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Investigation of Impacts of Gas-Fired Power Plants on Ambient Carbon Monoxide (CO) of Neighboring Communities

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ABSTRACT

Operation of gas power plants creates emissions of various air pollutants including carbon monoxide with associated health and environmental effects. This study investigated the ground level concentrations of carbon monoxide from units of the 4 MW Gas Power Plants of a leading utility, gas and energy company in Lagos, Nigeria. Air emissions of CO from the gas power plants at the project site were calculated using the emission factors. The AERMOD dispersion modelling tool (version 9.6.1) was used to model ground level concentrations of CO associated with air emissions from the two units of 1364 kW and 774 kW of Gas Power Plants. Three different scenarios involving the gas turbines operations were considered. Scenario 1 and 2 involved the operation of 1364 kW and 774 kW, respectively while scenario 3 involved the simultaneous operation of both gas power plants. The predicted ground level CO concentrations from the three scenarios in all locations considered were within the FMEnv's limits, though, the ambient CO at the project site in scenario 1, 2 and 3 changed by 2.31%, 1.72%, and 2.68% of limit, respectively. However, sites using gas power plants near communities may further reduced emissions of air pollutants by developing relevant control techniques with continuous monitoring of these emissions at the site. This study also provides stake holders necessary information that can help in making profitable decisions and guidelines in similar situation.

KEYWORDS: Carbon monoxide, air quality, powerplants, air pollutants emissions, AERMOD

1. INTRODUCTION

The demand for reliable and cleaner energy sources has led many countries to adopt gas-fired power plants as alternatives to coal and oil-based plants. Natural gas, primarily composed of methane (CH_4), is often perceived as a cleaner fossil fuel due to its lower carbon dioxide (CO_2) emissions upon combustion. However, one of the less discussed but significant by-products of natural gas combustion is carbon monoxide (CO), a colorless, odorless, and toxic gas. Ambient CO concentrations, especially in areas proximal to power generation stations, pose potential health risks and environmental concerns.[11] Carbon monoxide is produced due to incomplete combustion of carbon-containing fuels. When released into the atmosphere, it does not only affect human health by impairing oxygen delivery to the body's organs and tissues but also contributes to the formation of ground-level ozone and secondary pollutants.[13] While vehicular emissions have traditionally been the dominant source of CO in urban areas, stationary sources like gas-fired power plants are increasingly recognized as contributors to localized pollution hotspots.[1] A power plant or generating station is broadly any facility that houses one or more generators to produce electricity for distribution or dedicated use, and according to the U.S. Energy Information Administration (EIA), the category of utility scale power plants includes facilities with at least 1 MW of generating capacity, while smaller units are considered distributed or small scale generation.[12] Numerous studies have examined the environmental impact of power generation facilities, especially regarding their contributions to air pollution. Gulliver and Briggs demonstrated the spatial variability of air pollutants near industrial facilities and highlighted the role of meteorological conditions and terrain in pollutant dispersion.[6] Recent research has further shown that dispersion modelling tools such as AERMOD and CALPUFF provide critical insights into ground level concentrations of pollutants from energy facilities, allowing regulators to make more precise policy decisions.[15] Studies conducted in developing countries highlight that poorly maintained gas-fired plants often release CO at concentrations above recommended safety thresholds, particularly when multiple turbines are operated simultaneously.[8] Similarly, Anenberg et al. and Smith et al. emphasized that even transition fuels like natural gas which is usually considered as a cleaner alternative fuel, still contribute significantly to localized air quality degradation, with combustion resulting in emissions of CO, NO_x, and particulate matter.[2,10] In Nigeria, where energy demand is growing rapidly, Olalekan et al. reported that communities near power plants face increased risks of both acute and chronic exposure to CO.[9] Furthermore, from a public health perspective, the World Health Organization and the U.S. Environmental Protection Agency provide guidelines on acceptable exposure levels to carbon monoxide, emphasizing that

prolonged exposure even at moderate levels can lead to cardiovascular and neurological issues.[13,11] Zhang et al. demonstrated that integrating continuous emissions monitoring systems (CEMS) into plant operations significantly improves compliance and reduces exceedances in pollutant concentrations.[14] In similar manner, Li et al. explored the link between combustion efficiency and CO output in gas turbines. They found that maintenance schedules and operational practices significantly influenced emission levels, suggesting that better regulation and technological upgrades could reduce CO emissions.[7] This study reveals the importance of localized investigations into CO emissions, especially in rapidly urbanizing regions where energy demand and population density intersect, considering different scenarios, location and distance of receptors. This study essentially investigates the extent to which gas-fired power plants influence ambient carbon monoxide concentrations in neighboring communities.

