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ENERGY AND ECONOMIC LOSSES DUE TO CONSTANT POWER OUTAGES IN NIGERIA

H.U. Ugwu[a], **B.N. Nwankwojike**[b], **E.A. Ogbonnaya**[c], **E.J. Ekoi**[d]

Department of Mechanical Engineering, Michael Okpara University of Agriculture, Umudike-Umuahia, Abia State, Nigeria. ***Emails:*** *[a]ubadyke2001@yahoo.com.au; [b]jikeobodo@yahoo.com; [c]ezenwaogbonnaya@yahoo.com; [d]saintnuez@yahoo.com*

Abstract

This study assesses the economic implication of electricity self-generation in Nigeria. In this regard, energy and exergetic utilization efficiencies of 19 representative generators and gas turbines from Afam power station were assessed based on real data obtained through survey of companies, oral interview, individuals and also experiments carried out during the course of the study. Energy and exergy analyses were conducted to study the variations of energy and exergetic efficiencies for petrol, diesel and natural gas generators. Energy and exergetic efficiencies for the generators were found to be the same. Energy/exergetic efficiencies were in the range of 0.19% to 16.20% and the average energy/exergetic efficiencies for diesel, petrol and natural gas generators were found to be 9.59%, 4.43% and 0.27%, respectively. The results of the analysis also show that the economic losses associated with self-generation of electricity is high. Compared to an average Power Holding Company of Nigeria tariff of 12.20/kWh, the average costs of self-generation for petrol, diesel and natural gas generators were found to be ₦ 46.30/kWh, ₦ 47.74/kWh and₦ 6.44/kWh, while the average cost rates of exergy losses were found to be ₦ 1,076.34, ₦ 114,165.34 and ₦ 238,810.76, respectively. The study also suggested some solutions to Nigeria's constant power outages. Therefore, it is expected that the results of this study will be helpful to an average nigerian in understanding the naira losses associated with the use of generators. These will also assist energy policy makers and governments at all levels in developing highly applicable and productive planning for future energy policies in Nigeria.

Keywords: energy, exergetic efficiency, power outages, electricity self-generation, economic losses, energy policy

1. Introduction

Energy has a major impact on every of our socio-economic life. It plays a vital role in the economic, social and political development of our nation. Inadequate supply of energy restricts socio-economic activities, limits economic growth and adversely affects the quality of life [1]. Despite Nigeria being energy-resource abundant, there are still constant power outages. Industries and individuals cannot rely on electricity from the national grid for high productivity. Nigeria's electricity market, dominated on the supply side by the state-owned Power Holding Company of Nigeria (PHCN) formerly called National Electric Power Authority (NEPA) has been incapable of providing minimum acceptable international standards of electricity service reliability, accessibility and availability for the past three decades. The nature of the poor record in electricity supply is apparent in the trend in transmission and distribution losses (Figure 1).

The double digit transmission and distribution losses are extremely large; by international standards, they are among the highest in the world [2]. The Nigerian population, which entails the industries and the domestic sector, in losing faith in the Nigerian power sector, have resorted to self-generation of electricity. However, the environmental and cost impacts may have either been deemed negligible or have not been brought to the notice of the Nigerian population and the National Energy Policy makers. The cost of self-generation of electricity by the use of fossil fuelled generators as compared to the cost of generation from the national grid has not been studied. Also, an average Nigerian does not consider the implication of the efficiency of the generating sets and the economic implications. Thus, it becomes important and expedient, that an accurate statistics be provided for an average

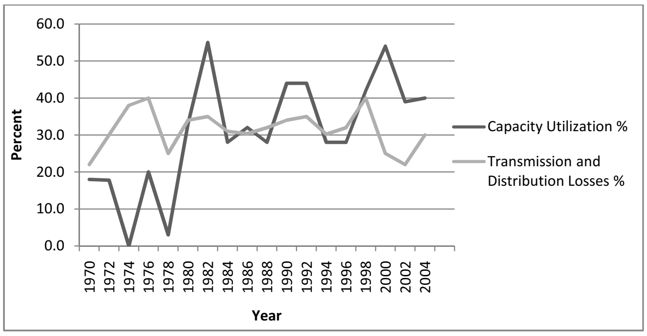

Figure 1: Indicators of electricity crisis in Nigeria from 1970 to 2004 [2].

