NIPES

Journal of Energy Technology and Environment

Journal homepage: www.nipesjournals.org.ng

Economic-Based Comparative analysis of Gasoline and Liquefied Petroleum Gas for Small Scale Power Generation in Nigeria

Victor Okon David* and **Aniekan Essienubong Ikpe**

Akwa Ibom State Polytechnic, Ikot Osurua, Ikot Ekpe, Akwa Ibom State, Nigeria. PMB 1200

*Corresponding Author: alfreddavid9414@gmail.com.

Article information

Article History
Received 18 September 2022
Revised 12 October 2022
Accepted 20 October 2022
Available online 16 December 2022

Power generation, Natural gas, Gasoline, Energy, Economic analysis

https://doi.org/10.5281/zenodo.7445287
https://nipesjournals.org.ng
© 2022 NIPES Pub. All rights reserved

Abstract

In this study, economic and environmental benefits of using natural gas in Nigeria, particularly for small-scale power generation sets was analyzed. A 3.5 kVA generator, an LPG carburetor, a Wattmeter, and other equipment were used to perform the analysis experimentally. A code written in Engineering Equation Solver served as the theoretical basis for the analysis of energy conversion methods starting from first principles. The experiment lasted for eight hours, and lifespan of the generating set was predicted to be five years. The results indicated that for delivering the same output of 3.5 kW, the instantaneous PMS and LPG consumption were 0.511 liters/h and 0.391 kg/h, respectively. When using PMS, the cost of electricity per unit was determined to be 183.5 ₦/kWh, while the cost of electricity per unit for LPG at the current prices of PMS and LPG was high at 324.2 ₦/kWh. However, when using LPG at a lower LPG price per kilogram, the unit cost of electricity was determined as 175.6 ₦/kWh. Furthermore, PMS seemed to be a more cost-effective choice given the high cost of LPG at the moment, which is about ₦750 per kilogram. Hence, with LPG price reduction to ₦350, using LPG is economically viable with greater potential for cutting down greenhouse gas emissions in Nigeria.

1. Introduction

The availability of energy is a crucial global indicator of industrialization, economic expansion, and sustainable development [1, 2]. With an estimated seven billion people on the planet and ongoing population growth, energy demand is expected to increase. It is driven by the desire for quality lifestyle and to improve ourselves, families and our communities. In many nation, efforts to match this rising population and economic development with adequate energy supply have had negative environmental effects because the processes used to produce energy emit pollutants, many of which are detrimental to the ecosystem. In actuality, burning fossil fuels causes the release of significant amounts of greenhouse gases, especially carbon dioxide [3].

Following this pattern, energy conversion technologies have made significant strides in recent years to keep pace with the rising demand for energy in both industrial and residential settings. Burning fossil fuels has historically been the most popular way to convert energy, making up a significant portion of energy generation methods [4]. It is admirable that efforts are being made to meet energy needs, but it is also important to strike a balance between environmental sustainability and energy efficiency. The long-term risks of ongoing carbon dioxide emissions to the atmosphere have recently received attention in the media and published works [5, 6]. It is amazing how research and technology are presenting alternative energy sources and ways to use waste energy, particularly from energy conversion plants.

For instance, the energy infrastructure in Nigeria is made up of burning fossil fuels in power plants that are unstable and insufficient for the teeming population [7]. Due to the effects it has on public health, safety and environment, the government is now concerned with the use of alternative energy resources for the production of electrical energy. This is most pronounced in rural areas where the lack of access road has stunted the growth of small businesses and industries, which in ideal circumstance should have served as a source of employment and means of income, thereby preventing the local economy from stifling. Experiences over the years in Nigeria's urban areas demonstrate that the erratic and epileptic power supply has severely hampered economic growth, forcing businesses to shut down because they cannot afford the high maintenance costs of private electric generating plants. The experience of Nigeria highlights the significance of electricity for economic growth, especially in developing nations, and the crucial need to improve the operations of the electric power industries if the process of economic development is to be effectively supported [8].

Following poor power supply, the use of stand-alone generation sets for electricity supply has been in extensive use in the country especially for residential and small scale businesses. These systems are mostly powered by premium motor spirit (PMS) for light use, while heavier applications require the use of diesel. In addition to the effects of noise pollution and emissions, they require steady use of these operating fluids for their operation which can be very expensive especially with the volatile nature of petroleum prices in the country. To remedy this drawback, the use of natural gas is proposed as a substitute in the local generating sets. This is intended to check the vast noise caused by these systems, reduce cost as well as greenhouse gas emissions in homes and business premises where there are domiciled. In recent times, a number of studies have been carried out on performance analysis of LPG and PMS powered generators.

For example, Chidera et al. [9] experimentally investigated the efficiency of using PMS and Propane gas in a 3.0KVA generator (Sumec Fireman) petrol engine. The investigation revealed that propane gas in internal combustion engines yielded higher thermal efficiency and better fuel economy (fuel consumption) compared to petrol (PMS). It was observed that propane gas contains low carbon, as a result produced lower carbon emissions and reduced engine noise compared to PMS. This offered a better service performance to the generator set due to the absence of carbon deposits accumulation compared to PMS.

A quasi-dimensional spark ignition engine (SIE) cycle model was employed by Bayraktar and Durgun [10] to predict the cycle, performance and exhaust emissions of an automotive engine for gasoline and LPG. Comparatively, the results indicated that if LPG fuelled SI engines are operated with the same conditions as those of gasoline fuelled SI engines, the burning rate of fuel is increased, and thus, the combustion duration is decreased. Also, LPG reduces the engine volumetric efficiency and, thus, engine effective power, while the mole fractions of CO and NO included in the exhaust gases decreases with LPG.

