within each industry were then consolidated in order to come up with total CO₂ industry emission using equation 2.

$$\text{Emission}_{\text{CO}_2} = \sum_{\text{fuels}} \text{Emission}_{\text{CO}_2, \text{fuel}} \dots \dots \dots \text{Eq. 2}$$

CO₂ emission was however was then calculated using the GHGs protocol established tool for stationary combustion version 4.1 (WRI, 2015). The total amount of CO₂ emitted by the assessed industries was then compared with the inclusion threshold (i.e. the maximum amount of CO₂ that can be emitted by an emitter/emission source before it can be included in an emission trading programme (International carbon action partnership {ICAP}, 2016) of various emission management programs around the world. This is because Nigeria is a non-annex (developing nation) member party of the UNFCCC and as such, it is currently not required to reduce its GHGs emissions, hence the country presently do not have any CO₂ emission regulation/standards/programme where a cap or a predetermined maximum allowable amount of CO₂ will be allocated to industries as a control measure to regulate CO₂ emission. Table 2 presents the IPCC's emission factors for the three fuels combusted in the assessed industries.

Table 2: CO₂ emission factors for fuel consumption data that have been supplied on different measurement bases.

Fuel types	Emission factors
Natural gas	1.88496 kg/m ³
Automated gas oils	2.676492 kg/ litre
Liquefied petroleum gas	2984.63 kg/tones

Source: World Resource institute, 2015

Method of data analyses

The identified CO₂ emission sources within each industry and the type of fossil fuels combusted were presented using descriptive statistics. The 12-month fuel use records of each identified emission sources were analyzed with descriptive statistics, however only the total annual fuel consumption data was presented. CO₂ emitted from the different sources within each industry was compared using the parametric tests of comparison of means in order to check for any significant difference(s) in the average emission of the sources within each industry. However,

before these tests were carried out, relevant preliminary test of fulfillment of the assumptions of parametric statistic (test of normality of distribution and homogeneity of variances) were run. The normality of the data were confirmed by using the Shapiro Wilk test of normality, visual inspection of histogram, normal Q-Q Plots and box plot as well as the skewness and kurtosis of the data. The Levene's test of homogeneity of variance was used to determine the equality of variance of the data used in the analysis.

In situations where the data were not normally distributed, the data were transformed using the log or square root transformation and luckily enough all data that were not normal became normal after transformation, hence there was no need in using the non parametric versions of the tests. One way Analysis of variance (One way ANOVA) or the independent sample T test with “equality of variance assumed” were applied in situation where the variances of the data to be compared were confirmed to be homogenous and in situation where the data were not homogenous, the more robust Welch test was adopted instead of the regular ANOVA and the independent sample T test with “equality of variance not assumed” was also adopted as the case may be. Tukey and Games Howell Post hoc tests were respectively used to reveal the pairwise comparison. All significance tests were conducted at $P < 0.05$. Thus, this provided a comprehensive understanding of the contribution of the different emission sources and fuel type to CO₂ emissions.

RESULTS AND DISCUSSION

Identified stationery emission sources

Table 3 presents all the stationary CO₂ emission sources in each of the selected industry in the study area as well as the types of fossil fuel that were combusted during the period under study (June 2015- May 2016). From Table 3, the total of fifty eight stationary CO₂ emission sources was identified. These emission sources basically include the electricity generators (both the gas and diesel fired), tri generation plants, industrial steam boilers, industrial ovens, furnaces, e.t.c which are basically large CO₂ emitting sources. Also, only three types of fossil fuel namely, natural gas, automated gas oil and liquefied petroleum gas were combusted in the identified emission sources. This is in line with the finding of Bradshaw *et al* (2006) in the IPCC special report on CO₂ capture and storage where it was stated that oil and gas are the primary fuels in the refining and chemical sectors (including manufacturing industries).

Table 3: Identified emission sources in each of the assessed industries.