Nigerian and the National Energy Policy makers in terms of:

- Comparisons of the thermal efficiency of the various generating sets and their economic implications; and
- Comparisons of the cost of self-generation of electricity and that of the national grid.

2. Materials and Methods

2.1. Parameters of evaluation

The parameters used for the evaluation are grouped into the following:

- Thermal Efficiency
- Heat Rate
- Exergetic Efficiency
- Economic Losses
- Pollution and Environmental Effects.

2.1.1. Thermal efficiency

The thermal efficiency gauges the extent to which the energy input is converted to the net work output. Thus, the thermal efficiency [3] is given by:

$$\eta_{Thermal} = \frac{\text{Energy Generated in kWh}}{M_f \times C_v} \tag{1}$$

where: M_f = Fuel Consumed in Nm^3 and C_v = Calorific value in kJ/m^3. However, M_f for natural gas is in Standard Cubic Foot (SCF) and is converted to Nm^3 thus[3]:

$$\text{Gas consumed in Nm}^3 = \frac{\text{Gas in SCF}}{3.281^3} \tag{2}$$

It is to be noted that the net calorific values (NCV) or the lower calorific values for fuel were used.

2.1.2. Heat rate

Power plant/Generator efficiencies are typically defined as the amount of heat content in (Btu) per the amount of electric energy output in kWh. This is commonly called a heat rate in Btu/kWh. Heat rate therefore, is an ideal measure of efficiency since it defines the ratio of the input as fuel (Btu) to output as power (kWh). Hence:

$$\text{Heat Rate} = \frac{\text{Heat input(Btu)}}{\text{Work Output (kWh)}} = \frac{\text{Input (kJ)}}{\text{Output (kWh)}} \tag{3}$$

$$\therefore \text{Heat Rate} = \frac{M_f \times C_v}{\text{Energy generated in kWh}} \tag{4}$$

where: Input = $M_f \times C_v$ in kJ and Output = Energy generated in kWh. Note: 1Btu = 1.0551kJ [4].

2.1.3. Exergetic efficiency

In order to compare the quality levels of various energy carriers, e.g. fuels, it is necessary to determine the equivalents of each energy quantity at a particular grade level. This can be done using exergy concept, which overcomes the limitations of the first law of thermodynamics, though however, based on both the first and the second law [5]. An exergy analysis can identify locations of energy degradation and rank them in terms of their significance [4].

Exergy analysis has been used to analyze and understand energy utilization and its efficiency on the national level. It has been reported [5] that this approach was first used by Reisted [6]. He applied it to the overall U.S economy in 1970. Since then as reported [5], the exergy analysis approach has been adopted by several researchers for other countries such as Japan [7], Canada [8] and Brazil [9], respectively.

Exergy calculation

By describing the use of energy resources in the society in terms of exergy, important knowledge and understanding can be gained, and areas can be identified where large improvements could be obtained by applying efficient technology in the sense of more efficient energy-source conversions [5]. In principle, exergy matter can be determined by bringing it to the dead state by means of reversible processes. The formulae used in exergy analysis are as follows:

Exergy of fuel

The specific exergy of the fuel at environmental conditions reduces to chemical exergy, which can be written as:

$$\varepsilon_f = \gamma_f C_v \tag{5}$$

where: ε_f = fuel specific exergy, γ_f = exergy grade function and C_v = lower calorific value.

Table 1 shows lower calorific value, chemical exergy, and fuel exergy grade function of petrol, diesel and natural gas considered in this study. As shown in the

Table 1: Lower heating value, chemical exergy, and exergy grade function for petrol, diesel and natural gas (at 25°C and 1 atm) [5, 3].