Olaoye et al. [11] carried out the design, construction and testing of C1 conversion kit for 1.7 kVA generator to enable the generators use both petrol and propane as fuel sources. The generator was tested with petrol and propane while carrying 288 Watt of load for 4 hour 15 minutes. The results showed 4.3% CO_2 reduction when petrol was used as fuel and 80.66% CO reduction when propane was used. An average of 0.21kg/h of propane was used as against 0.83kg/h of petrol for the same load. Adouane et al. [12] investigated the possibility of using a stand-alone photovoltaic/LPG generator hybrid power system for low-cost electricity production. The findings revealed that considerable cost and fuel savings can be achieved with photovoltaic hybrid systems using backup generator running on butane gas. Moreover, butane gas operated generators can reduce the emission of pollutants (particularly CO_2 and CO) by approximately 50% compared to the use of diesel generator in hybrid energy system. However, Sambandam et al. [13] tested a hydroxy gas in 197-cc gasoline engine power generator powered with ethanol-gasoline blend. It was observed that thermal efficiency increased up to 23.6 % and fuel consumption decreased up to 36% on a volume basis, which was a significant improvement over the base engine. Furthermore, the hazardous carbon monoxide reduction reached 11.45% and the unburned hydrocarbon emissions reached 17.6%.

The effect of carbon emissions and temperature level from generators running separately with propane and petrol in varying loading conditions was evaluated by Lawal et al. [14]. It was observed that petrol-fired generators produced more carbon emissions than propane-fired generators for the same size of generator considered at the various loading conditions. However, emissions were found to reduce with higher loads in petrol-fired generators while ambient temperature was found to increase with higher the loads in propane gas-fired generator.

Antarius and Dalimi [15] carried out a techno-economic and distribution analysis of using LPG for power generation in Indonesia. The findings suggested LPG as a good replacement for gasification operations in the fuel-oil-driven power plants which were facing challenges due to high cost of LNG regasification infrastructure. This was based on the fact that LPG is also a better and low-emission alternative to other fuel types, with power generation approximately equal to other natural gas such as Liquefied Natural Gas (LNG) or Compressed Natural Gas (CNG).

The present study proposes an economic-based comparative analysis of gasoline and natural gas for small scale power generation in Nigeria. The objectives were to theoretically develop the energy generation processes in power generation sets using LPG and petrol; present the economic implications for the choice of generator operating fuel; assess the environmental impact from the use of LPG and petrol as the operating fuel in the plant. With the present investigation of LPG as an alternative fuel for powering small scale power generating sets, several savings can be made in terms of cost and greenhouse gas emissions.

2. Materials and Method

2.1. Materials

The materials used for the study include a petrol generator rated at 3.5 kVA (SUMEC Firman), an LPG (liquefied petroleum gas) carburetor, 12.5 kg of LPG, 10 liters of premium motor spirit (PMS), and Wattmeter for measuring the power output over time. A stop clock was used for measuring time in the course of the experiment. Lastly, an electronic mass balance was used for computation of the mass of both LPG and PMS used during the experiment.

2.2. Method

The method employed in the analysis of this study are presented under this section.

2.2.1. Petrol Generator Modelling

The hourly energy $E_{GEN}|t|$ by the petrol generator with rated power output, P_{GEN} and rated efficiency, η_{GEN} is defined with the relationship [16].

$$E_{GEN}|t| = \eta_{DGEN}.P_{GEN} \quad (1)$$

For better performance and higher efficiency, the generator will always operate between 80 and 100 per cent of their kW rating [17]. The quantity of petrol consumption in liters per hour, F_{Gen} is directly related to the power output and can be modeled as [18].

$$F_{Gen} = B_{Gen} \times P_{Gen-rated} + A_{Gen} \times P_{Gen-out} \quad (2)$$

Where, the rated power of the generator and the actual power output are expressed with $P_{Gen-rated}$ and $P_{Gen-out}$, respectively. The coefficients of fuel consumption curve are similarly represented with A_{Gen} and B_{Gen} measured in litres per kilowatt hour which can be approximated as 0.2831[19]. The expression in Equation 1 also holds for the relationship between the generator output and the quantity of LPG when it is used as the operating fuel.

2.2.2. Economic Analysis of the Plant

The cost of the system is estimated using the life cycle cost LCC (N), annualized life cycle cost ALCC (N/yr), unit cost of energy, UCOE (N/kWh) and breakeven point, BEP (yr). The relationships for these expressions are given as [20]:

$$LCC = \sum_{q=1}^{z} C_q; q \in \{plant\} \quad (3)$$

Where C_q is the cost of the plant component, q. The life cycle cost of each component is related to the levelised purchase equipment cost Z_k expressed as cost per unit of time $\dot{Z}_k$ (N/s) for the kth component [21].

$$\dot{Z}_k = \frac{\varphi CRF Z_k}{N} \quad (4)$$

Where φ is the maintenance factor, N is the number of plant operating time POT in hours, *CRF* is the capital recovery factor expressed with the relationship:

$$CRF = \frac{|i|1+i|^n|}{||1+i|^n-1|} \quad (5)$$

The annualized life cycle cost ALCC (N/yr) is estimated as:

$$ALCC = LCC\left|\frac{1-\left|\frac{1+d}{1+i}\right|}{\left|\frac{1+d}{1+i}\right|^n}\right| \quad (6)$$

Where d is the inflation rate and i is the interest rate. Similarly, the unit cost of electricity (UCOE), and the breakeven period, BEP is obtained as follows:

$$UCOE = \frac{ALCC}{365E_s} \quad (7)$$

$$BEP = \frac{LCC}{Q_{AP} \times UEC_{MC}} \quad (8)$$

$$E_s = 24W_{Plant} \quad (9)$$

$$Q_{AP} = 365E_S \quad (10)$$

Where Q_{AP} (kWh/yr) is the annual energy production; UEC_{MC} (N/kWh) is the cost of the conventional electricity supply; E_s (kWh/day) is the daily energy demand; and W_{Plant} (kW) is the plant capacity.

