Analysis of Environmental Effects of the Major Stand-alone Power Generators Used in Nigeria and Sub-saharan Africa

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Abstract

Private individuals, Businesses and Industries have long resulted in the use of stand-alone generators as an alternative source to a public utility. These sources burn fossil fuels to power the loads connected to them. The environmental effects of using the common fuel sources; petrol and propane gas for the generators were however investigated in this article. Measurement, observation and analysis of the carbon-monoxide emission, ambient temperature, and sound level of the two sources were independently carried out at various loading conditions. Observations however depicted the two sources raising ambient temperature of the environment they are put in by close to 15%. The carbon monoxide emission for propane fired generator was maximum at 240W load with 204ppm while that of petrol fired generator was maximum at no load with 733ppm. The carbon monoxide emissions were constant for the propane-fired generator but reduces as the load increases for the petrol fired generator. The emission for both sources was above the WHO standard exposure limits of 87ppm for 15minutes. The sound level of approximately 90dB for both sources, when compared with EPA standards, should not be exposed to in proximity for more than 90minutes. Running these generators far away from living rooms will have a little direct effect on people's health but a lot on the depletion of the ozone layer thereby causing global warming. They will however be more directly harmful when they are run close to our living rooms, and offices causing several diseases/impairments which may ultimately lead to death.

Keywords: *Carbon-monoxide, Emissions, Environmental Effect, Generators, Sound*

Introduction

An estimated 645 million Africans have no access to electricity. Power consumption per capita in Sub-Saharan Africa is the lowest of all continents, currently estimated at 181 kWh per annum, compared to 6,500 kWh in Europe and 13,000 kWh in the United States. (Akinwunmi, 2019). Although there is limited information about air quality in Uganda, the 2018 world air quality report ranked Uganda, second after Nigeria among the African countries with the worst particulate matter pollution (IOAir, 2018).

Cole et al (2018) also assessed the scope to which power outages impact the turnover for organisations in the African continent. Using World Bank Enterprise Surveys data for 14 countries, it was evident from their findings that firms that did not own a generator set were more negatively affected in sales due to the epileptic nature of the power supply.

It was also established that downsizing of the expected outage levels to those achieved by the South Africa economy during the study period would result in the organisations' overall turnover rise by 85.1 per cent. This would lead to a 117.4 per cent rise for firms without a generator facility. Winifred et al. (2020) in their study concluded that the relationship between electric power outage dynamics and financial performance of manufacturing firms in Kenya was statistically significant.

At the United Nations climate change conference in Paris (COP 21), governments agreed that mobilizing stronger and more ambitious climate action is urgently required to achieve the goals of the Paris Agreement. Action must come from governments, cities, regions, businesses, and investors (UNFPP, 2017). Everyone has a role to play in effectively implementing the Paris Agreement.

The outcome of COP 23, which was to evaluate the implementation of CO P21 showed a dramatic reality of recent extreme weather events and scientific findings that climate change is accelerating and that greenhouse gas emissions are again on the rise. Nigeria's economy still dependent on oil, monthly and yearly increase in gas flared at oil exploration sites will still be a major factor contributing to the emission of GHGs from the shores of Nigeria.

Nigeria's Internally Determined Contributions (INDCs) target to reduce CO_2 emission by 30% by the year 2030 cannot be met. Likewise, the country's projection of a power generation of 78,000MW by the year

2030 will be a wild goose chase if the volume of Natural gas flared is not harnessed to complement the current power generation capacity of the country (Lawal et al, 2018).

The INDCs, therefore, focuses on the delivery of direct development benefits and sustainable growth of the economy. A shortfall in generation capacity has led to the proliferation of small generators, which are inefficient and polluting the environment. Most rural communities remain off the grid, about 60% of the population lack access to electricity. At the current rate of grid expansion, they will largely remain under-served. (Mohammed, 2019).

In 2014, Nigeria became the largest economy in sub-Sahara Africa. Nigeria is a lower middle income developing country, The Gross Domestic Product (GDP) in Nigeria was worth 448.10 billion US dollars in 2019, according to official data from the World Bank and projections from Trading Economics. The GDP value of Nigeria represents 0.37 per cent of the world economy (World Bank Reports, 2019) .

