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Coping with a Broken Grid: The Effects of Fossil Fuel Backup Generators in Maiduguri, Nigeria

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ABSTRACT

The cost of power outage can be substantial. Epileptic power supply and grid cut off is a commonplace in Maiduguri Metropolis, Borno State, Nigeria. To meet energy needs, there is an increasing attention to the use of backup generators for self-generation. Continual dependence on these backup generators does not come without revelatory monetary costs to the populace. The study analysed the energy generation, fuel consumption, pollutants emissions, and the costs associated with the servicing and maintenance of backup generators. Fuel cost for operating the backup generators in a month sums up to 116.8 million Naira, which is about 11.3% of the cost of purchasing the backup generators. Also, the high emissions of CO_2, NO_x *and* $PM_{2.5}$ *make these generators a potential source of ground-level ozone formation and also contribute to air pollution. Comparing the overall spending of the operation of the diesel generating sets and the environmental hazards over a long period of time with the cost of acquiring them, the cost of operation becomes dominant. The unreliability of the power grid and the recent events that put the city of Maiduguri into total blackout warrant the search for an alternative source of energy.*

1. INTRODUCTION

Maiduguri the Borno State capital and its environs were thrown into blackout when, in January 2021, insurgents attacked the 330 kV Damaturu-Maiduguri Transmission Line destroying three transmission towers and cutting off the State capital from the national power grid (The Guardian, 2021). It took the Transmission Company of Nigeria (TCN) nearly two months of concerted efforts to restore power back to the city and its environs. Few days after the restoration, the transmission infrastructures were damaged again along the Maiduguri-Damaturu Road, throwing the town into a second phase of blackout (Echewofun, 2021). Even when the city is connected to the grid, there is always an epileptic electric power supply.

Living with this blackout has become the reality of the people. To meet their energy needs, there is an increasing attention to the use of backup generators for self-generation and this has become the stopgap measure. These generators powered by diesel or petrol are deployed across every corner of the city at homes, schools, businesses and production sites, and are used for long hours in a day. Continual dependence on these backup generators does not come without revelatory monetary costs to the populace. The financial cost of operating petrol or diesel for long hours in a day is very high (Opeoluwa, 2021). With a pump price of 227 Naira for diesel and 166.62 Naira for petrol, it costs almost twice as much to run backup generators compared with the subsidized power from the national grid (Opeoluwa, 2021). In addition to this, these backup generators contribute significantly to negative health, climate effects and noise pollution which further reduces the quality of life of the people (Seleye-Fubara et al., 2011; Akindele, 2016).

Whereas it is a common knowledge that this dependence on backup generators can be reduced by moving towards the utilization of alternative sources of energy such as solar, having an insight on this requires an understanding of the extent to which the people use backup generators, their cost of operation and their impact to health and environment. This study is an attempt to address the impact of backup generators serving energy needs in Maiduguri Metropolis, taking the University of Maiduguri as a case study.

2. METHODOLOGY

This investigation emphasizes on backup generators operations in the University of Maiduguri. The framework employed used data on numbers of generators, runtime and generator performance characteristics to estimate their impacts of operation. Thus, it highlights effects that directly relate to the consumption of, and expenditure on fuels and backup generators as determinants of financial costs. The workflow for the study is presented in Figure 1.

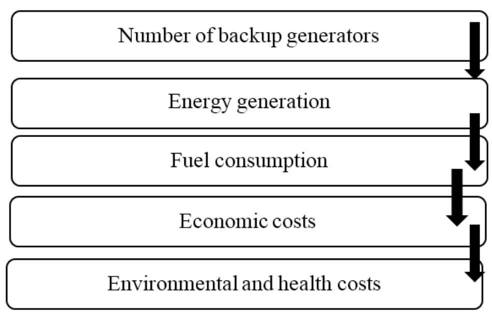

Figure 1: Research framework

2.1. Number of Generating Sets

The total number of diesel generators in the institution, their power rating and operating conditions were obtained from the institution's Department of Works.