Selected Industry	Industrial category	Identified emission sources	Type of fuel combusted in the sources
Industry N	Domestic and industrial plastic product, rubber and foam sectoral group	Ref	
		1 Two 2188 KVA Cummings gas generators	Natural gas
		2 Two 1450 KVA Cummings gas generators	Natural gas
		3 1279 KVA Cummings diesel generator	Automated Gas Oil (AGO)/ Diesel oil
		4 Two 1256 KVA Cummings diesel generators	Automated Gas Oil (AGO)/ Diesel oil
Industry G	Chemical and pharmaceutical sectoral group	Ref	
		1 Three 1000KVA Caterpillar diesel generators.	Automated Gas Oil (AGO)/ Diesel oil
		2 Four 1500KVA Jenbacher gas generators.	Natural gas
		3 Two 4 tons per hour dual engine Babcock steam boilers.	Natural gas and AGO
		4 One 5 tons per hour dual engine Cochren steam boilers.	Natural gas and AGO
Industry Q	Basic metal, Iron and steel and fabricated metal products sectoral group	Ref	
		1 Two 2250 KVA Cummins diesel generators	Automated Gas Oil (AGO)/ Diesel oil
		2 One 1400 KVA Cummins diesel generator	Automated Gas Oil (AGO)/ Diesel oil
		3 Three 2188 KVA gas generators.	Natural gas
		4 Two 1450 KVA Cummins gas generators	Natural gas
		5 One four tons per hour shell max steam boiler.	Natural gas
6 One 5000 cans per minute internal bake oven	Natural gas and liquefied petroleum gas (LPG)		

			7	One PIN oven	Natural gas and liquefied petroleum gas (LPG)
			8	One Dry off oven	Natural gas and liquefied petroleum gas (LPG)
Industry D	Food, beverages and tobacco sectoral group	Ref	1	One 10 tons/hour dual engine LOOS steam boiler	Natural gas and AGO.
			2	Two 15 tons/hour dual engine LOOS steam boilers	Natural gas and AGO.
			3	One 25 tons/hour dual engine LOOS steam boiler	Natural gas and AGO.
			4	Three 2000 KVA caterpillar diesel engines.	AGO
			5	Dual fired trigeneration plant with a power output of almost 8MW.	Natural gas and AGO.
Industry P	Nonmetallic mineral product sectoral group	Ref	1	Continuous glass furnace with a maximum pull of 200 tons of batch materials per day (TPD).	Natural gas and AGO.
			2	Continuous glass furnace with a maximum pull of 180 tons of batch materials per day (TPD).	Natural gas and AGO.
			3	A 3.5 MW Ruston gas turbine	Natural gas
			4	Seven annealing ovens (lehrs)	Natural gas and LPG
			5	One 2100 KVA Cummins gas engine	Natural gas
			6	Three 2000 KVA Perkins diesel engines	AGO
			7	Working ends: flaming of crates and packaging.	Natural gas and LPG

Source: Authors field research, 2016

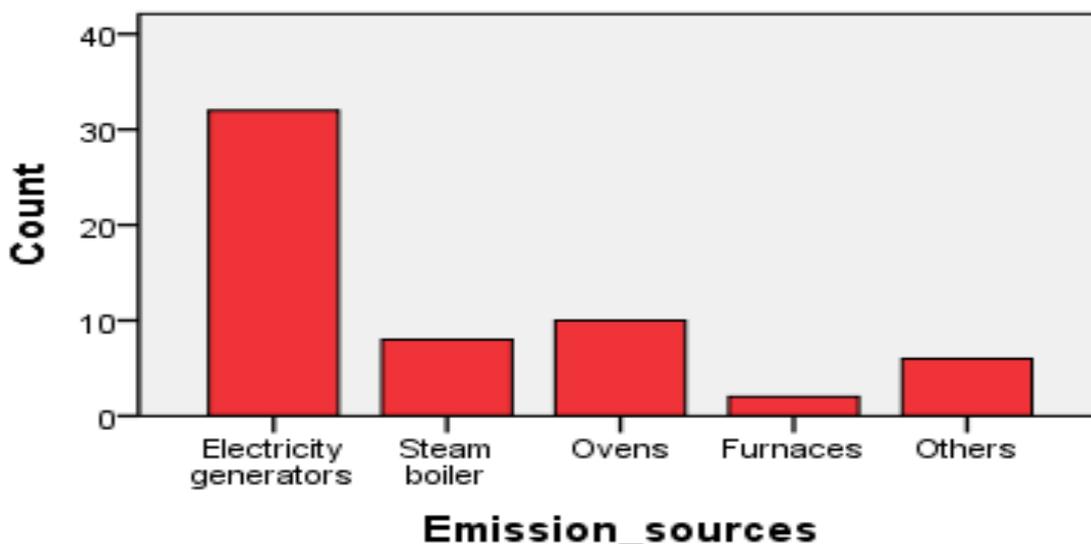


Fig 2: The distribution of emission sources across all the selected industry.