Literature Review

Generating electricity happens through the generator by converting motive power into electrical power for external use. They may run on petrol, natural gas, propane or they come as a hybrid dual-fuel power. Complete or incomplete combustion of gasoline produces carbon monoxide (CO), hydrogen cyanide (HCN), hydrogen sulphide (H_2S), hydrogen fluoride (H_2F), Nitric oxide (NO), Nitrogen dioxide (NO_2) and Sulphur dioxide (SO_2). These gases have long been proved to be hazardous.

Nigerian residents have been forced into the extensive use of electric power generators due to the incessant electric power failures that have been witnessed over the years. Aside from commercial and industrial consumption, as of 2009 more than six million Nigerians own power generating set and spend a staggering ₦1.56trillion ($13.35Million) to fuel them in a year (Nanahang, 2009, Akindele, 2019).

A generator set is a product of an engineering invention developed to provide continuous electric power. The machine uses a fossil fuel-based engine which converts the chemical energy in fossil fuels to mechanical energy and then to electrical energy (Stanley 2010) Efforts are then geared towards reducing the pollutions and other negative contributions of the human invention called electric generator and to make human lives safer. Products of the fractional distillation of crude oil such as petrol and propane gas are fuel sources for these generators found in, homes, offices, and business centres (Onawumi et al. 2016).

Figure. 1.1 Petrol-fired Generator set

Figure 1.2 Propane-fired Generator set

Figures 1.1 and 1.2 represent generator sets fired by petrol and propane gas respectively.

From the results that were obtained in a study by Karzan et al (2020), it was concluded that using fossil fuel generators will lead to emitting a higher amount of the toxic gases of NO_2 then SO_2 rather than CO and HC as well as greenhouse gas of Co_2.

Moreover, domestic sources were the main cause of emitting the investigated gases because the demand for electric power in residential buildings was many times greater than for commercial purposes. They recommended those in the position of authority to place a mandatory price on the emissions of greenhouse gases and other air pollutants by the internal combustion engines to reduce emissions and their consequent environmental and health impacts.

The health-related dangers of carbon monoxide poisoning because of operating electrical generators indoors has been poorly appreciated, even by health workers. There is a need for wider public education on the subject in Nigeria, and especially in the mass media and at schools and hospitals.

Our environment is a complicated reactive system. Pollution in it spreads due to biological, physical, and chemical processes which may occur simultaneously and requires the intervention of science, law and policies. The intervention of knowledge of science in the control of pollution is however expedient in, automobile, mining, and farming industries. (Chandrappa & Das, 2021). Between 1999 and 2004, 400 Americans died annually from unintentional carbon monoxide poisoning. Twenty thousand presented at the emergency room, and 4000 were hospitalised owing to carbon monoxide poisoning (CDC, 2007).

World Health Organisation's Guidelines for Community Noise suggests unwanted sound exposure can cause hearing loss, fatigue, loss of balance, nausea, reduced sex drive, headaches, and mental disorders. Others link noise pollution with susceptibility to colds, changes in blood pressure, and heart disease (Stansfeld et al., 2000, Wakefield, 2002, Charles, 2005; Oyedepo, 2012 and Afolayan 2014).

Carbon monoxide is a colourless, odourless, non-irritating, but poisonous gas, produced by the incomplete combustion of a hydrocarbon in gasoline engines used to power several home appliances. Carbon monoxide is a silent killer since it is odourless, colourless but poisonous (Bluementhal, 2001).

The most common symptoms of carbon monoxide poisoning include headaches, dizziness, weakness, convulsions, seizures, confusion, chest pain, vomiting, diarrhoea, coma or even death (Asani et al, 2004; CDC, 2007).

Several authors and studies such as Steiner et al. (2016), Majewski and Khair (2006) and Resitoglu et al. (2015) have reported that the regulated emissions from internal diesel combustion engines are composed of the following chemical compounds; carbon dioxide (CO2), carbon-monoxide (CO), methane (CH4), numerous Polycyclic Aromatic Hydrocarbons (PAH), Volatile Organic Compounds (VOCs), Nitrous Oxides (NO_x), Sulphur Oxides (SO_x), Heavy Metals (HM) and Particulate Matter or Black Carbon (PM or BC) which will be released as basic components of diesel engine exhaust and they have many implications on health and environment. These contaminants acidify the soil, hence depleting soil nutrient.