2.2.3. Experimental Procedures/Parameters

The experiment was carried out by running the same engine-generator set with PMS and LPG to determine the consumption rate of each kilogram of fuel used. The generator was operated first with PMS while the time was recorded at different electrical loads, followed by LPG. The operation time of the generator was recorded, which was used to determine the quantity by weight of both PMS and LPG consumed (instantaneous PMS and LPG consumption) from a predetermined quantity of PMS and LPG in the generator. The parameters considered in the experimental procedure include the volume of fuel, mass of LPG and PMS, energy output from the generator, and the time of operation of the system. These are linked with the unit cost of electricity, the breakeven period if the system is to sell power out, all referenced from the use of LPG and PMS, respectively.

3. Results and Discussion

The results of the experiments are presented in line with the developed methods in terms of energy and economics. The 3.5 kVA generator was run, first with PMS, and then with LPG using an LPG carburetor. The power output of the generator was calculated by a Wattmeter connected to the secondary voltage and current outputs from the unit potential and current transformers. The volume of primary fuel consumption from LPG was measured at intervals using an electronic mass balance, while noting corresponding output Wattage. In the case of the use of PMS for powering the system, the mass or volume of PMS was measured using the fuel tank of the generator at intervals.

3.1. Energy Performance Output of the System

The system performance is summarized in Table 1. The energy performance indices include the Wattage from the generator at time intervals, the quantity of fuel consumption, and the time interval.

Table 1: System performance

Time (hrs)	**PMS**			**LPG**		
	Output (kW)	Fuel (Litr.)	Energy (kWh)	Output (kW)	Fuel (kg)	Energy (kWh)
1	3.325	0.511	3.325	3.325	0.391	3.325
2	3.325	1.023	6.65	3.325	0.783	6.65
3	3.325	1.534	9.975	3.325	1.174	9.975
4	3.325	2.045	13.3	3.325	1.565	13.3
5	3.325	2.557	16.625	3.325	1.957	16.625
6	3.325	3.068	19.95	3.325	2.348	19.95

7	3.325	3.579	23.275	3.325	2.739	23.275
8	3.325	4.091	26.6	3.325	3.131	26.6

The instantaneous PMS and LPG consumption were obtained as 0.00009943 liters/s and 0.00007609 kg/s, using the experimental procedures in Section 2.2.3. At this rate, the hourly fuel consumption, power output and energy output were obtained and shown in Table 1. Under the same operating conditions, the cumulative power output from the generator set was 3.325 kWh when operated with PMS, and same was recorded when LPG was used as fuel. This uniform power output was based on the adjustment of the LPG carburetor to meter out corresponding LPG mass flow to obtain 3.325 kW. The generator output was obtained as 95 percent. Additionally, under rated operating conditions of the generator, the working fluid requirement was observed to be higher when operated with PMS than LPG. For instance, after 8 hours of operation, LPG and PMS requirements were recorded as 3.131 kilograms and 4.019 liters, respectively. These trend is highlighted in Figure 1.

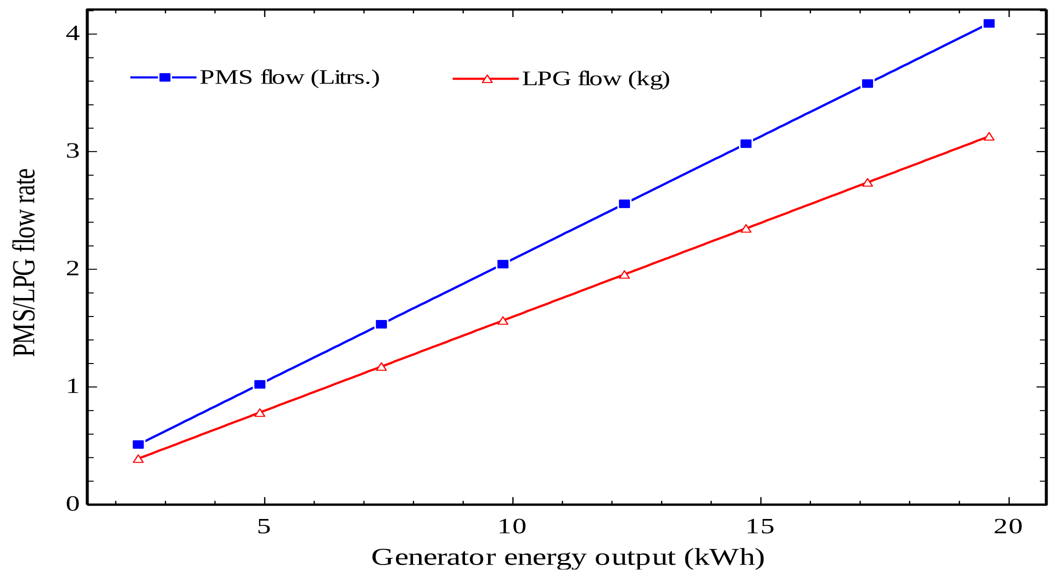

Figure 1. Relationship between working fluid and generator output after 8 hours operation