Fig 2 shows the distribution of the emission sources across all the industries. From Fig. 2, it is glaring that in terms of quantity, emission sources that are used in generating electricity are the dominant, and this is not unexpected because of the epileptic nature of power supply in the study area which has forced the industries to opt for a more reliable source of power i.e. by generating it themselves. Also as pinpointed by Bradshaw *et al* (2006) that in the power generation and industrial sectors, many sources have large emission volumes that make them amenable to the addition of CO₂ capture technology, it is obvious that these sources are large stationary sources that produces large volumes of CO₂. Hence there is a potential opportunity for these plants to be equipped with CO₂ capture plants to produce a source of high-purity CO₂ for subsequent storage (carbon sequestration).

Fuel consumption records of the emission sources in each of the selected industries

Tables 4 present an annual breakdown of the amount of natural gas in cubic meters, automated Gas Oil (AGO) diesel oil in liters and Liquefied Petroleum Gas (LPG) in tones that was combusted by the different emission sources across all the assessed industries in the study area. As shown in Table 4, Industry N has two groups of CO₂ emission sources; the gas and

diesel generators. A total of 3,838851.61m³ of natural gas was combusted in the gas generators during the period considered while in the diesel generators, a total of 178805 Litre of diesel was combusted for power generation. In Industry G, three groups of CO₂ emission sources exist: gas generators, diesel generators, and steam boilers. The steam boilers are dual fired i.e. they have two sets of engines; gas engine and diesel engine making them to be able to combust both natural gas and automated gas oil. A total of 23,544,977 m³ of natural gas and 356,354L of diesel were combusted across all the emission sources in the industry. The bulk of the natural gas and diesel fuel were combusted by the gas generators and diesel generators respectively with only a fraction combusted by the steam boilers. A total of 23,469,231 m³ of natural gas was combusted in the gas generators. This amount is far greater than the amount combusted in the steam boilers because the gas generators are much more fuel consuming and they are always run to power one process or the other in the factory. A total of 353,760 Litre of diesel was combusted in the diesel generators which are used as a backup for the gas generators. This is also far greater than what is combusted in the steam boilers.

Table 4: One year (June 2015-May 2016) Natural gas, Automated Gas Oil (AGO) and Liquefied petroleum gas (LPG) consumption of the different emission sources in the assessed industries

Emission sources	Gas generators	Diesel generators	Industrial boilers		Trigeneration plant		Glass furnaces		Annealing ovens (Lehrs)		Gas turbines	Others (industrial ovens and flaming of crates and packaging)	
Type of fuel combusted	NG (m ³)	AGO (L)	NG (m ³)	AGO (L)	NG (m ³)	AGO (L)	NG (m ³)	AGO (L)	NG (m ³)	LPG (tonnes)	NG (m ³)	NG (m ³)	LPG (tonnes)
<i>Industries</i>													
Industry N	3,838,851.61	178,805.00											
Industry G	23,469,231.00	353,760.00	75,746.00	2,594.00									
Industry Q	3,180,442.00	430,189.00	84,685.00									388,160.00	54.70
Industry D		2,585,105.00	1,118,050.44		20,664,411.11	1,949,365.00							
Industry P	1,692,708.05	2,388,706.00					14,664,980.26	345,763.00	945,145.86	439.00	3,822,490.10	345,126.43	49.00

Source: Authors field research, 2016

Industry Q has three groups of CO₂ emission sources namely: gas generators, diesel generators and steam boiler and Ovens. In addition to diesel and natural gas, liquefied petroleum gas was also used as a source of fuel to power the industrial ovens which are used in drying the company’s product at some stages in its production. In this company, the steam boiler combusts only natural gas while the ovens combust both natural gas and liquefied petroleum gas. A total of 3,653,287 m³ of natural gas, 430,189 Litre of diesel and 54.70 tones of LPG were combusted across all the emission sources in the industry. The gas generators consumed

87.06% of the natural gas supplied to this industry during the studied period.