Studies have shown that crops within such vicinity get reduced in nutritional values. In some cases, vegetation in the areas surrounding the flare is grossly affected partly due to the quantity of heat causing stunted growth of plants as well as low feeds for livestock that is produced owing to the acidic nature of soil pH (Ubani and Onyejekwe, 2013).

Materials and Method

The metrics used in this analysis were temperature, Carbon-monoxide (CO) emission and the sound outputs at various percentages of consumer loads. Resistive loads such as electric bulbs and heaters were used in the study. The hybrid generator was fuelled firstly with propane gas and measurements were taken at no load and random loads of 200W, 240W, 1000W and 1240W which are approximately 0%, 8%, 10%, 40% and 50% loading of the 2.5kVA generator used. After an hour, the same procedure was repeated for when the generator was fuelled with gasoline with the parameters measured at an interval of 10 seconds for an overall period of 120 seconds.

Documentation and a comparative analysis of how the average CO emission, temperature and sound level vary with the loading conditions when the generator was fuelled with gasoline and when it was fuelled with propane gas was done. Equipment used were carbon monoxide sensor, temperature analyser and a sound spectrum analyser used in taking measurements at different load ratings and time interval.

The sound spectrum analyser at a complete absence of sound reads -120dB and the sound level increases towards the 0dB mark as the sound level increases.

The Carbon Monoxide meter has a capacity of between 0 ppm and 1000ppm and a temperature range of 0 to 50 ^{0}C. With these rating, a completely free zone that has no carbon monoxide will read 0 ppm on the meter and a temperature of the surrounding environment.

The World Health Organisation (WHO) and Environment Protection Agency (EPA) set the standard exposure limit for carbon monoxide emission and noise exposure. The standard limit emission ranges between 6 ppm and 87 ppm for carbon-monoxide at normal indoor air level for between 24hrs and 15 mins respectively (WHO, 2004).

WHO in the same document set the outdoor noise level capable of causing hearing impairment to 100dB for no more than 4hrs and 5 times in a year. The EPA noise exposure limit has it that any noise or sound level above 82dB should not be exposed to humans for more than 90 minutes and that greater than 97dB should not be exposed to humans for more than 3 minutes (EPA, 1974). These standards will be the bases of comparison to analyse the environmental effects of the stand-alone generator set sources.

Results Discussion

Figure 2.3 shows the Average carbon-monoxide emission at different loads for petrol and gas used as fuel. The average emission is given as:

$$\text{Average emission} = \frac{\text{Total emission}}{12} \text{ at different load rating}$$

