Emissions from Private Power Generating Equipment in Port Harcourt, Nigeria

Precious N. Ede, Ikechi B. Oriji

Institute of Geosciences and Space Technology, Rivers State University of Science and Technology
Nkpolu-Oroworukwo, Port Harcourt, Nigeria. preciousnwobidiede@gmail.com

Abstract: Incessant power outages have made Nigerians to be one of the highest users of private power generators in the world. This study evaluates emissions from generators in Port Harcourt, Nigeria, with a view to determine the implications of their widespread use. The study used the US EPA NONROAD 2005 model with some modifications suited to the study environment. Primary data and other model inputs were obtained from appropriately designed questionnaire that were administered in the study area. Wherever necessary, these were augmented with interviews and sales data from major dealers in generators in the city of Port Harcourt. The total emissions from the model output were 26.1 tons of THC, 362.79 tons of NO_x, 138.33 tons of CO, 23.49 tons of PM_{10} and 44800.65 tons of CO_2 per year for diesel generators; and 1096.2 tons of THC, 70.47 tons of NO_x, 20,175.3 tons of CO, 93.96 tons of PM_{10} and 34,718.22 tons of CO_2 per year for gasoline generators. Assuming a steady growth in the economy, and if contributions from other sources are introduced into the calculation, the air quality of the city will get worse. Environmental managers in the country should begin to consider inventorying every emission source and stipulate standards as long-time measures. City managers should also provide guidance to residents on placement criteria for private power plants so that they do not endanger the lives of their household members and that of their neighbours.

[Ede PN, Oriji IB. **Emissions from Private Power Generating Equipment in Port Harcourt, Nigeria.** *Nat Sci* 2013;11(4):59-64]. (ISSN: 1545-0740). http://www.sciencepub.net/nature. 11

Keywords: Emission modelling; non-road equipment; NONROAD 2005, generating sets, Port Harcourt

1. Introduction

Persistent and prolonged public power outages have made Nigerians to be one of the most users of private power generators in the world. Generators, like other non-road equipment such as lawn mowers, water pumping machines, excavators, vulcanizing machines, outboard and inboard engines on marine vessels when powered with petroleum based fuels have been shown to give off gaseous emissions which could contribute to air quality problems over cities (US EPA 1991). The city of Port Harcourt with over 2 million people in 2011 is host to several industries including most of those in the oil and gas sectors of the nation's economy. Thus, it has over the years witnessed a steady influx of people and business activities. According to Ede *et al.* (2006), significant amounts of pollutants are currently being released into the atmosphere from surrounding gas flare points around the city associated with petroleum extraction. When emissions from other industrial activities in the city and mobile sources are added, it becomes very pertinent that serious efforts, be put in place to protect the city's air quality and environment.

Population and industrial growth, and the dependence on internal combustion engines have over time increased the concentration of gaseous and particulate emissions in cities (Rao and Rao, 2006). Studies on the causes and effects of air pollution have documented the need for emission inventories, auto emission modelling, land use control, impact on health, economic and environmental strategies for pollution prevention and alternative fuels. This study evaluates emissions from generators in Port Harcourt, Nigeria, with a view to determine the implications of their widespread use to the city's air quality.

2. Materials and Methods

The fundamental framework for the study was based on US EPA's NONROAD 2005 model. This model was developed by the United States Environmental Protection Agency (US EPA) to assist states and local regulatory agencies in the generation of accurate non-road emission inventories for all areas of the United States. Primary data and other model inputs were obtained from appropriately designed questionnaires that were administered in the study area. Wherever necessary, these were augmented with interviews and sales data from major dealers in generators in the city of Port Harcourt.

The model generates emissions for specific non-road equipment by multiplying the input data estimates for the following parameters as prescribed in US EPA (2005):

i. Equipment population for base year (or base year population projected to a future year, i.e., 2011),
ii. Average load factor expressed as average fraction of available power,
iii. Available power in horsepower,
iv. Activity in hours of use per year; and,
v. Emission factor with deterioration and / or new standards.

The emission estimates so derived are then temporally and geographically allocated using appropriate allocation factors provided with the model. The model also comes with several input files that contain default values needed to compute and allocate emission estimates. These files include basic data for emission factors, base year equipment population, activity, load factor, average lifetime, scrappage function, growth estimates, geographic and temporal allocation. The model however allows users to replace these default values with locality-specific data whenever necessary as was done in this study. The files can also be modified to simulate and test control strategies (US EPA, 2005).