Fuel	C_v(kJ/m^3)	ε_f(kJ/m^3)	$\gamma_f(\varepsilon_f/C_v)$
Petrol	35720	36021.72	1.008
Diesel	35700	35502.60	0.994
Natural gas	37519	39810.54	1.061

table, all values of the exergy grade function are very close to unity. Consequently, the common practice in such cases is to assume that the exergy of the fuel is approximately equal to the lower calorific values. [5, 10.11].From the definition of exergy, electricity, W_e, is identical to the physical exergy, E^{We} [5] as:

$$E^{We} = W_e \tag{6}$$

Energy and exergetic efficiencies

Energy efficiency (η) and exergetic efficiency (ψ) are defined as:

$$\eta = \frac{\text{Energy in products}}{\text{Total energy input}} \times 100\% \tag{7}$$

and

$$\psi = \frac{\text{Exergy in products}}{\text{Total exergy input}} \times 100\% \tag{8}$$

Conversely, energy ($\eta_{thermal}$), and exergetic (ψ_e), efficiencies for electricity generation through fossil fuels, M_f, thus can be expressed as follows:

$$\eta_{thermal} = \left(\frac{W_e}{M_f C_v}\right) \times 100\% \tag{9}$$

$$\psi_e = \left(\frac{E^{We}}{M_f C_v}\right) \times 100\%$$

and

$$\therefore \eta_{thermal} = \frac{E^{We}}{M_f \varepsilon_f} = \left(\frac{W_e}{M_f \gamma_f C_v}\right) \times 100\% \tag{10}$$

Therefore, exergetic efficiency for electricity generation process can be taken as equivalent to the corresponding energy efficiency [5, 11]. This will be used in the results of section 3: Data Analysis and Results.

2.1.4. Economic losses

Parameters for quantifying economic losses fall into 2 groups:

1. Cost of a kWh self-generation by a generator, K (₦/ kWh); and
2. Cost rate of exergy losses in (₦).

Cost of a kWh self-generation by a generator, K (₦/ kWh)

For a generator K, the cost of kWh self-generation, C_k was calculated as the ratio of the expenses incurred for the self-generation and the energy actually provided in a given working time. Also, the expenses for a given year included maintenance costs of generators, the cost of generators, and that of fuel. C_k therefore, was thus obtained through the following operation:

$$C_k = \frac{M_k + Q_k F_m + \lambda G_k}{P_k T_k} \tag{11}$$

where: C_k = Cost of a kWh self-generated electricity by a generator, K (₦/ kWh); and M_k = Annual cost of maintenance of the generator(s), ₦. This cost included operational and maintenance costs; Q_k = Annual consumption of fuel (litres); F_m = Average price of a litre of fuel (₦/ litre); λ = Coefficient of depreciation of the generator; G_k = Price at which the generators were purchased (₦); P_k = Power supplied by generators (kW) and T_k= Working time of generators (hr); respectively.

It is to be noted that the generators and equipment will have a certain period of useful life. Hence, after years of use, the equipment may have to be changed even when fairly new, if more efficient equipment has come into market. To enable this to be done when necessary, some money is put aside annually for this purpose and is known as the depreciation fund. In this study, straight-line method [12] was used in accumulating the money for depreciation fund. This method was based on the assumption that depreciation occurred uniformly every year according to a straight line law. The money saved neglected any interest. Therefore, depreciation charge per year was given by the following relation [12, 13, 14]:

$$D = \frac{G_k - S}{N} \tag{12}$$

where: D = depreciation charge per year, G_k = capital cost of the generator(s) in ₦, S = salvage value after N useful years in ₦, and N = useful life of the generators in years.