Table 4 also shows the monthly fuel consumption record of Industry D. Here as well, the emission sources are in three groups: Tri-generation plant, Steam boilers and Diesel generators. A total of 21,782,461.55 m³ of natural gas and 4,534,470 Litre of diesel were supplied to the industry during the study period. Out of this figure, 94.87% of the natural gas was combusted in the tri-generation plant and the diesel consumption is more evenly shared between the tri-generation plant (42.99%) and the diesel generators (57.01%), therefore it is easy to conclude that the tri-generation plant (a cogeneration plant synchronized to produce electricity, hot water and chilled water from single fuel combustion) has the largest share of the fuel consumed in the industry.

In Industry P, the CO₂ emission source in this industry is quite diverse when compared with those of the other assessed industries. This industry is also highly energy intensive considering the fuel consumption records; it is explicit from this Table 4 that a total of 21,470,450.70 m³ of natural gas, 2,734,469 Litre of diesel and 488 tones of LPG were combusted across the various emission sources in the industry. Table 4 also showed that the glass furnaces are responsible for combusting the largest percentage (68.30%) of the natural gas supplied to the industry within the studied duration and about 87.36% of diesel supplied was combusted in the diesel generators and the bulk (89.96%) of the liquefied petroleum gas was combusted by the annealing ovens.

From the fuel consumption records of all the industries, it is clear that natural gas is preferred to diesel oil and other fossil fuel like black oil and LPG in powering the various industrial processes. Firstly, is the fact that the whole industrial estate has a direct access to natural gas supply from shell Nigeria (a major petrochemical industry in Nigeria), hence for these industries, natural gas supply is generally more reliable than liquid fuel supply in trucks because it is a continuous flow stream through the pipeline and what customers need do is to just open the valve. Secondly, there's no need for huge capital investment on storage facilities because natural gas flows from the wellhead

through pipelines and processing systems to locations where it is required. The third explanation is that the natural gas supply is highly abundant and almost always available except in few situations of pipe line maintenance and vandalization and more importantly is the fact that natural gas is cheaper compared to all other fossil fuel.

Quantity of CO₂ emitted from the different emission sources

Table 5 showed grand total of 7,714.65 tones of CO₂ were emitted from the identified sources during the assessed period in Industry N and 93.80% of this amount was contributed by the combustion of natural gas in the gas generators while the 6.20% was contributed by the combustion of diesel in the diesel generators.

Table 5: Annual estimated CO₂ emission from the different emission sources in the assessed industries

Emission sources	Gas generators	Diesel generators	Industrial boilers		Trigeneration plant		Glass furnaces		Annealing ovens		Gas turbines	Others (industrial ovens and flaming of crates and packaging)	
	NG (tones)	AGO (tones)	NG (tones)	AGO (tones)	NG (tones)	AGO (tones)	NG (tones)	AGO (tones)	NG (tones)	LPG (tones)	NG (tones)	NG (tones)	LPG (tones)
Industry N	7236.08	478.57											
Industry G	44,238.56	666.82	143.12	6.94									
Industry Q	5,995.01	1,151.40	159.62									731.67	163.25
Industry D		6,919.01	2,107.48		38,951.59	5,217.46							
Industry P	3,190.69	6,393.35					27,642.90	925.43	1,781.56	1,310.25	7,205.24	652.10	146.25

Source: Authors field research, 2016

An independent sample T' test was conducted to test the hypothesis that, there are significant differences in the average tones of CO₂ emitted between combusted natural gas in the gas generator and combusted automated gas oil in the diesel generator. The result of an independent sample T test [t(22)=9.212,

p < 0.001] revealed that the average tones of CO₂ emitted as a result of combustion of natural gas in the gas generators is significantly larger than the average tones of CO₂ emitted from the combustion of automated gas oil in the diesel generators. The effect size d of .845 indicates a large effect.