2.1 Model application for the study: To facilitate the application of the NONROAD 2005 model for this study, several modifications were made in key input files to reflect study area data. These modifications were scenario or run-specific. This means that for every model run, study-area data pertaining to key run parameters were used. These include equipment type, population, engine power, engine load factor, and equipment usage or activity and minimum and maximum ambient temperature for run period, i.e., day, month or year. It is assumed that the modification to the modelling region holds constant for all model runs. The description of these parameters together with the modifications made to them, and the source of the data used for the modification are described later in this section. The NONROAD 2005 model estimates emissions from non-road sources or equipment using the following basic equation:

Emissions = (Pop)*(Power)*(LF)*(A)*(EF) ... (equ. 1)

Table 1 summarises the parameters and the magnitudes that were adopted for this study.

Table 1: Magnitude of Parameters in Equation 1

Parameter/symbol	**Gasoline** (1-16Hp)	**Diesel** (6-1000Hp)
Pop = Engine Population	29,400	5,024
*Power = Average Engine Power (hp)		
*LF= Load Factor (fraction of available power)		
A = Activity (hrs/yr)	6 hours	10 hours
*EF= Emission factor (g/hp-hr)		

*Internal to NOROAD 2005

The emission values obtained, using equation 1, other adjustments and factors internal to the model, are usually described as "best estimates" (US EPA, 2005).

Apart from the default data sets that are supplied with the model, there is an advanced option in the model's graphical user interface (GUI) that allows users to specify key locality-specific data or parameters that may be needed for different modelling scenarios. These parameters and the modifications needed for the study are further described below.

2.2 Equipment types and population: This parameter is used to give information to the model on the type of equipment, whose emission the user is interested in determining. For the purpose of this study, the model was supplied with only two types of non-road equipment: the 2- and 4-stroke gasoline generators, and diesel generators.

The 'Pop' variable in equation 1 refers to equipment population and the survey results for this study are presented in Tables 2 and 3. It is the key parameter required by the model to estimate emissions. The default values for the equipment types were substituted with study area specific data generated from retail outlets in the study area and from questionnaires administered to randomly selected users. These data were also augmented with interviews of officials of state owned electric power monopoly and sales data from major dealers in generators in the city of Port Harcourt.

Based on estimates from Greater Port Harcourt Master Plan 2008, the city's population in 2011 is projected as about 2 million. The average household size in Nigeria is 6 (NPC, 1998), therefore, the number of households in Port Harcourt in 2011 is 333,333. Survey indicates that the combined population of power generating sets in use in Port Harcourt in 2011 is 34,424, yielding one generating set for every nine households.

Table 2: Gasoline Generators in Port Harcourt

Engine Type	Capacity (Hp)	Default Population	Survey Data
2-stroke	0-1.0	285.3	56
"	1.1-3.0	7081.2	18,694
4-stroke	3.1-6.0	49,817.1	8,500
"	6.1-11.0	119,625.9	2,011
"	11.1-16.0	26,460.6	139
"	16.1-25.0	37,862.9	0.0
"	> 25	0.0	0.0
		Total	29,400

During the actual model run, these engine population values were appropriately distributed into the respective power ranges determined from the questionnaire. The survey also showed that the most commonly used gasoline generators were in the 1-16Hp power range and 6-1000Hp for diesel generators.

Table 3: Diesel Generators in Port Harcourt

Capacity (Hp)	Default Population	Survey Data
3-6.0	4,248.9	1,100
6.1-11.0	4,242.4	1,256
11.1-16.0	3,270.0	850
16.1-25.0	5,148.8	500
25.1-40.0	8,522.4	350
40.1-50.0	1,164.0	298
50.1-75.0	4,294.9	255
75.1-100.0	5,227.0	200
100.1-175.0	1,784.1	150
175.1-300.0	992.0	30
300.1-600.0	515.2	20
600.1-750.0	0.0	15
> 750	0.0	0.0
	Total	5,024

2.3 Fuel types and characteristics: Another basic input requirement of the model is the fuel type and characteristics. These parameters allow the user to specify the type of fuel used by the equipment and the characteristics of the fuel in terms of its oxygen and sulphur content in percentage/volume. The two main fuel types used in generators in the study area are gasoline (PMS), and diesel (AGO). For this study, fuel characteristics data was obtained from the Port Harcourt office laboratory and quality assurance department of the Nigerian National Petroleum Corporation. The essential characteristics of the fuel in use are the absence of oxygen and sulphur in them.