2.2. Fuel Consumption

The fuel consumption of generators is expressed as:

$$C_f = \sum N_f \, P_f \, CF_f \, C_{ave.,f} \quad (1)$$

Where C_f is the fuel consumption of the f-category generator, N_f is the number of generator of the f type category, P_f is the average rated ouput of a generator, T_f is the runtime of the generators calculated based on survey, CF_f is the capacitor factor – fraction of the rated capacity that is utilized when operated. $C_{ave.,f}$ is the average fuel consumption obtained from fuel consumption charts by the generator manufacturers.

2.3. Energy Generation

Equation 2 was used to calculate the energy generated by the backup generators.

$$E_f = \sum \frac{C_f}{C_{ave.,f}} \quad (2)$$

Where E_f is the energy generated by a category f type generator, C_f and $C_{ave.\_f}$ are as expressed in Equation (1).

2.4. Economic Cost

The economic costs involve the capital investment, the operation cost (fuel related cost) and the cost of maintenance. The capital cost represents the cost of purchasing the generators. Generators burn fuel to produce energy, therefore, expenditures on fuel is the dominant cost associated with their operation. Fuel cost is obtained from fuel price records. Maintenance cost is taken on the order of 15% of the fuel cost.

$$\text{Total cost} = \text{Capital cost} + \text{Cost of operation} + \text{Cost of maintenance} \quad (3)$$

2.5. Emission

The equation used for estimating emissions in this study is given as:

$$E_0 = \sum C_f \, EF \quad (4)$$

Where C_f is fuel consumption and EF is the emission factor of pollutants. Default emissions of particulate matter ($PM_{2.5}$), NO_x, SO_x, and CO_2 were adopted from Gilmor et al. (2010) and Farquharson (2019).

3. RESULTS AND DISCUSSION

3.1. Number of Generating Sets

Table 1 shows the number of functional backup generators in the University of Maiduguri. The 800 kVA generators are used to power student's hostels; the 500 kVA are used in various schools and Faculties in the institution while others are used in various centres and administrative units.

Table 1: Number of backup generators

Power rating of sets (kVA)	Number of sets
800	11
500	10
350	4
200	6
100	10
100*	20
80	1
45	1
40	2
20	2
14	2
Total	69

* Indicates 100 kVA generators of different model with different fuel consumption from the 100 kVA mentioned above

3.2. Energy Generation

The rating of the backup generators is designed in terms of apparent power measured in kVA. The real electric power provided by the generators for use by appliances and equipment is measured in kW. The ratio between the real and the apparent power is the power factor taken as 0.8 for this study (Jahnavi, 2020; Llyod, 2020). Fuel consumption per kWh of the generators is taken at 75% nominal power. Backup generators provide an estimated 2.518 GWh in the University of Maiduguri in a month with a runtime of 8 hours a day. Figure 2 shows the energy generated by each generating set. There is a steady decrease in energy generation as the power rating of the generators lowers. This is so because the higher the capacity generator, the higher the energy it generates. The 800 kVA generators generated about 102400 kWh while the 14 kVA generated about 1760 kVA within same period.

3.3. Fuel Consumption

An estimated 510, 403 litres of diesel is consumed monthly by backup generators. Heavy engine generators (800 kVA and 500 kVA) account for about 69% of the consumption. Figure 3 shows the backup generator fuel consumption per month for each generator set. From Figure 3, there is a steady decrease in the amount of fuel consumed per month as the rated power of the generators decreases. The fuel consumption by the generators decreases with decrease in the power rating of the generators when utilized for the same period of time because the heavy engine backup generators generate more energy and carry more loads than the light ones. Replacing electricity generation lost during power outages or blackout with backup diesel generation increases fossil energy consumption. Fuel consumption is the major portions of diesel generator set operation.