Quantity of co₂ emitted from the assessed industries by fuel types.

Table 6: Annual estimated CO₂ emission from the assessed industries by fuel type

Type of fuel combusted	Natural gas (tones)	Automated gas oil (tones)	Liquefied petroleum gas (tones)
<i>Industries</i>			
Industry N	7236.08	478.57	
Industry G	44,381.68	673.77	
Industry Q	6,886.30	1,151.40	163.25
Industry D	41,059.07	12,136.47	
Industry P	40,472.49	7,318.78	1,456.50

Source: Authors field research, 2016

In Industry G, as shown in Table 6, it is clear that out of an absolute total of 45,055.45 tones of CO₂ emitted from all the identified sources, 44,238.56 tones (98.19%) was as a result of combustion of natural gas in the gas generators while 666.82 tones (1.48%) and 150.06 tones (0.33%) was contributed by the diesel and the steam boilers respectively. The result of a robust test for equality of means (Welch test) conducted [$F(2, 15.275) = 7.254, p = 0.006$] showed that a statistically significant difference exist between the average tones of CO₂ emitted from the identified sources (gas generators, diesel generators and steam boilers). Games Howell post hoc test conducted in order to know how the emission from the sources are significantly different established that the average CO₂ emission from the gas generators is significantly larger than the average emission from the diesel generators ($p = 0.005$), while the average CO₂ emission from the gas generators is also significantly larger than the emission from the steam boilers ($p = 0.007$), however, the average CO₂ emission from the diesel generators is not significantly different from the emission from the steam boilers ($p = 0.742$). Also table 6 shows that the bulk of CO₂ emitted from the identified emission sources in the industry was as a result of natural gas combustion, while only a minute fraction was due to automated gas oil combustion. The independent sample T test [$t(22) = 4.392, p < 0.001$ at $p < 0.05$ sig level] confirmed that the average CO₂ emission from natural gas combustion in the emission sources is significantly higher than the emission from AGO combustion.

As for in Industry Q, it is obvious from Table 5, that about 8,200.94 tones of CO₂ were emitted from all the sources during the studied period and a huge percentage (73.10%) of this amount was as a result of combustion of fuel in the gas generators followed by the diesel generators (14.04%) and finally the steam boilers and ovens (12.86%). The result of the Welch test conducted [$F(2, 15.074) = 15.138, p < 0.001$ at $p < 0.05$ sig level] showed that a significant difference exist between the average emission from all the identified sources in the industry, while a Games

Howell post hoc test conducted revealed that the average emission from the gas generators is significantly higher than the emission from the diesel generators ($p = 0.002$). Emission from the diesel generators is also significantly higher than the emission from the steam boiler and ovens ($p = 0.001$). However, the post hoc test showed that there is no significant difference between the emissions from the diesel generators and the steam boilers and ovens ($p = 0.993$). Table 6 however, shows that out of a total of 8,200.94 tones of CO₂ emitted, 83.97% of the amount was as a result of combustion of natural gas, 14.04% was from automated gas oil and 1.99% was from liquefied petroleum gas. One way Analysis of variance test [$F(2, 33) = 35.55, p < 0.001$ at $p < 0.05$ sig level] showed that a significant difference exist between the average emission from all the combusted fuel types. The Tukey post hoc test conducted showed that emission from natural gas combustion is significantly higher than emission from AGO combustion ($p < 0.001$), average emission from natural gas is significantly higher than the average emission from LPG ($p < 0.001$). However, the test revealed that the average emission from AGO is not significantly different from the average emission from LPG ($p = 0.732$).