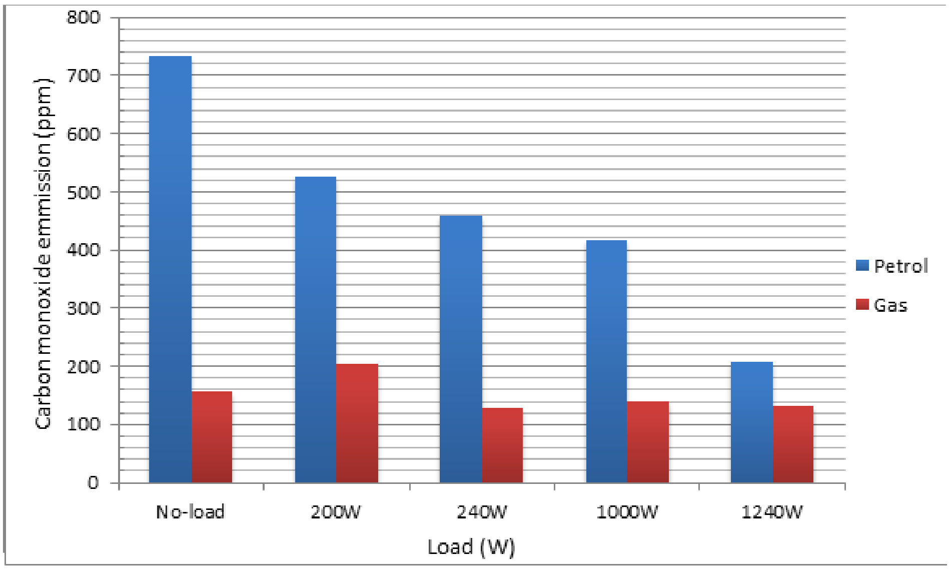

Figure 3.1: Average carbon-monoxide emission at different loads

Figure 3.1 depicts higher carbon-monoxide emission when a gasoline (petrol) generator is used as an alternative source of power generation when compared to a gas generator since, in each load rating, the carbon-monoxide emitted by gasoline (petrol) generator is higher.

Figure 3.2 shows the average temperature at different load rating for petrol and gas. The average temperature is given as:

$$\text{Average temperature} = \frac{\text{Total temperature}}{12} \text{ at different load rating}$$

It depicts that temperature would be higher when gasoline (petrol) fired generator is used as an alternative source of power generation when compared to gas (propane) generator since the ambient temperature when using gasoline (petrol) generator is the highest regardless of the loading.

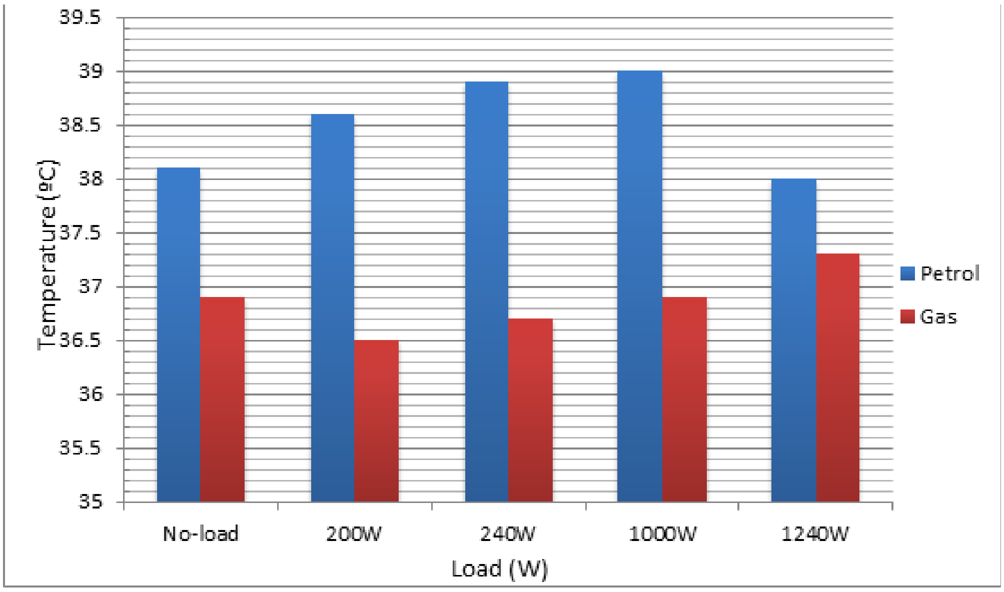

Figure 3.2: Average temperature at different loads

Temperature, Carbon-monoxide and Sound Effects

At no load and varying loading conditions used, it was observed that the gasoline-fired generator raised the ambient temperature of 1.5m away and around the generator from 32.5 degrees Celsius to between 37.7 and 39.4 degrees Celsius while the gas-fired generator has the same ambient temperature raised to between 36.0 and 37.5 degrees Celsius. This brings the percentage increase in temperature for the gasoline-fired generator from 16.0% to 21.2% and that of the gas-fired generator from 10.8% to 15.3%.

Similarly, at no load and varying loading conditions used, it was observed that the gasoline-fired generator raised the CO Emission (ppm) from 0 ppm to between 82ppm and 886 ppm while the gas-fired generator, raised the CO Emission (ppm) from 0 ppm to between 67 ppm and 383 ppm.