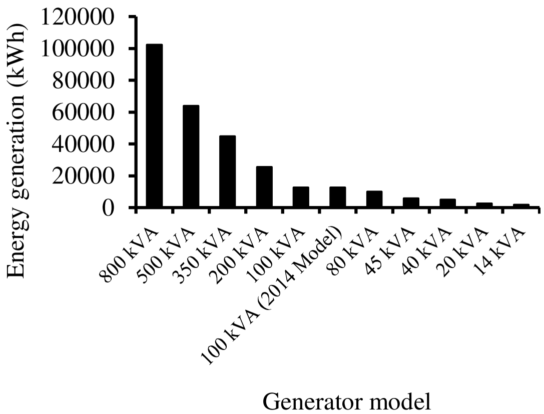

Figure 2: Energy generation per generating set

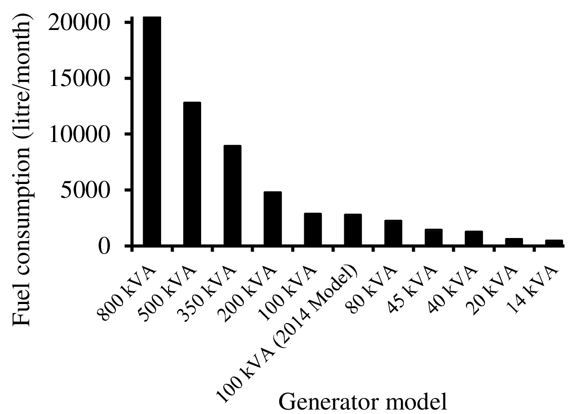

Figure 3: Fuel consumption by the backup generators

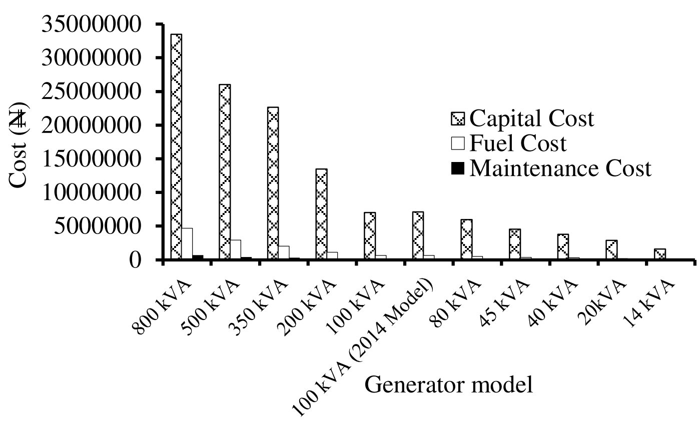

Figure 4: Cost associated with backup generators

3.4. Economic Cost

The economic cost of self-generation using backup generators involve the cost of purchase, fuel cost and the associated cost of regular maintenance and servicing of the generators. The worth of the backup generators based on their current prices obtained from Ogbonna (2020) and Okafor (2020) was estimated. The total capital cost of the generators is about 1.035 billion Naira. Fuel cost for operating the backup generators in a month sums up to 116.8 million Naira, which is about 11. 3% of the cost of purchasing the backup generators. The cost of maintenance and servicing is estimated at 1.77 million per month. Figure 4 shows the economic cost for each generating set. The capital cost of acquiring the generating sets diesel which is dependent on generating set's size, is higher than the cost of operation (fuel cost + maintenance and servicing cost) in a month. However, comparing the overall spending of the operation of the diesel generating sets over a long period of time with the cost of acquiring them, the cost of operation becomes dominant. The implication is that the cost of operation of backup generator over a year would overcome their replacement value.

3.5. Pollutant Emissions

Emission of CO_2, SO_2, NO_x and $PM_{2.5}$ were calculated for energy generated by the diesel generator sets. The two key parameters used in the estimation are the energy generated by the backup generator in a month and the emission factors. The emission factors adopted for this study is presented in Table 2. About 2.6 metric tons, 3.8 metric tons, 1.6 metric tons and 1377.1 metric tons of particulate matter of diameter less than 2.5 micrometres, NO_x, SO_2 and CO_2 respectively are emitted per month by the backup generators. The weighted pollutant emissions per month for different generator set are shown on Figures 5 and 6.