In Industry D, a total of 53,195.54 tones of CO₂ were emitted from the different emission sources, of which the tri-generation plant was responsible for 44,169.05 tones of CO₂ (83.03%). This was not unexpected because the plant is the central source from which the bulk of the energy (electricity and heat) used in powering the various companies' production processes is being generated. The diesel generators followed the tri-generation plant in term of amount of CO₂ emitted (13.01%) and the steam boilers contributed the least amount (3.96%). Welch test [$F(2, 14.944) = 36.474, p < 0.001$] revealed that a significant difference exist between the average emission from all the identified sources in the industry, while Games Howell post hoc test revealed that the average emission from the tri-generation plant is significantly higher than the emission from the steam boilers ($p < 0.001$),

emission from the plant is also significantly higher than the emission from the diesel generators ($p < 0.001$), however, there is no significant difference between the average emission of the diesel generators and the steam boilers ($p = 0.139$). It is also glaring from table 6 that 77.19% of all the emissions comes from the combustion of natural gas while 22.81% comes from the combustion of diesel oil. Independent sample T test conducted [$t(17.057) = 4.048$, $P=0.001$] revealed that a significant difference do exist between the average emission due to natural gas combustion and automated gas oil combustion.

As for Industry P, a total of 49,247.78 tones of CO₂ were emitted across the various sources in the industry during the assessed period. Out of this quantity, the continuous glass furnaces contributed the highest percentage 58.01% and the rest sources contributed less as shown in Table 5. Welch test [$F(5, 26.503) = 59.945$, $p < 0.001$] revealed that a significant difference exist between the average emission from all the identified sources in the industry, while Games Howell post hoc test conducted showed that the average emission from the continuous glass furnaces is significantly higher than the average emission from all other emission sources in the industries with $p < 0.001$ in all cases. The test also revealed that average emission from the annealing ovens is not significantly different from that of all other sources except from that of the working ends (source 7) where it is significantly higher ($p = 0.001$) and glass furnaces where it is significantly lower. Average emission from the gas turbines is not significantly different from that of the gas and diesel generators ($p = 0.099$, $p = 1.00$ respectively), however a significant difference exist when compared to that of the working ends ($p = 0.003$). The average emission from the gas generators is not significantly different when compared with that of the diesel generators ($p = 0.78$) and working ends ($p = 0.50$). Finally, no significant difference exists between the average emission from the diesel generators and the working ends ($p = 0.246$). In table 6, 82.18% of all the emissions came from

the combustion of natural gas while 14.86% came from the combustion of diesel oil and 2.96% came from the combustion of LPG. Welch test [$F(2, 16.678) = 40.953$, $p < 0.001$] revealed that a significant difference exist between the average emission due to natural gas, automated gas oil and liquefied petroleum gas combustion and a Games Howell post hoc test conducted revealed that average emission from natural gas combustion is significantly higher than that from AGO ($p < 0.001$), average emission from natural gas is also significantly higher than that from LPG ($p < 0.001$) and average emission from AGO is also significantly higher than that from LPG ($p = 0.004$).

The results show that all of assessed facilities as well as other facilities in the study have a similar pattern in their CO₂ emission, this is in the sense that natural gas and natural gas combusting sources are overwhelmingly the dominant contributor to the CO₂ emissions. This is because these companies has a direct access to cheap and verily available natural gas and many of the companies have built and developed their processes around this source of fuel. Therefore, Carbon emission management of these industries needs to be focused on natural gas usage. Also, this pattern of emission where natural gas is the dominant contributor to CO₂ emission may likely be different from other industries that do not have direct access to natural gas.

Furthermore, even though these companies basically rely on natural gas which is a much more environmental friendly fossil fuel when compared with other fuel alternatives, they still emit a significant amount of CO₂ from their stationary installations annually. Industry N emitted a total of 7714.65 tones of CO₂, Industry G emitted 45,055.45 tones of CO₂, Industry Q emitted 8,200.94 tones of CO₂, Industry D emitted 53,195.54 tones of CO₂ and Industry P emitted 49,247.78 tones of CO₂ during the studied period. These figures are large figures that would be required to be reduced over time in many carbon management programs around the world.

For example, these figures are way beyond the “inclusion threshold” of many carbon management programme especially emissions trading programme around the world. Inclusion threshold is the maximum amount of CO₂ that can be emitted by an emitter/emission source

before it can be included in an emission trading programme (International carbon action partnership {ICAP}, 2016). Table 7 presents the inclusion thresholds of some major emission trading/cap and trade programs around the world.