2.4 Engine power: Engine power represents the 'Power' variable in equation 1. Due to the equipment classification scheme it uses, the model accepts data for this variable in ranges. It actually recognises nineteen power classes ranging from 0Hp to 3000+ Hp. For any power range specified, the model computes and uses the average. The 'Power' data for the study was obtained through the questionnaire administered for the purpose of the study and also through interview of technical personnel. Most of the 'power' ratings obtained through the questionnaire were expressed in Kilovolts Amperes (KVA). These were converted to the model's power units (Hp) using the relation:

Power (Hp) = Power (KVA)/0.75...... (2)

2.5 Load factor, equipment usage and emission factor: Load factor represents the 'LF' variable in equation 1. For all the equipment types modelled in this study, the default values provided with the model were used. 'A' represents level of usage for equipment in equation 1. It denotes the average number of hours the equipment is in use in a year. This data was obtained from the questionnaire and through discussion with relevant technical personnel. The data so generated were substituted for the default values, in the 'activity' data file that was supplied with the model, for the study equipment types. 'EF' is the emission factor variable in equation 1. The study used the default data that was supplied with the model. These default values were developed using appropriate deterioration factors and current emission standards (US EPA, 2005).

2.6 Minimum and maximum ambient temperature: Ambient minimum and maximum temperatures were part of the options internal to the model. Temperature data for the study area was obtained from the metrological station at the Port Harcourt International Airport that is located on the outskirts of the city. Temperature values in Celsius (^oC) were converted to the model recognized Fahrenheit (^oF) scale using the relation:

Temp. (^oF) = 1.8*Temp (^oC) + 32.......... (3)

The values for this study were: minimum temperature – 84 ^oF; maximum temperature – 89 ^oF and a mean of 87 ^oF.

2.7 Model run scenarios

For the purpose of this study, the NONROAD 2005 model was run for the following scenarios:

i) Emission estimates, for a typical day in a year (2011), from 2- stroke and 4-stroke gasoline generators.
ii) Emission estimates for typical day in a year (2011), from diesel generators.

The emission considered include total hydrocarbons (THC), exhaust oxides of nitrogen (NO_X), exhaust carbon monoxide (CO), exhaust particulate matter less than or equal to 10µm (PM_{10}), exhaust sulphur dioxide (SO_2) and exhaust carbon dioxide (CO_2).

2.8 Assumptions and limitations

Obstacles to a successful adaptation of this model for a location outside the United States were overcome through the authors' communication to Craig Harvey of the US EPA office of Transportation and Air Quality. The assumptions are:

i) That the study area could approximate the Miami-Dade County in the state of Florida in the United States of America. The choice of Florida is basically hinged on climatic similarities between it and the study area which are essentially coastal, low topography, tropical and wet.
ii) Apart from the above modifications, all other data pertaining to Miami-Dade county and Florida as supplied with the model are assumed to hold true for the study area.
iii) There is no form of controls on refuelling emissions in the study area. Appropriately, zero is entered for 'control policy effectiveness' under the /STAGE II/ packet in the model's default input files.

The model, as presently configured, cannot accommodate multiple scenarios in a single run. Also, the emission values that were generated are only "best estimates", so described due to the variability of emission factors value. The extent of this uncertainty can be seen in the work of Bammi (2001).

3. Results

The results from the model run were analyzed with respect to equipment type, horsepower and pollutant. The results, together with accompanying graphs, are shown in Tables 4 and 5.The emission values were expressed in tons per day.

Table 4: Emissions Totals by Horsepower, Equipment Type and Pollutant Gasoline (Tons/Day)
Daily Exhaust Emissions from 2- and 4- stroke Gasoline Generators, PORT HARCOURT COUNTY, 2011 (ging1), Typical weekday for year: 2011, Date of Model Run: Sept. 26; 02:45:27; 2011

Source Classification	**Horsepower**	**Exhaust THC**	**Exhaust NO_X**	**Exhaust CO**	**Exhaust PM_{10}**	**Exhaust SO_2**	**Exhaust CO_2**
COMMERCIAL EQUIPMENT	0 < HP <= 1	0.00	0.00	0.00	0.00	0.00	0.00
Generator Sets	1 < HP <= 3	2.10	0.06	13.10	0.34	0.00	44.71
	3 < HP <= 6	1.86	0.14	41.00	0.01	0.00	59.87
	6 < HP <= 11	0.22	0.06	20.67	0.00	0.00	25.34
	11 < HP <= 16	0.03	0.01	2.53	0.00	0.00	3.10
	16 < HP <= 25	0.00	0.00	0.00	0.00	0.00	0.00
	25 < HP <= 40	0.00	0.00	0.00	0.00	0.00	0.00
	40 < HP <= 50	0.00	0.00	0.00	0.00	0.00	0.00
	50 < HP <= 75	0.00	0.00	0.00	0.00	0.00	0.00
	75 < HP <= 100	0.00	0.00	0.00	0.00	0.00	0.00
	100 < HP <= 175	0.00	0.00	0.00	0.00	0.00	0.00
	175 < HP <= 300	0.00	0.00	0.00	0.00	0.00	0.00
Commercial Equipment Totals:		**4.20**	**0.27**	**77.30**	**0.35**	**0.00**	**133.02**
Grand Totals:		**4.20**	**0.27**	**77.30**	**0.35**	**0.00**	**133.02**