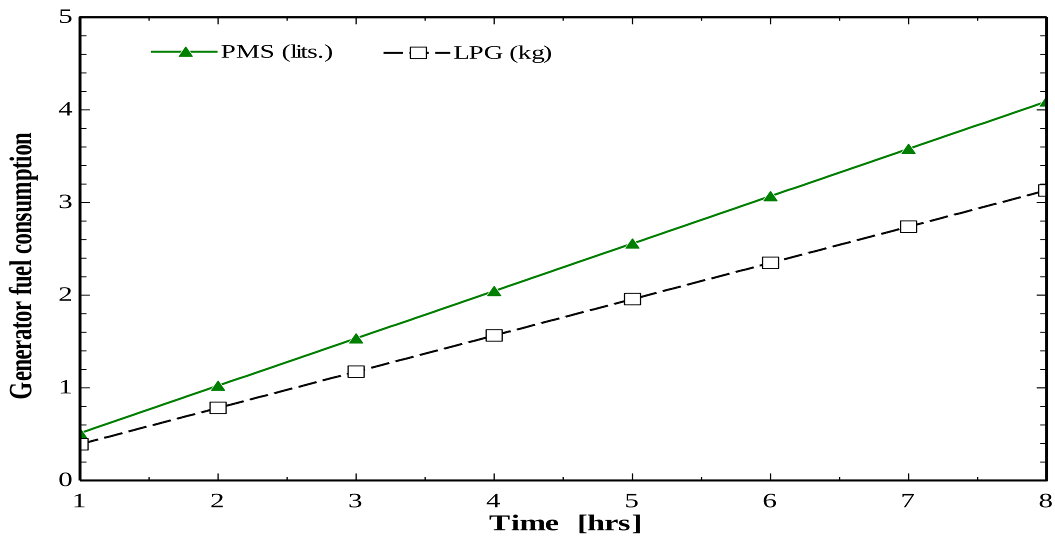

Figure 2: Comparison between the hourly quantity of LPG and PMS consumption

The comparison of the fuel type used in the analysis is shown in Figure 2. Hourly PMS and LPG consumption rates at constant output of 3.5 kW shows less of LPG consumption against PMS. For instance, after eight hours, the system consumed 3.131 Kgs of LPG while the PMS was at a value of 4.091 liters. This trend can be attributed to the higher calorific value of LPG. Therefore, in terms of fuel consumption, operating the system with LPG is better with respect to fuel economy and impact on the environment [22, 23]. However, in a study conducted by Kalra et al. [24], the concentration level of CO, HC and CO_2 in SI engine was on the lower side for LPG compared to gasoline for the same power output, while the concentration of NOx for the same power output was higher for LPG than gasoline. There was a slight decrease in power output and volumetric efficiency for SI engine powered with LPG compared to gasoline while the values obtained for specific fuel consumption with LPG was slightly higher than gasoline.

3.2. Economic Performance Output of the System

In line with the aim of this work, the techno economic analysis of the system is presented for LPG and PMS in Tables 2 and 3, respectively. For effective comparison, the indicators are compared in Figures 3 through 6. The techno-economic indicator considered include the breakeven period, BEP, capital recovery factor, CRF, total operation cost, TOC, which is a function of generator and LPG carburetor cost and the cost of maintenance. Others are the daily energy consumption, the levelised yearly cost of the system, and the annualized life cycle cost. The cost computations were evaluated using a developed soft code in Engineering Equation Solver (EES). Also included is the unit electricity cost. For the purpose of the analysis, the following initial conditions were considered.

a. The plant was assumed to have a life span of five years.
b. The daily hourly operation of the system was taken as 8 hours.
c. The price of LPG was taken as ₦750 per kilogram.
d. The price of fuel was taken as ₦185 per liter.
e. The generator was rated at 3.5 kVA.
f. The system operated at steady state conditions.
g. The generator is operated at for 8 hours daily.

Table 2: Summary of techno-economic performance of the system when operated with PMS at current prices

ALCC (N/yr)	BEP (Years)	CRF	Fuel CoP (N)	E Daily (kWh)	UCOE (N/kWh)	Z (N/s)	PMS (lits)	PMS (kg)
1875414.8	0.933	0.637	193364	28.00	183.50	128.00	0.0000994	0.0000795
1875832.5	0.932	0.637	193485	28.02	183.40	128.00	0.0000995	0.0000796
1876250.1	0.932	0.637	193606	28.03	183.40	128.00	0.0000996	0.0000796
1876667.8	0.932	0.637	193727	28.05	183.30	128.10	0.0000996	0.0000797
1877085.4	0.931	0.637	193848	28.07	183.20	128.10	0.0000997	0.0000797
1877503.1	0.931	0.637	193969	28.09	183.10	128.10	0.0000997	0.0000798
1877920.7	0.931	0.637	194090	28.10	183.10	128.10	0.0000998	0.0000798
1878338.3	0.930	0.637	194211	28.12	183.00	128.20	0.0000999	0.0000799
1878756.0	0.930	0.637	194332	28.14	182.90	128.20	0.0000999	0.0000799
1879173.6	0.929	0.637	194453	28.16	182.80	128.20	0.0001000	0.0000800

a. ALCC-Annual life cycle cost.
b. BEP-Break even period.
c. CRF-Capital recovery factor.
d. Fuel CoP-Cost of operation with respect to fuel (PMS or LPG) for the plant life.
e. E. Daily-Energy output from the generator, daily when operated for eight hours.

f. UCOE-Unit cost of electricity.
g. Z-Levelised cost of operation.
h. PMS (kgs)-Premium motor spirit kilograms.
i. LPG (kgs)-Liquefied petroleum gas in kilograms.