Table 7: The inclusion thresholds of different emission trading/cap and trade programme around the world

Emission trading scheme	Inclusion threshold
Québec Cap-and Trade System in Canada	>25,000t CO ₂ e/year
Beijing pilot system- China	>10,000t CO ₂ e/year
Guangdong pilot system in China	>20,000 tCO ₂ e/year
EU Emissions Trading System (EU ETS)	Varies with included sectors but are all typically >10,000 t CO ₂ e/year
Korea Emissions Trading Scheme	>25,000 tCO ₂ e/year
Swiss ETS	>25,000 tCO ₂ e/year
California Cap-and-Trade Program- USA	≥25,000tCO ₂ e (metric) per data year.

Source: ICAP, 2016

Comparing the emissions of the assessed industries with the inclusion thresholds of these programs, it is clear that apart from the emission of Industry N and Q that are lower than the thresholds, other industries emission are way higher. It is also worthy to note that the emissions from Industry N and Q are also much likely to be higher than the thresholds when emissions from other sources (non stationery emission and other GHGs) are included. It is also noteworthy to mention that, Nigeria is a non-annex (developing nation) member party of the UNFCCC and as such, it is currently not required to reduce its GHGs emissions, hence the country presently do not have any CO₂ emission regulation/standards/programme where a cap or a predetermined maximum allowable amount of CO₂ is allocated to industries as a control

measure to regulate emission. Therefore there is no locally developed emission cap to compare these figures (emissions from the different assessed industries) with.

CONCLUSION

It can be concluded from the study that Natural and natural gas combusting stationery equipments are basically responsible for the CO₂ emitted in the assessed industries during the study period. Also, significant amount of CO₂ was emitted by these industries which will be required to be managed/ reduced by the standard of many carbon management programs around the world. There are various opportunities for mitigation of CO₂ emissions from these industries and these may fall into the following categories:

- a) **Energy efficiency:** Energy efficiency opportunities could be found in various systems such as steam systems, process heating systems (furnaces and boilers), and electric motor systems (e.g., pumps, fans, air compressor, refrigerators, material handling). The companies could also improve their energy efficiency by improving their heat management via better heat exchange between hot and cold gases and fluids, improved insulation, capture and use of heat in hot products, and use of exhaust heat for electricity generation or as an input to lower temperature processes.
- b) **Emissions efficiency:** Carbon reduction opportunities for these industries also lie in CO₂ capture and storage; this is because many of the sources have large emission volumes that make them amenable to the addition of CO₂ capture technology.
- c) **Material efficiency:** A significant opportunity for industrial emissions abatement lie in the reduction of yield losses in production and this can be achieved via process innovations and new approaches to design as suggested by Milford *et. al*, 2011.
- d) **Re-use of materials and recycling of products:** the industries can also look into Re-use and Recycling because as suggested by Fishedick *et. al.*, 2011 they can help to reduce energy demand, as it can be a strategy to create material with less energy.
- a result of which they will be able to figure out where reduction can be realized.
- b) The industries should prioritize natural gas usage and natural gas combusting sources as the area of carbon emissions that need to be controlled and target areas where reduction in emissions will have a high impact on the overall measure.
- c) The industries should fix an emission reduction target to demonstrate their commitment and intentions to track their progress in CO₂ emission reduction. This should be done through public reporting. They should however, monitor their CO₂ emissions for a period before setting targets.
- d) There is need for the appropriate regulatory bodies to also incorporate the monitoring of CO₂ and other GHGs from the point of view of their impact on climate change into their responsibilities. This will ensure that industries are more committed to mitigating the impact of their activities on the climate system.
- e) There is need for studies of this type in other industrial area in the country where natural gas is not the major source of fuel for industrial activities. Also, the CO₂ emission from other industrial sectors like pulp, paper and paper products, printing and publishing sectoral group, textile, wearing apparel, carpet, leather/leather footwear sectoral group, and wood and wood products including furniture sectoral group, should also be investigated because they also represent a large source of CO₂ emission. This will help in consolidation and provision of an intelligent basis for accounting of the emissions due to manufacturing industries activity in the country.