Cost rate of exergy loss (₦)

Tasks such as space heating, heating in industrial furnaces, process steam generation and electricity generation commonly involve the combustion of coal, oil, or natural gas. When the products of combustion are at a temperature significantly greater than required by a given task, the end use is not well matched to the fuel burned [4]. Since the source of energy loss by heat transfer is the fuel input, the economic value of the loss was accounted for in terms of the unit cost of fuel based on exergy, C_f in (₦/kWh) as follows [4]:

$$\text{Cost rate of exergy loss} = C_f \left(1 - \frac{T_o}{T_1}\right) Q_1 \tag{13}$$

where: C_f = Unit cost of fuel (₦/kWh), i.e.

$$C_f = \frac{\text{Annual fuel cost(N)}}{\text{Annual generated energy(kWh)}} \tag{14}$$

T_o = Ambient temperature in Kelvin, 25℃= 298K, T_1 = Temperature of the exhaust in Kelvin k and Q_1 = Energy lost to the surroundings by heat transfer in kWh (unit energy generated)

$$Q_1 = F_f \times C_v \tag{15}$$

where: F_f = Fuel consumption rate in m^3/hr

2.1.5. Pollution and environmental effects

Global warming, or the greenhouse effect is an environmental issue that deals with the potential for global climate change due to increased levels of atmospheric 'greenhouse gases (GHGs)'.The principal GHGs include water vapour, carbon dioxide, methane, nitrogen oxides, and some engineered chemicals such as chlorofluorocarbons. While most of these gases occur in the atmosphere naturally, their levels have been increasing due to the wide spread burning of fossil fuels by growing human populations.

2.2. Data collection procedures

The data collection was done mainly through questionnaires, oral interviews, consultation of literature on industrial and domestic generators and direct measurement. The oral interviews were preferred because its flexibility made it possible for one to ask and twist a question in several ways until the specific useful information needed and required were obtained. This was done since some of the technical personnel were not able to digest the question, even though the questionnaire was explicit. Hence, to drive home the point, in order to obtain the useful information and data required, some questions contained in the questionnaire presented were orally twisted for flexibility since most energy data are rarely kept for industries. For example, some of them could not give correctly the quantity of fuel used in the generators for a year. To actualize this, a daily consumption was obtained from them orally, while the weekly and monthly values were extrapolated to determine the yearly consumption.

Thus, the main parts of the interviews were: specifics on electric energy supply from the natural grid and self-generation of electricity. In order to make sure that the information given out by the respondents was correct, collaboration was usually needed. This was achieved by interviewing the generator operators and personnel where applicable. In this regards, questionnaires were thus used to confirm further some data which could not be obtained at the very time of administering them to the respondents.

Table 2: Load specification for household using generator A.

Appliances	**Qty**	**Power rating (W)**	**Total power (W)**	**Daily duty cycle (hr/day)**
(a) Lighting				
Room	2	20	40	4
Security	1	60	60	6
(b) Others				
Radio/cassette	1	120	120	2
TV set	1	100	100	4
DVD Player	1	12	12	4
Phone Set	2	1.75	3.5	1
Fan	1	60	60	6
Total			395.5	

Table 3: Load specification for household using generator B.

Appliances	**Qty**	**Power rating (W)**	**Total power (W)**	**Daily duty cycle (hr/day)**
(a) Lighting				
Room	4	20	80	4
Security	1	100	100	6
(b) Others				
CD set	1	800	800	4
TV set	1	100	100	4
DVD player	1	12	12	4
Phone set	2	1.75	3.5	1
Table-top refrigerator	1	50	50	24
Standing fan	1	60	60	2
Ceiling fan	1	60	60	6
Laptop Computer	1	65	65	2
Total			1330.5	

The questionnaire method [15] was adopted with some modifications. The main parts of the questionnaire were: identification of the survey unit, electric energy supply from the national grid, and self-generation of electricity. Consequently, experimental data were gotten directly by performing the experiments with the permission of the various companies and individuals involved. Once the data were collected, other parameters such as: the thermal efficiencies, heat rate, exergetic efficiencies, economic losses, pollution and environmental effects of generators were analysed following the method below:

2.3. Data analysis procedure

Tables 2, 3 and 4 show details for Generators A, B and C respectively.The load configurations of the other generators used in the survey are as follows:

Generator D – Same as generator B plus pressing iron rated 1000W at a duty cycle of 2hr/week minus standing fan and laptop computer rated at 125W (Total power = 2205.5W)

Generator E = Same as generator C plus pressing iron rated 1000W at a duty cycle of 2hr/week (Total

Table 4: Load specification for household using generator C.