Table 2: Emission factors of pollutants (Gilmor et al., 2010; Farquharson, 2019)

Pollutant	Emission factor (kg/MJ)
$PM_{2.5}$	1.361×10^{-4}
NO_x	1.896×10^{-3}
SO_2	8.598×10^{-5}
CO_2	0.071

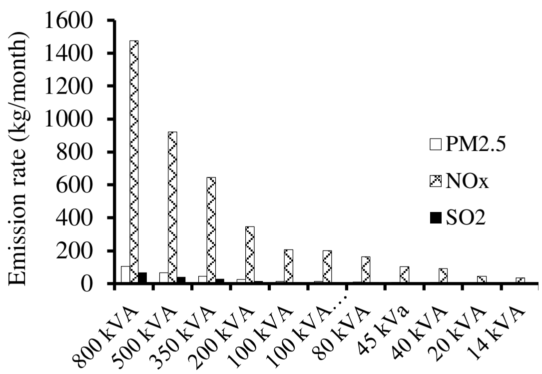

Figure 5: Contribution of backup generators to emission

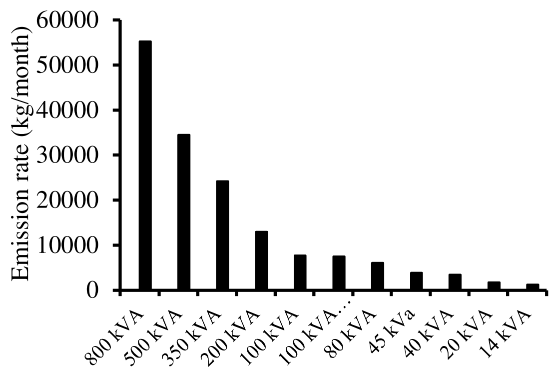

Figure 6: CO_2 Emission by backup generators

The estimation does not put into account poor fuel quality and fuel adulteration which could have negative effect on the performance of diesel generators. The large influence of CO_2 emissions by backup generators stands out among other pollutants examined, followed by NO_x. The rate of pollutant emission is directly related with fuel consumption as can be observed from Figures 5 and 6. Heavy engine diesel generators (800 kVA and 500 kVA) emit more pollutants because they consume more fuel when used the same number of hours with the smaller generators. Compared to power plants on grids, backup generators emit several times more pollution from each unit of fuel burned and each unit of electricity delivered (Farquharson et al., 2018). These high emissions of both CO_2, in comparison with NO_x and $PM_{2.5}$ emissions, make generators a potential source of ground level ozone formation (Marais and Christine, 2016) and also contributes to air pollution which is the leading cause of premature death and diseases in many countries (IHME, 2017). This is mostly true in developing countries, like Nigeria, where the health sector is crumbling. These pollutants that affect human health also have harmful effects to the environment.

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4. CONCLUSION

Electricity from backup generators is expensive. The total capital cost of the generators is about 1.035 billion Naira. Fuel cost for operating the backup generators in a month sums up to 116.8 million Naira, which is about 11.3% of the cost of purchasing the backup generators. Comparing the overall spending of the operation of the diesel generating sets over a long period of time with the cost of acquiring them, the cost of operation becomes dominant. Much of the financial cost of backup generators operations is determined by the overwhelming quantity of fossil fuel they consume. Also, the high emissions of CO_2, NO_x and $PM_{2.5}$ make these generators a potential source of ground-level ozone formation and also contribute to air pollution. This provides a bar against which alternative sources of energy could compete. The study discloses the level of avoidable financial, health and environmental costs that can be addressed through actions that can lead to reduced dependence on diesel backup generators. Avoiding the pollutant emissions, negative health impacts, and operational costs imposed by fossil fuel backup generators signifies a hypothetically substantial opportunity to improve the welfare of people within the University of Maiduguri. The unreliability of the power grid and the recent events that put the city of Maiduguri into total blackout warrant the search for an alternative source of energy.

5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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