2. METHODOLOGY

This study investigated the ground level concentrations of carbon monoxide from units of the 4 MW Gas Power Plants of a leading utility, gas and energy company in Lagos, Nigeria. The immediate environment given adequate attention was within 50 km radius of the site. Three different scenarios involving the gas turbines operations were considered. Scenario 1 and 2 involved the operation of 1364 kW and 774 kW, respectively while scenario 3 involved the simultaneous operation of both gas power plants, approximately 2 MW. The 1364 kW and 774 kW units of the Gas Power System operated with natural gas consumption rate of 129 scm/hr and 73 scm/hr respectively. The map of the area was generated using ARC-GIS Tool (Figure 1).

The emission rates and the exhaust vent stack parameters including height, diameter, exhaust temperature, and the exit velocity used as model input parameters were obtained from the project details and site (Table 1). The calculation of air emissions of CO from the gas power plants at the project site were calculated using the emission factors.[4] The operation is assumed to be on the natural gas and at full capacity carrying the maximum load. It was assumed that all the gas reciprocating engines use natural gas and are in continuous operations at full capacity, while considering worst case scenario. American Meteorological Society/Environmental Protection Agency Regulatory Model, AERMOD (version 9.6.1); a steady-state Gaussian plume air dispersion model based on planetary boundary layer theory was used to model ground level concentrations of CO associated with air emissions from the two units of 1364 kW and 774 kW of Gas Power Plants. AERMOD considers several meteorological parameters, primarily processed by its pre-processor AERMET, which uses input data such as wind speed, wind direction, temperature, and cloud cover to calculate essential boundary layer parameters. Meteorological data from the Lakes Environmental meteorological observations on the study area, flat terrain, map of the study area and the modelling parameter in Table 1 were used in AERMOD Software for modelling. Furthermore, for the purpose of investigating the air quality implication on health and environment, the FMEnv standard for CO 11400 μg/m^3 was used.[5] The impact on project site and receptors (R) around the site were considered including: R1(0.3 km N), R2 (0.2 km NE), R3(0.17 km NW), R4(0.23 km SW) and R5 (0.3 km SW).

Figure 1: Plant project site and neighboring receptors

Table 1: Parameters used for modelling

Gas Power Plant kW	1364	774
Air Pollutant	CO	CO
Stack Emission rate (g/s)	1.1730	0.6700
Location X(m)	484.23	466.33
Location Y(m)	538.76	536.97
Discharge Temperature(K)	744	744
Base Elevation(m)	1.00	1.00
Release Height(m)	3.65	3.20
Stack Diameter(m)	0.1	0.1
Exit Velocity(m/s)	66.2	60

3. RESULTS AND DISCUSSION

Modelling results from the three operation scenarios considered in this study are presented and discussed in this subsection. The identified impacts on the ambient air quality of the host environment were also considered.

3.1 Predicted Ground Level Concentrations of CO

In Table 2, the anticipated 24 - hour ground level concentrations of CO from 1364 KW Deutz Gas power plant at the site as investigated in scenario 1 were 3.00 – 263 μg/m^3 (Figure 2). The operation of 774

KW Deutz gas power plant resulted in 24 - hour predicted concentrations of CO in the range of 2 - 196 μg/m^3 (Figure 3). In scenario 3, where the simultaneous operations of two power plants (1364 and 774 KW) were investigated, the expected concentrations of CO were 3 – 306 μg/m^3 (Figure 4).