Appliances	**Qty**	**Power rating (W)**	**Total power (W)**	**Daily duty cycle (hr/day)**
(a) Lighting				
Room(s)	4	20	80	4
Security	2	60	120	6
Kitchen	1	40	40	5
Toilet/bath	1	40	40	2
(b) Others				
CD set	1	800	800	4
TV set	2	100	200	4
DVD player	2	12	24	4
Ceiling fan	3	60	180	6
Laptop Computer	1	65	65	2
Phone set	3	1.75	5.25	1
Refrigerator	1	130	130	24
Radio/ cassette	1	60	60	6
Total			1744.25	

power = 2744.25W).

Generator F = Same as generator C plus air conditioner rated 2250W at duty cycle of 21hr/week (Total power = 3994.25W).

Similarly, the load parameters for generators G to S were obtained respectively in the same vein. However, they were used singly or as a combination of two or more generators as base loads and peak loads under variable or full load conditions. Thus, the total power capacities for generators A, B, C, . . . , S, are 0.4kW (0.5KVA), 1.6kW (2.0KVA). 2.0kW (2.5KVA) . . . , and 1018.4kW (1273KVA), respectively using a power factor of 0.8. Also, the Generator designation, T was for Gas Turbines (GT) found in PHCN (Afam Power Station) with an installed capacity of 726MW as presented in Tables 5.

2.3.1. Generator technical parameters

The power ratings of the appliances used in the household and companies as presented in Tables 2, 3 and 4 respectively, and that for the generators as shown in table 5, were calculated from the total power requirements of some households and the energy output of companies at a power factor of 0.8. Based on the highest duty cycle (for refrigerator) of 24hrs, and a continuous operation of companies, 8760hrs was assumed for all the generators. The fuel consumption rates of generators used in the study were gotten from the data from individual household, companies and Perkins generators. The generators were categorised into I, II and III for Petrol, Diesel and Natural gas fuel, respectively. The PHCN lower Calorific values of 35720 kJ/m^3, 35700 kJ/m^3 and 37519 kJ/m^3 were used for Petrol, Diesel and Natural gas, respectively. The values for fuel consumption and lower calorific values of the generators were used to calculate their thermal/exergetic efficiencies and heat rates, respectively.

2.3.2. Experimental data

Direct measurements were used in obtaining the data. For exergetic losses, thermometers were used to measure the temperature of the exhaust gases (T_1) and the ambient temperature (T_o) for each of the generators studied for use in exergetic loss computation. The Crowcon GAS and the Haz -dust apparatuses were used in determining the levels of GHGs and particulate emissions from the exhaust of the generators, respectively and the results are presented in Section 3.1. The units of measurements are μg/m^3 and ppm for particulate and gas emissions, respectively, and obtained as:

$$1\mu\text{g/m}^3 = \text{ppm} \times \left(\frac{PV}{TR}\right) \times \text{molar weight} \times 1000 \quad (16)$$

where: V = Volume; P = Pressure; T = Temperature; and R = Gas constant, calculated at standard temperature and pressure.

2.3.3. Economic losses

The capital costs of the generators were deduced from the owners of the generators in the household scenario and from the companies involved in this study where applicable. The operation and maintenance (O&M) costs included costs for services, minor overhaul and spare parts per 250 hours which thus were extrapolated and calculated into annual scenario. Salvage value of 20% of the capital cost was assumed in the computation for all the generators used for this study. A useful life of 25 years for the generators was assumed. The economic losses in terms of:

(i) Cost of a kWh self-generated electricity by a generator (C_k) in (₦/kWh); and
(ii) Exergetic losses accompanying combustion of the fuel in each generator in (₦) were then calculated and the results analysed.