From the results obtained, average carbon-monoxide emission was highest at no load with 733.6 ppm which is very much above the standard set by the statutory bodies and this is highest for gas at 200W load with a value of 204.3ppm. This implies, generators regardless of the fuel source should not be operated near the living room.

The sound graph adequately showed the generator sounds at various levels of load.

Each sound graph consists of a spectrum of sounds of different frequencies. The red plot showed the peak the sound has reached before the sound was measured. This has a little deviation from the green plot which is the sound being measured at a particular time. Figures 3.3 and 3.4 depicts the sound spectrum at no load, the sound level for petrol fired generator was between 89.8 dB and 93.6 dB while that of the gas-fired generator was between 91.4dB and 96.7dB

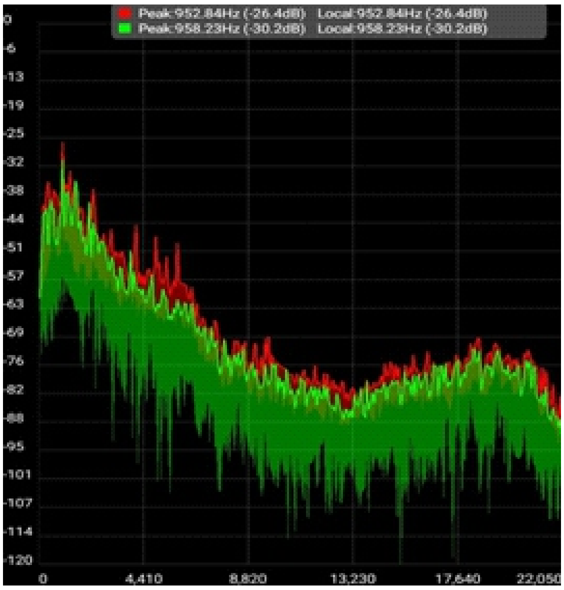

Figure 3.3: Sound output for petrol at no-load

Figure 3.4: Sound output for gas at no-load

Figures 3.5 and 3.6 depict the sound spectrum for load at 200W, the sound level for petrol fired generator was between 87.7dB and 90.1 dB while that of the gas-fired generator was between 85.5dB and 90.2dB

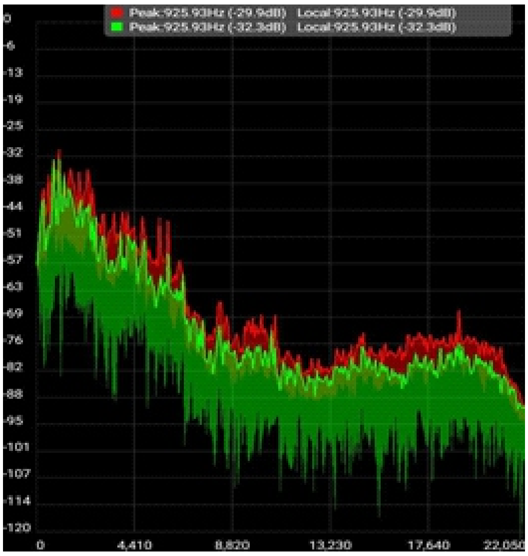

Figure 3.5: Sound output for petrol at 200W

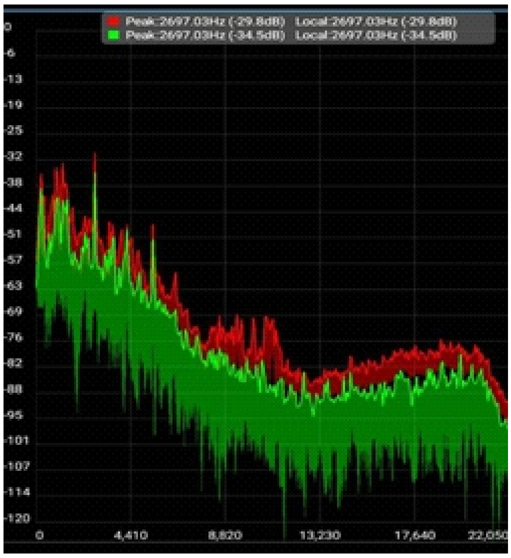

Figure 3.6: Sound output for gas at 200W

Figures 3.7 and 3.8 show the sound spectrum for load at 240W, the sound level for petrol fired generator read between 89.5dB to 89.9 dB while that of the gas-fired generator was between 84.3dB and 90.9dB