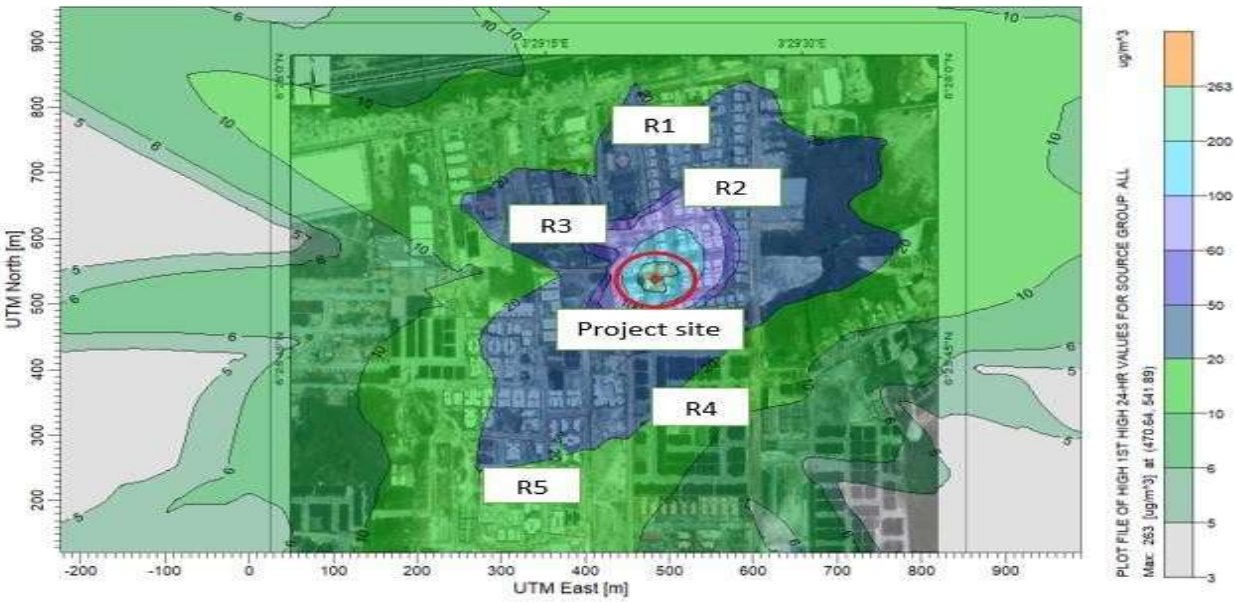

Figure 2: CO concentrations from scenario 1

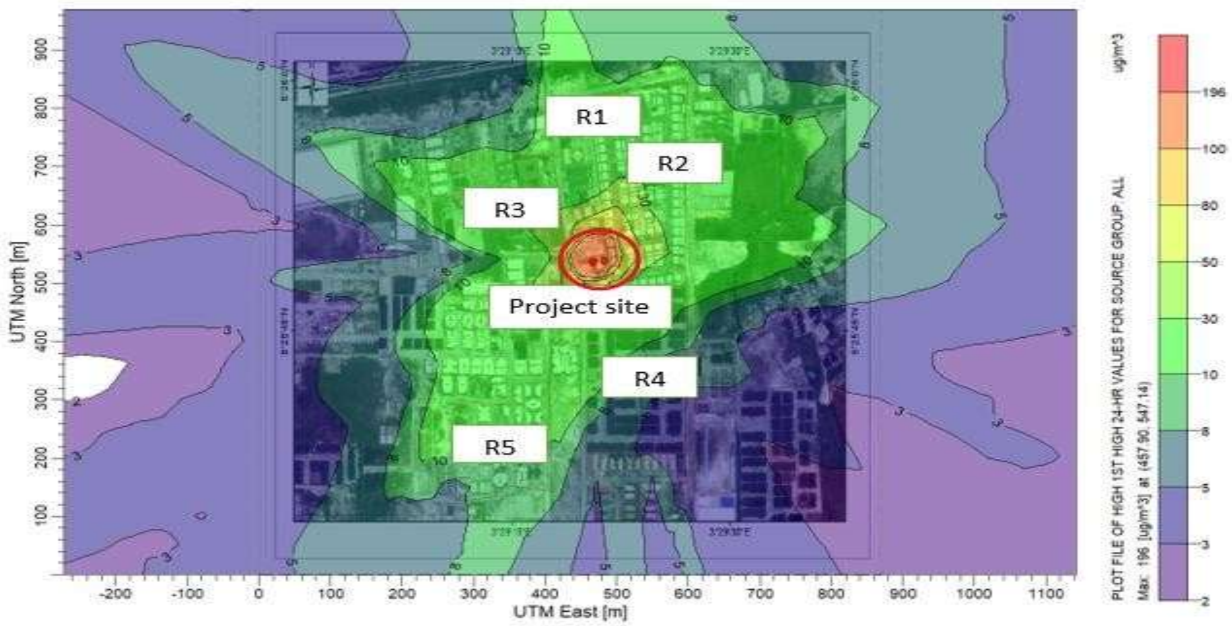

Figure 3: CO concentrations from scenario 2

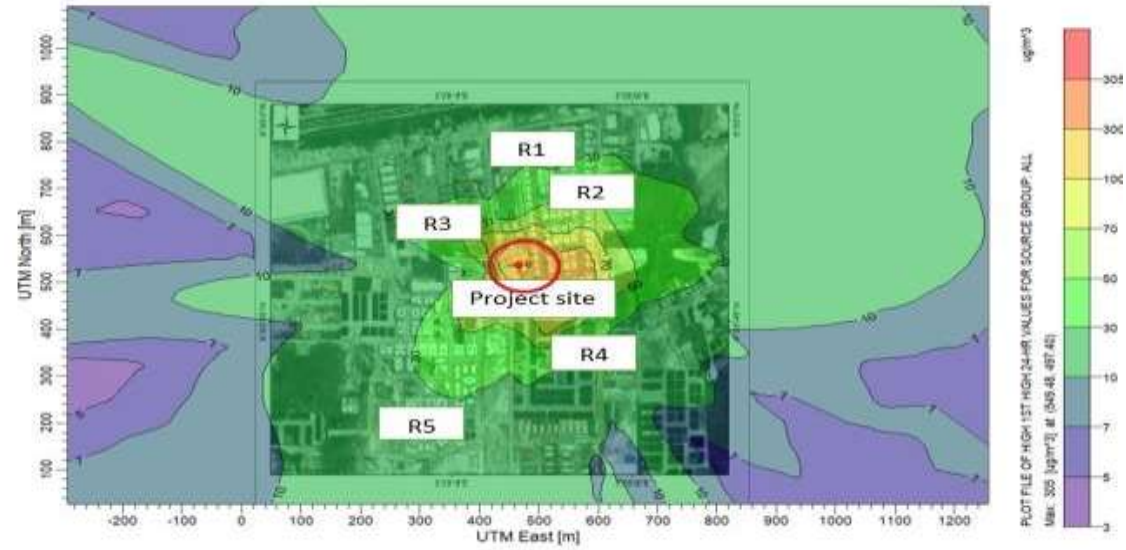

Figure 4: CO concentrations from scenario 3

3.2 Impact of Maximum Ground Level CO Concentrations on the Environment

As summarized in Table 2, considering scenario 1 - 3, the maximum 24 – hr CO concentrations from the power plants are 263.00 to 305.00 μg/m^3 at the project site, which represent 2.31 – 2.68% of FMEnv limits. In scenario 1, the investigation of 1364 kW Deutz Gas Power Plant showed that the anticipated daily CO ground level concentrations in the six (6) communities considered are 10 – 263 µg/m^3. These are 0.09 – 2.31% of FMEnV's limit. When a unit of 774 kW Deutz Gas Power Plant is operated as investigated in the scenario 2 of this study, the daily averaging period ground level concentrations of CO in the neighboring receptors are 5.00 – 196.00 µg/m^3 which are 0.04 – 1.72% of FMEnv's limit. Scenario 3 which is simultaneous operations of the two units of the gas power system (≈2 MW) will generate CO daily averaging period concentrations of 10.0 – 305.00 µg/m^3 which are 0.09 – 2.68% of limit. Figure 5 shows a graphical representation of the relationship between predicted CO concentrations at the project sites and receptors (1-5) from the source of air emission across scenario 1-3. In addition, the maximum 24-hour ground-level CO concentrations predicted for each operational scenario against the FMenv limit was illustrated in Figure 6.