3. Data Analysis and Results

3.1. Comparison of thermal/exergetic efficiency and heat rates of various sources of electrical energy

Equations 1, 2 and 3 were used in the computation of energy/exergetic efficiency and heat rates of the generators. The energy/exergetic efficiency and the heat rates are as shown in table 5, while table 6 shows the comparison between the average energy/exergetic efficiency and heat rate of Self-generating generators and PHCN, GT (Afam Power Station). From table 5, it is seen that GT has the lowest efficiency of 0.01% and highest heat rate of 1290174.66kJ/kWh, respectively.

Table 5: Thermal/exergetic efficiency and heat rates of generators.

Generator Designation	**Capacity**		**Fuel Type**	**Fuel consumption rates F_f**	**Annual Fuel Consumption M_f**	**Unit Energy Generated**	**Annual Generated Energy**	**Thermal Efficiency $\eta_{Thermal}$**	**Heat Rates**
	KVA	kW		(m^3/hr)	(m^3)	(kWh)	(kWh)	(%)	(kJ/kWh)
A	0.5	0.40	Petrol	3.960×10^{-4}	3.469	0.40	3504.0	2.83	35.36
B	2.0	1.60	Petrol	5.460×10^{-4}	4.783	1.49	13052.4	7.64	13.09
C	2.5	2.00	Petrol	1.308×10^{-3}	11.458	2.00	17520.0	4.28	23.36
D	2.8	2.24	petrol	1.609×10^{-3}	14.095	2.24	19622.4	3.90	25.66
E	3.8	3.04	Petrol	2.333×10^{-3}	20.437	3.04	26630.4	3.65	27.41
F	5.0	4.00	Petrol	2.625×10^{-3}	22.995	4.00	35040.0	4.27	23.44
G	7.5	6.00	Diesel	2.143×10^{-3}	18.773	6.00	52560.0	7.84	12.75
H	9.0	7.20	Diesel	3.000×10^{-3}	26.280	7.20	63072.0	6.72	14.88
I	13.0	10.40	Diesel	3.700×10^{-3}	32.412	10.40	91104.0	7.87	12.70
J	50.0	40.00	Diesel	6.923×10^{-3}	60.645	40.00	350400.0	16.20	6.18
K	500.0	400.00	Natural gas	1.840	16118.400	240.00	2104200.0	0.35	287.65
L	600.0	480.00	Diesel	0.127	1112.520	480.00	4204800.0	10.60	9.45
M	640.0	512.00	Diesel	0.137	1200.120	512.00	4485120.0	10.50	9.55
N	750.0	600.00	Diesel	0.157	1375.320	600.00	5256000.0	10.70	9.34
O	800.0	640.00	Diesel	0.250	2190.000	640.00	5606400.0	7.17	13.95
P	989.0	791.20	Diesel	0.207	1813.320	791.20	6930912.0	10.70	9.34
Q	1000.0	800.00	Natural gas	3.397	29757.720	241.00	2111160.0	0.19	528.85
R	1253.0	1002.40	Diesel	0.259	2268.840	1002.40	8781024.0	10.80	9.22
S	1273.0	1018.40	Diesel	0.175	1533.000	400.00	3504000.0	6.40	15.62
T	907500	726000	Gas Turbine	3550.69	31104022	10337.61	90557.5×10^3	0.01	1290174.66

Equations 11 and 12 were used in the computation of the average cost of self-generation of electricity from the generators. As shown in table 7, the average cost of self-generation by Petrol generators is ₦ 46.30 as against ₦ 12.20 from PHCN. In Diesel generators, the average cost of self-generation is ₦ 47.74 against ₦ 12.20 from PHCN. The two self-generation sources show Naira loss of ₦ 34.10 and ₦ 35.54, respectively. These amounts lost to self-generation are approximately equal to the cost of generation of 3kWh electricity from National grid. However, gas generators seem to show advantage over PHCN tariff as the average tariff is ₦ 6.44 as against ₦ 12.20 from the national grid. This shows a naira gain of ₦ 5.76, which approximates to the cost of generation of unit kWh electricity. This advantage is probably due to the price of fuel (natural gas) which is very low.