Table 3. Summary of techno-economic performance of the system when operated with LPG at current prices

ALCC (N/yr)	BEP (Years)	CRF	Fuel CoP (N)	E. Daily (kWh)	UCOE (N/kWh)	Z (N/s)	PMS (lits)	Tot. Cost (₦)
3313065	1.648	0.6368	599894	28.0	324.2	226.1	0.0000761	959894
3314335	1.647	0.6368	600261	28.0	324.1	226.2	0.0000761	960261
3315605	1.647	0.6368	600629	28.0	324	226.2	0.0000762	960629
3316875	1.647	0.6368	600997	28.1	323.9	226.3	0.0000762	960997
3318144	1.646	0.6368	601365	28.1	323.9	226.4	0.0000763	961365
3319414	1.646	0.6368	601733	28.1	323.8	226.5	0.0000763	961733
3320684	1.645	0.6368	602101	28.1	323.7	226.6	0.0000764	962101
3321954	1.645	0.6368	602469	28.1	323.6	226.7	0.0000764	962469
3323224	1.645	0.6368	602837	28.1	323.6	226.8	0.0000765	962837
3324494	1.644	0.6368	603205	28.2	323.5	226.8	0.0000765	963205

In Table 2, the economic parameters are listed for operating the system with PMS. A similar result is presented for LPG in Table 3. Although the system consume less LPG within the experimental period, the economic performance is advantageous with the use of PMS for operating system. This can be attributed to the high cost of LPG in the market. For instance, the unit cost of electricity was obtained as 183.5 N/kWh when operated with PMS, while the LPG corresponding value was high at 324.2 N/kWh (see Figure 3).Similarly, the break-even period for the system when operated with PMS was about a year compared to a year and six months when operated with PMS. All other indicators in Table 2 and 3 are pointers to the economic advantage of using PMS for running the system (see Figures 4, 5, and 6), except the hourly quantity of consumption using LPG. These results were evaluated using current prices of LPG and PMS commodities. However, with the price of LPG set at ₦185, the results are favorable with LPG use in terms of economics and energy efficiency. The capital recovery factor of the system is same when operated with LPG (0.6368) and PMS (0.637), respectively.