Table 5: Emissions Totals by Horsepower, Equipment Type and Pollutant Diesel (Tons/Day)
Daily Exhaust Emissions from Diesel Generators, PORT HARCOURT COUNTY, 2011 (ging2), Typical weekday for year: 2011, Date of Model Run: Sept 26; 03:23:10; 2011

Source Classification	**Horsepower**	**Exhaust THC**	**Exhaust NO_x**	**Exhaust CO**	**Exhaust PM_{10}**	**Exhaust SO_2**	**Exhaust CO_2**
COMMERCIAL EQUIPMENT Generator Sets							
	3 < HP <= 6	0.00	0.00	0.00	0.00	0.00	0.00
	6 < HP <= 11	0.01	0.06	0.06	0.01	0.00	7.59
	11 < HP <= 16	0.01	0.11	0.06	0.01	0.00	13.97
	16 < HP <= 25	0.01	0.12	0.06	0.01	0.00	14.86
	25 < HP <= 40	0.01	0.11	0.04	0.01	0.00	13.74
	40 < HP <= 50	0.01	0.11	0.04	0.01	0.00	12.99
	50 < HP <= 75	0.01	0.13	0.06	0.01	0.00	14.71
	75 < HP <= 100	0.01	0.15	0.08	0.01	0.00	18.08
	100 < HP <= 175	0.01	0.16	0.04	0.01	0.00	20.05
	175 < HP <= 300	0.01	0.19	0.04	0.01	0.00	26.37
	300 < HP <= 600	0.00	0.07	0.02	0.00	0.00	9.36
	600 < HP <= 750	0.00	0.08	0.03	0.00	0.00	10.08
	750 < HP <= 1000	0.01	0.11	0.02	0.00	0.00	9.83
	1000 < HP <= 1200	0.00	0.00	0.00	0.00	0.00	0.00
	1200 < HP <= 2000	0.00	0.00	0.00	0.00	0.00	0.00
	2000 < HP <= 3000	0.00	0.00	0.00	0.00	0.00	0.00
Commercial Equipment Totals:		**0.10**	**1.39**	**0.53**	**0.09**	**0.00**	**171.65**
Grand Totals:		**0.10**	**1.39**	**0.53**	**0.09**	**0.00**	**171.65**

4. Discussion

The results in Table 4 show that gasoline generators emit significant quantities of CO_2 and CO. The very high quantity of CO (77.30 tons per day) confirms the high toxicity of gasoline powered generators (EmergencyPower.com, 2008). Using 261 week days per year, the emissions data in Table 4 translates into 1096.2 tons of THC, 70.47 tons of NO_x, 20,175.3 tons of CO, 93.96 tons of PM_{10}, and 34,718.22 tons of CO_2 per year for gasoline generators. These emission values, coming from only gasoline generators, are quite significant for the air quality of the city especially when we factor in emissions from other sources.

The very significant CO emissions from gasoline generators portend danger for majority of the residents in the city given the prevalence of these classes of power generators. Recently, there have been several domestic fatalities from CO poisoning where gasoline generators were being used in Port Harcourt. The data in Table 5 show that diesel generators emit very significant quantities of CO_2 compared to other pollutants. This may be as a result of more efficient combustion in diesel engines. However, the emissions of other pollutants from diesel generators can still be significant over time. For instance, the emissions in Table 5 translates into 26.1 tons of THC, 362.79 tons of NO_x, 138.33 tons of CO, 23.49 tons of PM_{10}, and 44800.65 tons of CO_2 per year from diesel generators.

Tables 4 and 5 show that neither gasoline nor diesel generators emitted any appreciable amount of sulphur dioxide (SO_2). This is as a result of the sulphur-free nature of the Nigerian crude. The relatively lower emissions of pollutants from diesel generators could be attributed to better technology used in their manufacture (EmergencyPower.com, 2008). The very high emission of CO_2 observed in both tables suggests that recent control measures put in the manufacture of generators are beginning to result in better combustion in these machines. However, the increasing and persistent use of generators could, in the long run, add large amounts of CO_2 to the atmosphere with its attendant negative effects.