In decreasing order, the average exergy cost rate of heat losses in naira (₦) as evident from table 8 are ₦ 238,810.76, ₦ 114,165.34 and ₦ 1,076.34 for Natural gas, Diesel and Petrol generators, respectively. Also, the exergy cost rate of heat analysis as presented were carried out based on experimental data from field work/survey, while equation 13 was used for the analysis and computation.

The hourly average emission levels of particulate, carbon monoxide, nitrogen dioxide and sulphur dioxide were $165.71\mu g/m^3$, 1511.96 ppm, 2.08 ppm and 2.68 ppm, respectively for the generators studied. Conversely, table 9 gives the average hourly fossil fuel emission levels for Petrol, Diesel, Gas generators and the Nigerian ambient air quality standard for each of the emitted gases. As shown in the table, the Nigerian ambient air quality standard limits for Carbon monoxide, Nitrogen dioxide, Sulphur dioxide and Particulates are 10.00ppm, (0.04 − 0.06) ppm, 0.01ppm and $250.00\mu g/m^3$, respectively. These results suggest that the generators should not be used in confined environment as the emission levels are almost above the Nigerian Ambient Air Quality Standard. It is also clear from the table that for Nitrogen dioxide gas, Diesel generator shows the highest emission level of 2.45ppm followed by Petrol and Natural gas generators with emissions of 1.55 ppm and 0.56 ppm, respectively.For Sulphur dioxide, Diesel generator also shows the highest emission level of 3.56ppm, followed by Petrol generator with 1.97ppm while Natural gas generator shows zero level of emission of Sulphurdioxide.

The reason for the differences observed can be adduced that Diesel is composed of the highest carbon ratio, nitrogen and sulphur, followed by Petrol and Natural gas. This means that during combustion, diesel would release the highest level of pollutants followed by petrol and natural gas.

3.2. Discussion of results

From table 6, the highest and the lowest heat rates for self-generation are exhibited by Natural gas generators and Diesel generators, respectively. The im-

Table 6: Comparison of average energy/exergetic efficiency and heat rate of generators and PHCN.

S/N	Types of generators	Energy/Exergetic Efficiency (%)	Heat Rate (kJ/K)
1	Petrol	4.43	24.72
2	Diesel	9.59	11.18
3	Natural Gas	0.27	408.25
4	GT (Afam), PHCN	0.01	1290174.66

Table 7: Average cost of self-generation by various generators and PHCN tariff.

S/N	Type of generator	Cost of generation (₦/kWh)
1	Petrol	46.30
2	Diesel	47.74
3	Natural Gas	6.44
4	GT(Afam)	12.20*

* Source: [16]

plication is that for Diesel generators, less fuel would be required to generate each kWh of electricity. In effect, more fuel is now available than would be otherwise. Also, there is an impact on the level of emissions the generators released. Since less fuel is required for a given kWh, therefore, the emission levels would be low. The reverse is the case for Natural gas generators. The thermal/exergetic efficiency for petrol, diesel and natural gas generators from the table indicate that diesel generators would be the most efficient. The difference in efficiencies can be attributed to the fact that most heavy duty generators are diesel fuelled and as such, there has been improvement in the diesel engine design so that a more efficient diesel engine is available for power generation. Natural gas generators on the other hand are not common generators and as such, the technology is not well developed as that for petrol and diesel generators. Thus, very low thermal/exergetic efficiency was observed.