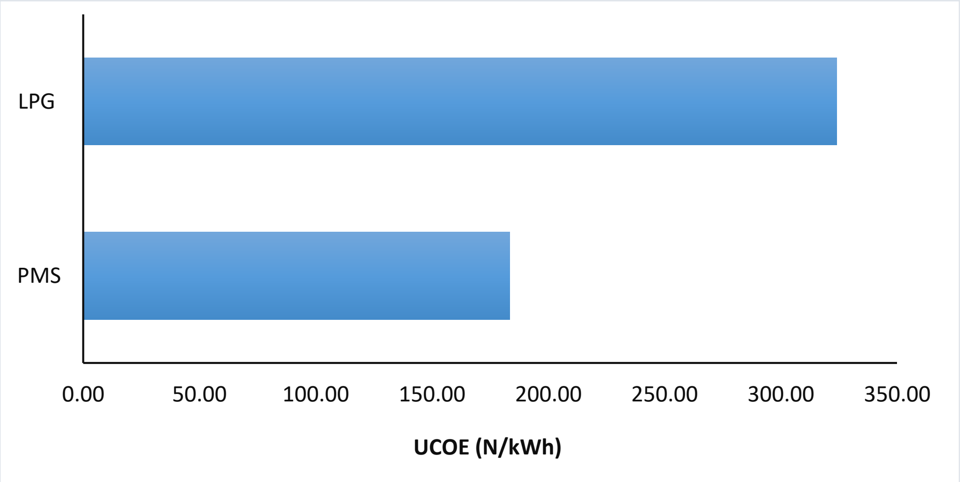

Figure 3: Comparative unit cost of electricity at current fuel prices

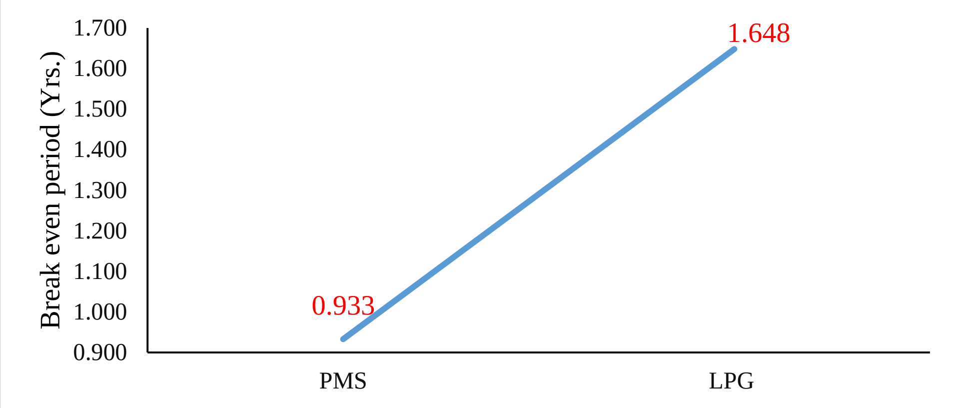

Figure 4: Comparative break even period at current fuel prices

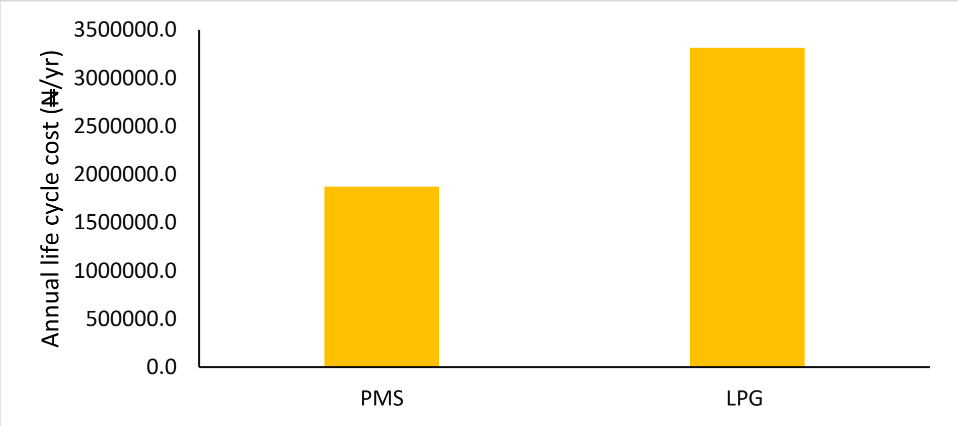

Figure 5: Comparative annual life cycle cost at current fuel prices

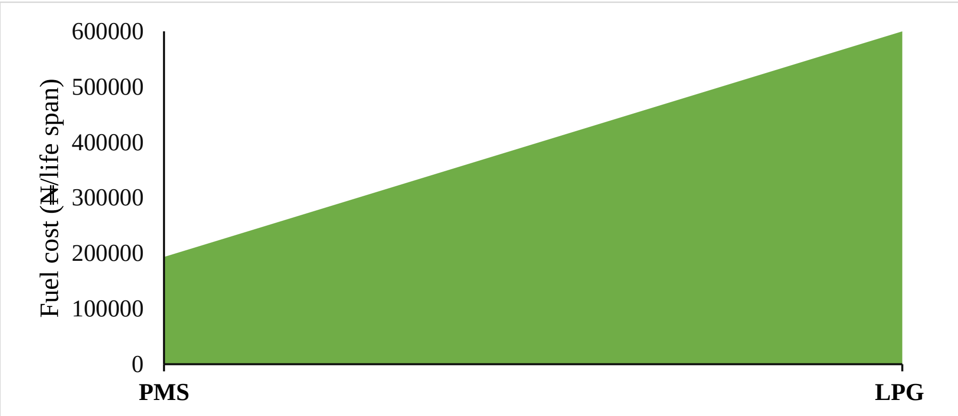

Figure 6: Comparative LPG/PMS cost over systems life span at current fuel prices

3.3. Comparative Results Based on LPG Price Variation

The results presented in the previous sections indicates that PMS is economically better than LPG when used to run the same generator over a 5-year period. As indicated, this was attributed to the recent high price of LPG. LPG price per kilogram had skyrocketed just within the last one year from ₦280 to ₦750. Therefore, a comparative analysis is presented for different prices of fuel, starting from ₦200. With LPG known to emit less greenhouse gases, the economic feasibility of using LPG for domestic power generation can form a roadmap for government policy on its use with resultant reduction in emissions. Summary of techno-economic performance of the system when operated with LPG at ₦200 and ₦300 per kg is presented in Tables 4 and 5 respectively.

Table 4. Summary of techno-economic performance of the system when operated with LPG at ₦200 per kg

ALCC (N/yr)	BEP (Years)	CRF	Fuel CoP (N)	E. Daily (kWh)	UCOE (N/kWh)	Z (N/s)	PMS (lits)	Tot. Cost (₦)
3313065	1.648	0.6368	599894	28.0	324.2	226.1	0.0000761	959894
3314335	1.647	0.6368	600261	28.0	324.1	226.2	0.0000761	960261
3315605	1.647	0.6368	600629	28.0	324	226.2	0.0000762	960629
3316875	1.647	0.6368	600997	28.1	323.9	226.3	0.0000762	960997
3318144	1.646	0.6368	601365	28.1	323.9	226.4	0.0000763	961365
3319414	1.646	0.6368	601733	28.1	323.8	226.5	0.0000763	961733
3320684	1.645	0.6368	602101	28.1	323.7	226.6	0.0000764	962101
3321954	1.645	0.6368	602469	28.1	323.6	226.7	0.0000764	962469
3323224	1.645	0.6368	602837	28.1	323.6	226.8	0.0000765	962837
3324494	1.644	0.6368	603205	28.2	323.5	226.8	0.0000765	963205

Table 5. Summary of techno-economic performance of the system when operated with LPG at ₦300 per kilogram

ALCC (N/yr)	BEP (Years)	CRF	Fuel CoP (N)	E. Daily (kWh)	UCOE (N/kWh)	Z (N/s)	PMS (lits)	Tot. Cost (₦)
3313065	1.648	0.6368	599894	28.0	324.2	226.1	0.0000761	959894
3314335	1.647	0.6368	600261	28.0	324.1	226.2	0.0000761	960261
3315605	1.647	0.6368	600629	28.0	324	226.2	0.0000762	960629
3316875	1.647	0.6368	600997	28.1	323.9	226.3	0.0000762	960997
3318144	1.646	0.6368	601365	28.1	323.9	226.4	0.0000763	961365
3319414	1.646	0.6368	601733	28.1	323.8	226.5	0.0000763	961733
3320684	1.645	0.6368	602101	28.1	323.7	226.6	0.0000764	962101
3321954	1.645	0.6368	602469	28.1	323.6	226.7	0.0000764	962469
3323224	1.645	0.6368	602837	28.1	323.6	226.8	0.0000765	962837
3324494	1.644	0.6368	603205	28.2	323.5	226.8	0.0000765	963205