Table 2: Predicted Ground Level 24 - hour ground level concentrations of CO and their implications from scenario 1-3

Location	**Scenario 1**		**Scenario 2**		**Scenario 3**	
	24 – Hr Maximum Predicted Concentrations (µg/m^3)	**% of Standard**	24 – Hr Maximum Predicted Concentrations (µg/m^3)	**% of Standard**	24 – Hr Maximum Predicted Concentrations (µg/m^3)	**% of Standard**
Project Site	263.00	**2.31**	196.00	**1.72**	305.00	**2.68**
R1 (0.23km N)	20.00	**0.18**	10.00	**0.09`**	50.00	**0.44**
R2(0.2km NE)	60.00	**0.53**	30.00	**0.26**	100.00	**0.88**
R3 (0.17km NW)	20.00	**0.18**	10.00	**0.09**	50.00	**0.44**
R4 (0.23km SE)	10.00	**0.09**	5.00	**0.04**	10.00	**0.09**

R5 (0.3km SW)	10.00	**0.09**	10.00	**0.09**	30.00	**0.26**

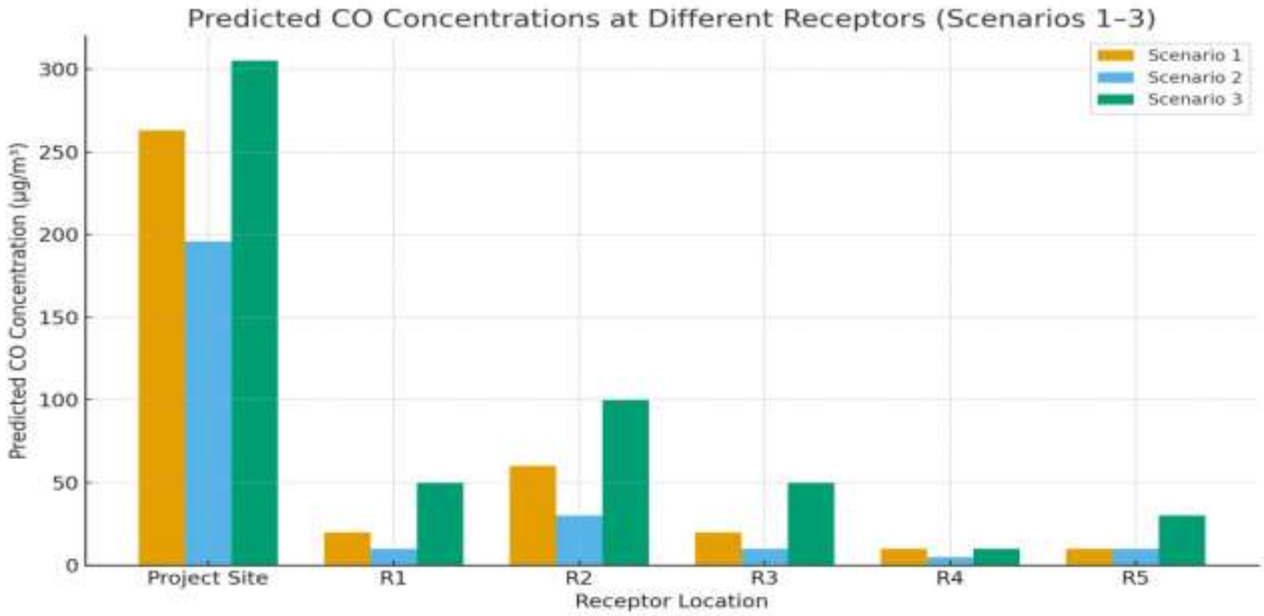

Figure 5: The predicted CO concentrations at each receptor location across Scenarios 1–3.