The following recommendations were provided for the assessed industries, environmental regulators and further studies based on the result of this work:

- a) CO₂ reduction opportunities for the assessed companies obviously lies in the usage of natural gas, these companies should therefore look into how their production processes and activities contributes to natural gas consumption as
- f) There is need for consideration of the other greenhouse gas emissions in subsequent studies as this is vital for a proper greenhouse gas emission inventories and the development of emission abatement policies in the industrial sector in Nigeria.

REFERENCES

- Agbara Estate Limited (AEL). (2008). *Agbara Estate Limited Unveils Development Plan, Real Estate*. Brochure of Ministry of Housing, Ogun State, Nigeria.
- Bradshaw, J., Zhenlin, C., Amit, G., Dario, G., HansHolger, R., Dale, S., Robert, W. (2006). *Sources of CO₂. IPCC Special Report on Carbon dioxide Capture and Storage*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- Edeoja, J.A. and Edeoja, A.O. (2015). Carbon Emission Management in the Construction Industry – Case Studies of Nigerian Construction Industry[PDF]. *American Journal of Engineering Research (AJER)*, 4(7),112-122.
- Federal Ministry of Environment. (2015). *Nigeria's intended nationally determined contribution*. Available from <http://www4.unfccc.int/submissions/INDC/Submission%20Pages/submissions.aspx>
- Federal Ministry of Environment. (2014). *Nigeria's second national communication under the united nation framework convention on climate change*. Available from <http://www4.unfccc.int/submissions/INDC/Submission%20Pages/submissions.aspx>
- Fischedick, M., Schaeffer, R., Adedoyin, A., Akai, M., Bruckner, T., Clarke, L., Krey, V., Savolainen, I., Teske, S., Urge-Vorsatz, D., and Wright, R. (2011). *Mitigation Potential and Costs*. In: *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation*. Prepared by Working Group III of the Intergovernmental Panel on Climate Change
- International carbon action partnership (ICAP). (2015). *Emissions Trading Worldwide International Carbon Action Partnership (ICAP) Status Report 2015*. Available from <https://icapcarbonaction.com>. Accessed on 30/08/2016.
- Intergovernmental Panel on Climate Change (IPCC). (2014). *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, Pachauri R.K., and Meyer, L.A. (eds.)]. IPCC, Geneva, Switzerland. pp151
- Intergovernmental Panel on Climate Change (IPCC). (2007). *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland. pp 104
- Intergovernmental Panel on Climate Change (IPCC). (2001). *Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change* [Houghton, J. T., Ding, Y., Griggs, D. J., Noquer, M., van der Linden, P. J., Dai, X., Maskell, K., and Johnson, C. A. (eds.)].
- Milford, R.L., Allwood, J.M., and Cullen, J.M. (2011). Assessing the potential of yield improvements, through process scrap reduction, for energy and CO₂ abatement in the steel and aluminum sectors. *Resources, Conservation and Recycling*, 55, 1185-1195. doi: 10.1016/j.resconrec.2011.05.021.
- Nwaichi, E.O. and Uzazobona, M.A. (2011). Estimation of the CO₂ level due to gas flaring in the Niger Delta. *Research Journal of Environmental Science*. 5(6):565-572. DOI:10.3923/rjes.2011.565.572
- Okhimamhe, A. A. and Okelola, O.F. (2013). Assessment of carbon dioxide emission at road Junction in the Southeast of Niger State. *International Journal of Sustainable Tropical Design Research and Practice*, 6(2): 59-71.
- Simmons, T. (2010). *CO₂ emissions from stationary combustion of fossil fuels: Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*. Avonlog Limited, UK.
- United Nations. (2013). *World Economic and Social Survey 2013: Sustainable Development Challenges*. <https://sustainabledevelopment.un.org/.../2843WESS2013...>
- World Resource institute (WRI). (2015). *GHG protocol tool for stationary combustion (version 4.1)* [computer software]. Available from www.ghgprotocol.org
- World Resource institute (WRI). (2006). *Hotclimate, cool commerce, a service sector guide to greenhouse gas management*. Retrieved from <http://www.wri.org/publication/hot-climate-cool-commerce>
- World Resource institute (WRI). (2015). *GHG protocol tool for stationary combustion (version 4.1)* [computer software]. Available from www.ghgprotocol.org