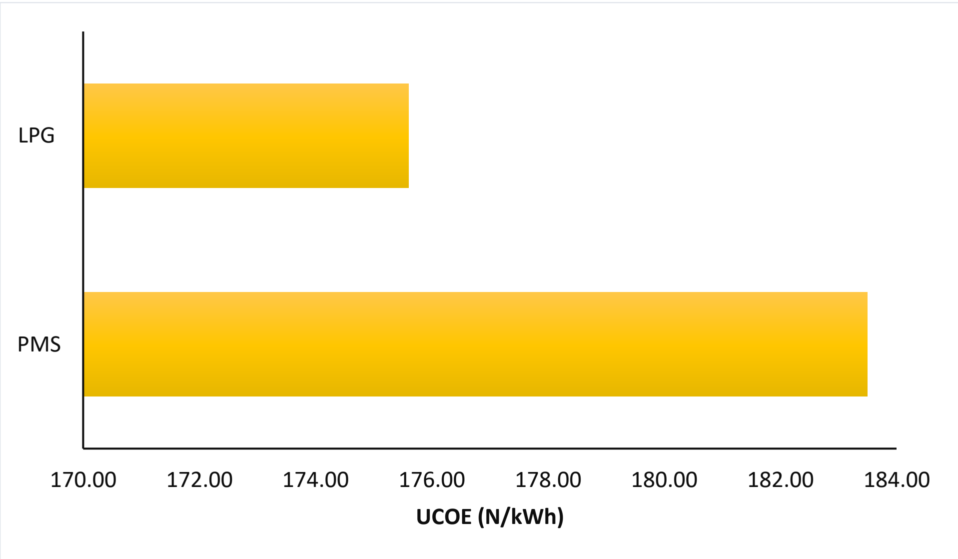

Figure 7: Comparative unit cost of electricity at reduced fuel prices

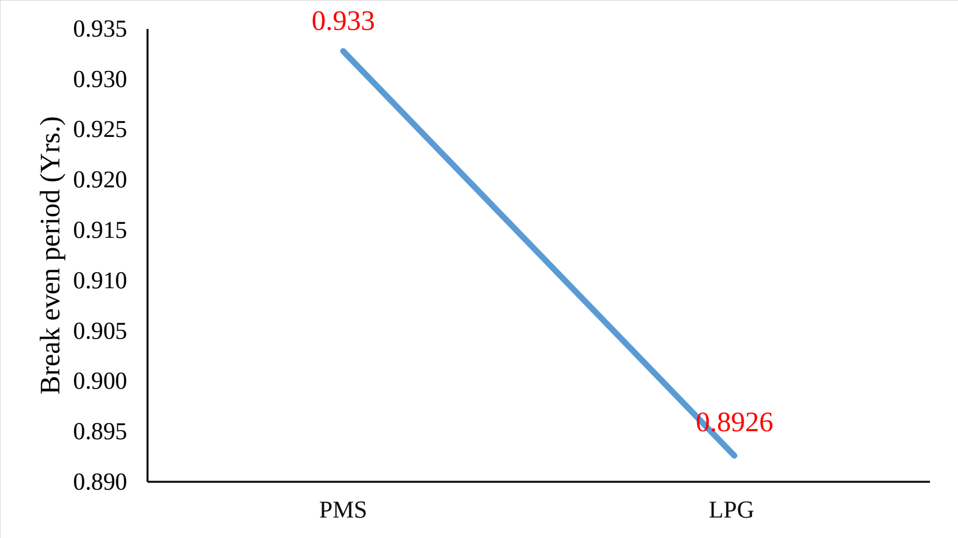

Figure 8: Comparative break even period at reduced fuel prices

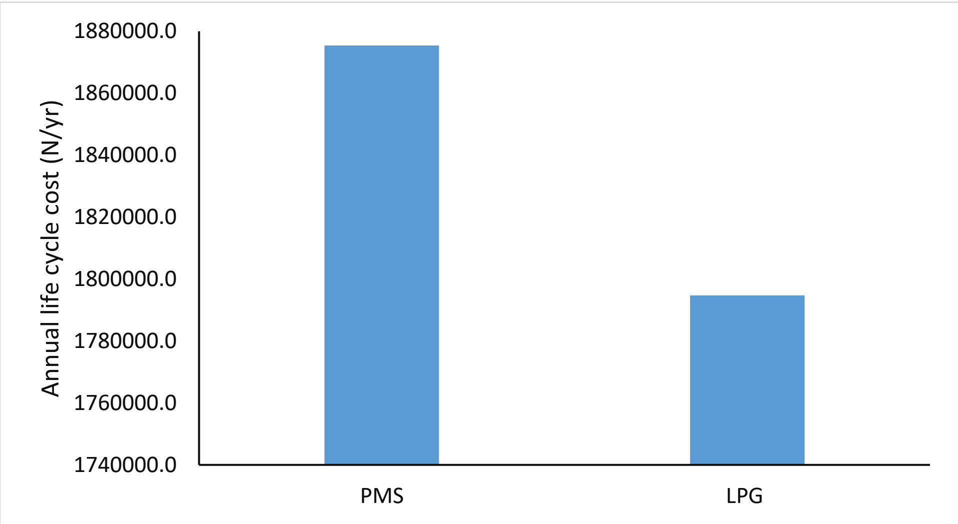

Figure 9: Comparative annual life cycle cost at reduced fuel prices

Figure 10: Comparative LPG/PMS cost over systems life span at reduced fuel prices

The results in this section demonstrates the economic feasibility of using LPG as a substitute fuel for powering home generators for domestic power consumption. However, at the current high LPG price of up to ₦750 per kilogram, PMS appears a better economic option following a detailed comparative analysis that is presented from first principles of energy conversion.

4. Conclusion

Due to poor power supply in the country, the use of stand-alone generation sets for electricity supply has been in extensive use in residential and small scale businesses. These systems are mostly powered by premium spirit (PMS) for light use, while heavier applications require the use of diesel. In addition to their pollution effects from noise and emissions, they require steady use of these operating fluids for their operation which can be very capital intensive especially with the volatile nature of petroleum prices in the country. To remedy this drawback, the use of natural gas is proposed as a substitute in the local power generating sets. This is intended to check the vast noise caused by these systems, reduce cost and enhance reduced greenhouse gas emissions in homes and business premises where there are domiciled. Therefore, the present study comparatively presents the economic and environmental gains associated with the use of natural gas for powering local power generation sets in Nigeria, especially, for small scale power production. Following a detailed experimental procedure and first principles analysis, the following conclusions were drawn from the study:

i. The instantaneous PMS and LPG consumption were obtained as 0.511 liters/h and 0.391 kg/h, respectively.
ii. Hourly PMS and LPG consumption rates at constant output of 3.5 kW showed less of LPG consumption against PMS. After eight hours, the system consumed 3.131 kg of LPG while the PMS was at a value of 4.091 liters.
iii. The unit cost of electricity was obtained as 183.5 N/kWh when operated with PMS, while the LPG corresponding value was higher at 324.2 N/kWh at current prices.
iv. The unit cost of electricity was obtained as 183.5 N/kWh when operated with PMS, while the LPG corresponding value was high at 175.6 N/kWh at reduced LPG price per kilogram.
v. At the current high LPG price of up to ₦750 per kilogram, PMS appears a better economic option. However, with LPG price reduction to ₦350, using LPG is more economically viable.