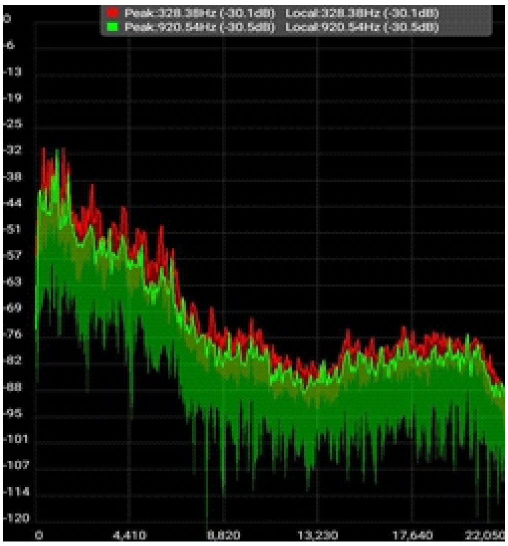

Figure 3.7: Sound output for petrol at 240W

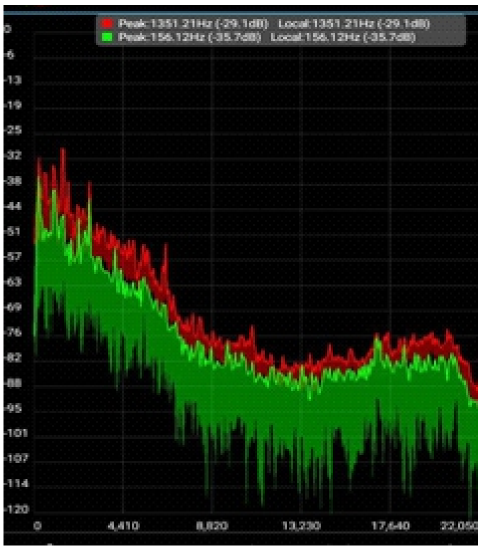

Figure 3.8: Sound output for gas at 240W

Figures 3.9 and 3.10 show the sound spectrum for load at 1000W, the sound level for petrol fired generator read between 96.6dB to 98.1 dB while that of the gas-fired generator was between 93.6dB and 97.3dB