The comparison of the emission values from Tables 4 and 5 with some international emissions standards for the same class of equipment show the need for concern for the air quality over the city. For instance, an emission regulation in the state of Connecticut, in the US, limits emissions from generators to not more than 15 tons per year for pollutants like CO, THC, NO_x, and SO_2 (Weston, 2005). Similarly, US EPA (2007; 2008) proposes to stipulate stringent guidelines and standards on non-road equipment emissions. Unfortunately, there are no such regulations limiting emissions from non-road equipment in Nigeria. Increasing affluence and perennial power outages means more of these and other non-road equipment will be put to use in the study area (see Figure 1). Thus, there is an urgent need for a monitoring and regulatory framework for air quality over large urban places in Nigeria.

Figure 1: Cluster of Generating Sets

5. Conclusions

Air, due to its ubiquitous nature, is one component of the environment that we regularly immersed and live in. This explains recent and on-going discourse on the air quality over human settlements. The overarching purpose of this study was to contribute to this important theme of quality environment with particular emphasis on emissions from electric power generating sets used extensively in the city of Port Harcourt which is in the environmentally fragile Niger delta area of Nigeria. The findings from the study indicate that significant emissions of pollutants come from the use of gasoline and diesel generators. In fact, the emission values, though purely estimates, were found to be above some accepted safe limits for the considered pollutants. If emissions from other sources are added, there will be indeed cause for concern for the present and future air quality of the city. Assuming a steady growth in the economy, and contributions from other sources introduced into the calculation, the air quality of the city will get worse. Environmental managers in the country should begin to consider inventorying every emission source and stipulate standards as long-time measures. City managers should also provide guidance to residents on placement criteria for private power plants so that they do not endanger the lives of their household members and that of their neighbours. The national electric power company, a state monopoly that controls the generation and supply of electric power in Nigeria must begin to implement government's promise of a steady public power supply.

Corresponding Author:
Precious N. Ede
Institute of Geosciences and Space Technology,
Rivers State University of Science and Technology,
Nkpolu-Oroworukwo,
Port Harcourt, Nigeria.
Telephone: +234 803 3126 784
Email: preciousnwobidiede@gmail.com

References

1. US EPA (1991). Nonroad Engine and Vehicle Emission Study. EPA-21A-2001. Retrieved 10/01/2007 from http://www.epa.gov/otaq/nonrdmdl.htm.
2. Ede, P.N., Seiba, I. H. and Igwe, F. (2006): Combustion Efficiency Determined for Selected Flare Points in the Niger Delta Area. *African Journal of Environmental Pollution and Health* 5 (2): 19-25.
3. Rao, H. V. N. and Rao, M. N. (2006). *Air Pollution.* Tate McGraw Hill Publishing Company Limited, New Delhi – 110 020. Pp 6 – 12, 255 – 265.
4. US EPA (2005). *User's Guide for Final NONROAD2005 Model.*Retrieved 10/01/2007 from http://www.epa.gov/otaq/nonrdmdl.htm
5. Government of Rivers State of Nigeria (2008). *Greater Port Harcourt City Development Master Plan 2008.* Accus Gibbs. Vols 1-4
6. NPC (1998). 1991 Population Census of the Federal Republic of Nigeria: Analytical Report at the National Level. National Population Commission, Abuja, 455pp.
7. Bammi, S. (2001). Quantitative Analysis of Variability and Uncertainty in On-road and Non-Road Mobile Source Emission Factors. A thesis submitted to the Graduate Faculty of North Carolina State University in partial fulfilment of the requirements for the Degree of Master of Science, Raleigh, 261pp.
8 EmergencyPower.com (2008). Gas and Diesel Generators. Home, Commercial and Emergency Standby Generators. Retrieved 09/10/08 from http://www.emergencypower.com/gasgenerators.html
9. Weston F. (2005). Connecticut's Output-Based Emissions Standards for Distributed Generation. Retrieved 22/10/2008 from http://www.raponline.org
10 US EPA (2007). Federal Register, Part II, 40 CFR Parts 60, 63, *et al.* Control of Emissions from Nonroad Spark-Ignition Engines and Equipment; Proposed Rule. Environmental Protection Agency.
11. US EPA (2008). Federal Register, Part II, 40 CFR Parts 60, 63, *et al.* Standards of Performance for Stationary Spark Ignition Internal Combustion Engines and National Emission Standards for Hazardous Air Pollutants for Reciprocating Internal Combustion Engines; Final Rule. Environmental Protection Agency.

2/5/2013