Further, table 6 showed the thermal/exergetic efficiencies of Afam GT to be approximately zero. This could be attributed to the fact that most of the GTs in Nigeria are obsolete and have old technology; hence, they operate with negligible efficiencies. Consequently, for the generators studied, the cost of self-generation ranged from ₦ 67.49/kWh to ₦ 4.71/kWh. This implies that for a self-generation cost of ₦ 67.49/kWhfor unit kWh generated, the cost is ₦ 67.49. Moreso, from table 7, it can be seen that compared to PHCN tariff, the economic losses (Naira losses) associated with using petrol and diesel generators were respectively, ₦ 34.1/kWh and ₦ 35.54/kWh. This represented approximately the cost of 3kWh electricity. Natural gas generators on the other hand seemed to have edge over the PHCN as the cost of self-generation using natural gas generators was less

Table 8: Average exergy cost rate of heat loss accompanying heat transfer Q_1.

S/N	Type of Generators	Exergy Cost Rate of heat loss (₦)
1	Petrol	1076.34
2	Diesel	114165.34
3	Natural gas	238810.76

Table 9: Average hourly fossil fuel emission levels for petrol, diesel and gas generators and nigerian ambient air quality standard.

Pollutant	Petrol	Diesel	Natural Gas	Nigerian Ambient Air Quality Standard*
Carbon Monoxide (ppm)	1262.43	1670.40	2124.11	10.00
Nitrogen Dioxide (ppm)	1.55	2.45	0.56	0.04 – 0.06
Sulphur Dioxide ppm)	1.97	3.56	0.00	0.01
Particulates (μg/m^3)	140.22	207.56	11.99	250.00

* Source: [17]

than PHCN tariff.

However, since it would be incorrect to assign the same cost to heat loss independent of the temperature at which the loss is occurring [4], it was seen from table 8 that when considering the temperature of heat transfer (heat loss), the cost rate of exergy loss (₦) was highest for natural gas (₦ 238,810.76) and lowest for petrol (₦ 1,076.34). In addition, the particulate and the GHGs emission of the generators studied were analyzed and the result presented as in table 9. The result of the emissions from the generators studied when compared to the Nigerian Ambient Air Quality Standard showed that the effect was on the high side. However, the particulate emission level is within the daily 1 hour limit stipulated by the Federal Environmental Protection Agency (see table 9) [17]. However, as is the case with most users of generators in Nigeria, the daily 1 hour limit is always exceeded as most users use the generators for hours.

4. Conclusion and Recommendations

4.1. Conclusion

In this study, energy (thermal) and exergetic efficiencies were determined for generators ranging from 0.5KVA to 1273KVA. Calculated exergetic efficiency of the generators was the same as its corresponding thermal efficiency since for fossil fuels (petrol, diesel and natural gas), the exergy grade function is almost unity. The average thermal/exergetic efficiencies for petrol, diesel and natural gas were found to be 4.43%, 9.59% and 0.27%, respectively. PHCN in this case represented by Afam Power Station showed approximately zero efficiency (0.01%). Comparing these results of efficiencies, Diesel generators had the highest efficiency, while Natural gas generators showed the lowest efficiency. The implication was that more fuel was consumed than should have been in the process of electricity generation. Also, the average cost of self-generation for Petrol, Diesel and Natural gas was found to be respectively ₦ 46.30/kWh, ₦ 47.74/kWh and ₦ 6.44/kWh. When compared to the average PHCN tariff of ₦ 12.20/kWh, Petrol and Diesel generators had naira losses of ₦ 34.10/kWh and ₦ 35.54/kWh, respectively while Gas generators showed an advantage over PHCN tariff as its average cost of self-generation was ₦ 6.44/kWh.

However, considering the average cost rate of exergy loss associated with running each generators, Petrol generators had the lowest cost rate of exergy loss of ₦ 1,076.34 while Natural gas had the highest cost rate of ₦ 238,810.76. Therefore, the cost of self-generation was very high compared to PHCN tariff because of the low efficiencies associated with each type of generators studied. Thus, self-generation of electricity was therefore not a cost-effective measure.

4.2. Recommendations

The calculated efficiencies and cost of self-generation of the generators studied should be considered as important tools for the nation's policy makers and energy planners. Furthermore, such results should be taken as challenge by the society and concerned governmental institutions to achieve sustainable electricity supply from PHCN.

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