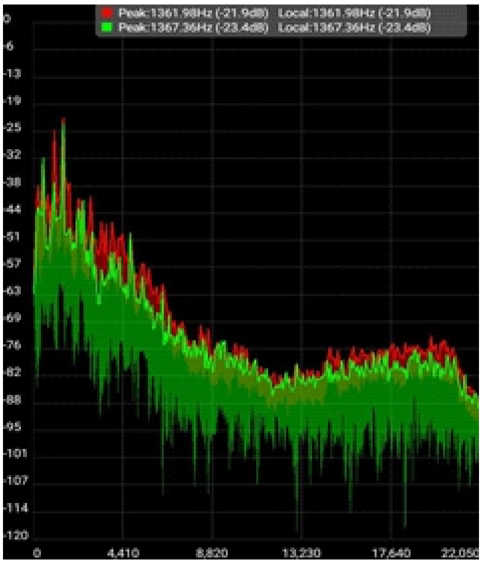

Figure 3.9: Sound output for petrol at 1000W

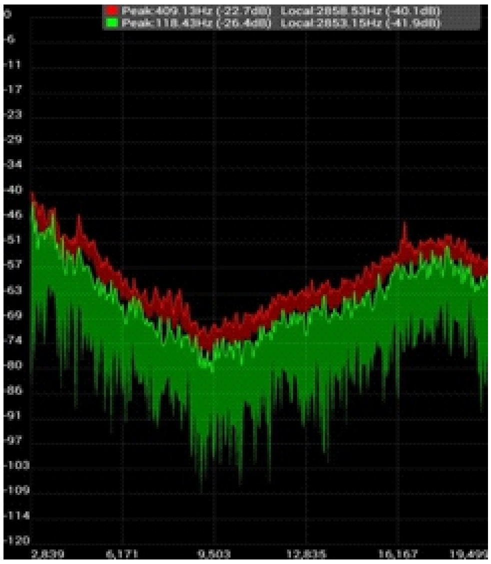

Figure 3.10: Sound output for gas at 1000W

Figures 3.11 and 3.12 depict the sound spectrum for load at 1240W, the sound output for petrol fired generator read between 80.6dB to 89.6dB while that of the gas-fired generator was between 87.7dB and 89.7dB

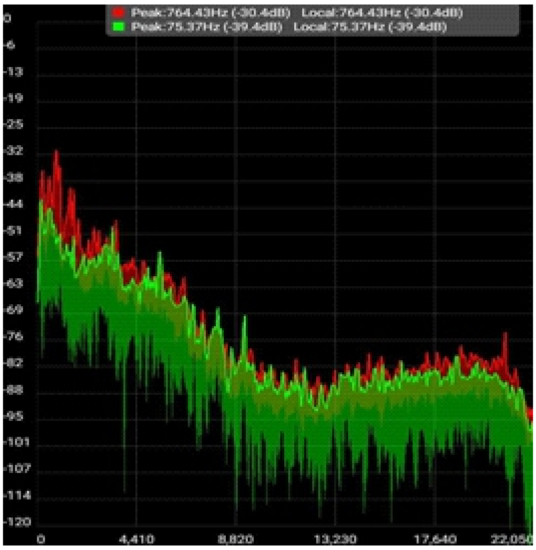

Figure 3.11: Sound output for petrol at 1240W

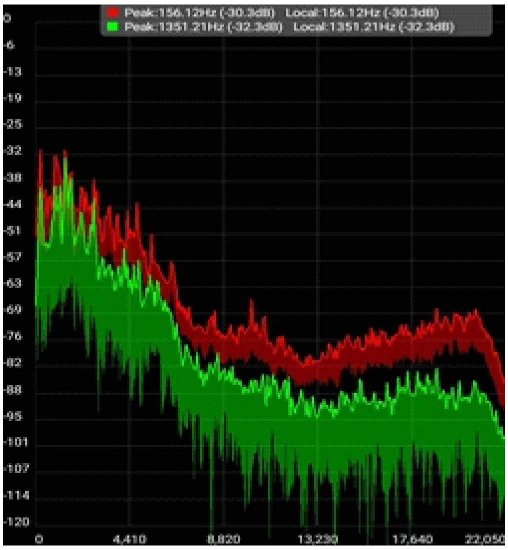

Fig. 3.12: Sound output for gas at 1240W

For the correlation analysis, there is a strong negative correlation between the load increase and carbon emission for petrol fired generator; this connotes that the higher the load, the lower the emission. No linear relationship however exists between temperature and load increase for the petrol fired generator.

For propane gas-powered generator, the correlation analysis showed that there is a moderate negative correlation between load increase and carbon emission. This shows that as the load increases, the extraordinarily little decrease is noticed in the ambient temperature. A strong positive correlation however exists between the increase in load and ambient temperature for a gas-fired generator which means that as the load increases, the ambient temperature of the generator also increases.

Conclusion

The effect of carbon-monoxide emissions, ambient temperature and a sound level of generators fuelled separately with propane and petrol in varying loading conditions have been compared in this study. Both sources having sound levels of approximately 90dB showed they will be harmful to humans if they are exposed to it often for more than 90 minutes according to EPA. Results depicted that petrol-fired generators have more carbon emission impact on the environment than the propane-fired generators for the same size of generator considered at the various loading conditions.

The correlation analysis also connotes that for a petrol-fired generator the higher the load, the lower the emission and for a propane gas-fired generator, the higher the loads, the higher the ambient temperature. The carbon emission for the petrol-fired generator was extreme and would be very much poisonous when one is exposed to it for a shorter time. Regardless of the fuel source, the use of generating sets close to the living room should be very much discouraged.

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