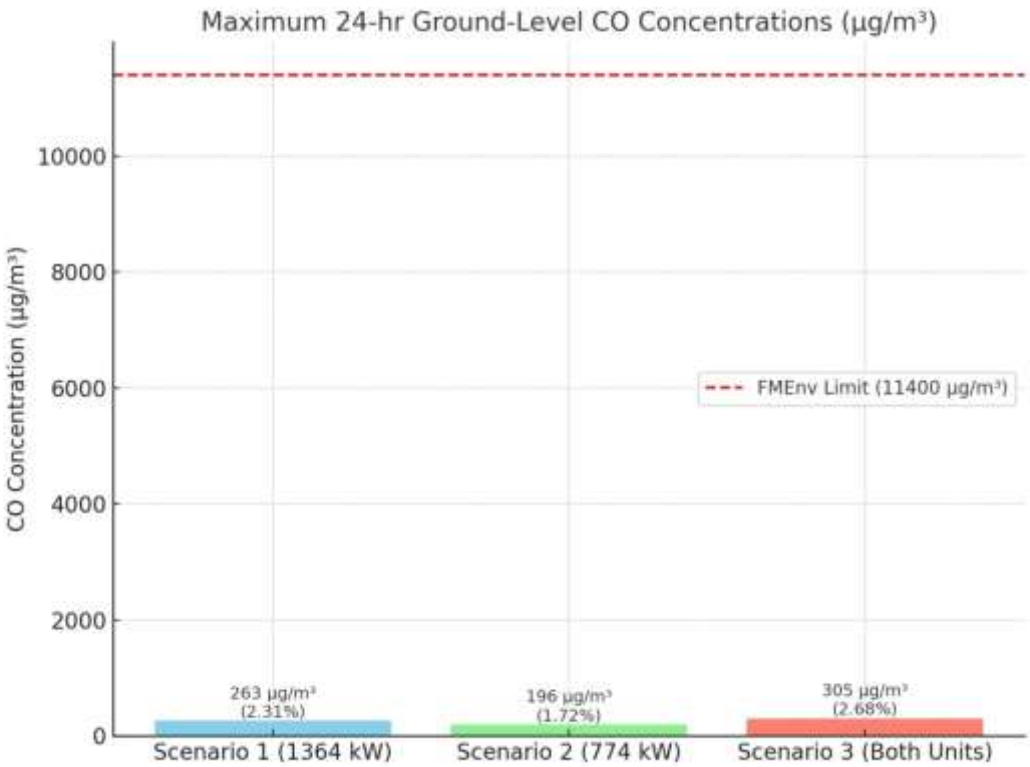

Figure 6: The maximum 24-hour ground-level CO concentrations predicted for each operational scenario

3.3 Discussion

Generally, in the three (3) scenarios and as illustrated in Figure 5, the maximum ground level concentrations of CO were recorded at the project site; 263 μg/m^3, 193 μg/m^3 and 305 μg/m^3 for scenarios 1, 2, and 3, respectively. This was followed by R2 (0.2 km NE of site) while the minimum ground level concentrations were recorded at R4 (0.23 km SE of site) and R5 (0.3 km SW of site). Since AERMOD modelling system predicts the concentration and dispersion of contaminants downwind, that is locations in the direction of the wind from the emission source, the dispersion was influenced by the prevailing southwesterly winds in Lagos, which transported emissions predominantly north of project site, explaining higher receptor values in downwind directions.[3] These findings align with previous studies that highlight the importance of wind direction and atmospheric stability in pollutant dispersion.[6,13]

Furthermore, as illustrated in Figure 6, the predicted ground level CO concentrations across scenario 1 (1364 kW), scenario 2 (774 kW), and scenario 3 (≈ 2 MW) in all the receptors considered, that is R1 to R5, have insignificant impacts on the ambient CO. However, they affect the ambient CO at the project site by 2.31%, 1.72%, and 2.68% of limit for scenario 1, 2 and 3, respectively. These percentages are still within FMEnv limits, confirming minimal environmental impact on surrounding communities. From the results obtained in Table 2, a cumulative effect from combining scenario 1, 2 and 3 (≈ 4 MW) will still have limited impact on the ambient CO of neighboring communities

4. CONCLUSION

AERMOD tool has been used to model the ground level concentrations of CO associated with air emissions across three scenarios from different units of the 4 MW Deutz power plants in Lagos community. Location of gas power plants with capacity around 1 to 4 MW do not significantly elevate ambient CO in surrounding communities around 0.17 km away from the project site or air emission source under worst-case operating scenarios. This may be applicable to areas in the region or country with similar meteorological conditions and terrain. Regular monitoring and adoption of emission control strategies are nonetheless recommended for cumulative impact management in areas where small scale or utility gas power plants are utilised for electricity generation.

CONFLICT OF INTERESTS

The authors declare no conflict of interests.

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