The following recommendations were drawn from results of the analysis conducted in this study:

i. Government should make policies on the adoption of LPG for powering small scale power sets to minimize greenhouse gas emissions (GHGE).
ii. At reduced LPG prices, using LPG to power small generators is economically friendly. Therefore, there is need to cut down the price of LPG to encourage people to use it for domestic power generation.
iii. Exhaust gas analysis should be conducted on both LPG and PMS fuels, as exhaust gas composition from each of the fuels can provide useful data about their effects on the ecosystem.

Nomenclature

PMS	Premium Motor Spirit
LPG	Liquefied Petroleum Gas
LNG	Liquefied Natural Gas
CNG	Compressed Natural Gas
LCC	Life Cycle Cost

ALCC	Annualized Life Cycle Cost
UCOE	Unit Cost of Energy
BEP	Breakeven Point
POT	Plant Operating Time
CRF	Capital Recovery Factor
EES	Engineering Equation Solver
TOC	Total Operation Cost
SIE	Spark Ignition Engine
GHGE	Greenhouse Gas Emissions
d	Inflation rate
i	Interest rate
₦	Naira
CoP	Cost of operation
Q_{AP}	Annual Energy Production (kWh/yr)
UEC_{MC}	Cost of the Conventional Electricity Supply (N/kWh)
E_s	Daily Energy Eemand (kWh/day)
W_{Plant}	Plant Capacity (kW)
C_q	Cost of the Plant Component
φ	Maintenance factor
q.	Plant component
Z_k	Levelised purchase equipment cost
$\dot{Z}_k$	Cost per unit of time (N/s)

References

[1] Haider, S., Adil, M. H. and Ganaie, A. A. (2019). Does industrialization and urbanization affect energy consumption: A relative study of India and Iran?. Econs. Bulletin., Vol.39(1), pp.176-185.

[2] Ahmad, M., and Zhao, Z. Y. (2018). Empirics on linkages among industrialization, urbanization, energy consumption, CO_2 emissions and economic growth: a heterogeneous panel study of China. Env. Sci. Pollut. Res., Vol.25, pp.30617-30632.

[3] Albuquerque, F. D. B., Maraqa, M. A., Chowdhury, R., Mauga, T. and Alzard, M. (2020). Greenhouse gas emissions associated with road transport projects: current status, benchmarking, and assessment tools. Trnsp. Res. Procedia., Vol.48, pp2018-2030.

[4] Nikhil, D. and Rajesh, A. (2015). Performance analysis of combined cycle power plant. Frontiers in Energy. Vol.9, pp.371-386.

[5] Motasemi, F., Muhammad, T. A, Arshad, A. S., Moghavvemi, M., Shekarchian, M., Zarifi, F. and Mohsin, R. (2014). Energy and exergy utilization efficiencies and emission performance of Canadian transportation sector. Energy., Vol.64, pp.355-366.

[6] Yousef, A., Eiman, E. and Esam, E. (2014). Approaches to reducing carbon dioxide emissions in the built environment: Low carbon cities. Int. J. of Sustainable Built Env. Vol.3(2), pp.167-178.

[7] Emodi, N. V., Emodi, C. C., Murthy, G. P., and Emodi, A. S. A. (2017). Energy policy for low carbon development in Nigeria: A LEAP model application. Renew. Sustainable Energy Rev. Vol.68(1), pp.247-261.

[8] Ikeme, J. and Obas, J. E. (2005). Nigeria's electric power sector reform: what should form the key objectives? Energy Policy. Vol.33(9), pp.1213-1221.

[9] Chidera, E, K., Eneojo, I., Moses, P. U., Daniel, S., Victor, D., Daniel, A., Anyadubalu, A., Cornellius, O., Halilu, S. and Enebosanwa, O. (2019). Investigation on the Efficiency of Premium Motor Spirit. Federal Polytechnic Idah, Kogi State, Nigeria.

[10] Bayraktar, H. and Durgun, O. (2005) Investigating the effects of LPG on spark ignition engine combustion and performance. Energy Convers. Manag. Vol.46, pp.2317-2333.

[11] Olaoye, O. S., Osunmakinde, L., Ibitowa O. A. and Abodunrin, O. D. (2014). Design, Construction and Performance Evaluation of a Propane Conversion Kit. Innov. Sys. Dsgn. Eng. Vol.5(9), pp.1-6.

[12] Adouane, M., Tabet, I., Rezzak, D., Touafek, K., Abdelkader, S. and Yahia, H. (2016). Feasibility study of a hybrid plants (photovoltaic-LPG generator) system for rural electrification. Renew. Energy Environ. Sustainability. Vol.1(15), pp.1-5.

[13] Sambandam, P., Murugesan, P., Shajahan, M. I., Sethuraman, B., Mohamed, H. and Hussein, A. (2022). Sustainability and Environmental Impact of Hydroxy Addition on a Light-Duty Generator Powered with an Ethanol-Gasoline Blend. J. of Renew. Energy Environ. Vol.9(2), pp.82-92.

[14] Lawal, O. A., Oba, M. Z. and Kabiru, L. (2020). Analysis of Environmental Effects of the Major Stand-alone Power Generators Used in Nigeria and Sub-saharan Africa. ATBU J. Environ. Tech. Vol.13(2), pp.14-27.

[15] Antarius, Y. D. and Dalimi, R. (2020). LPG for Power Generation in Indonesia: Techno-economic and Distribution Analysis. Adv. Econ. Bus. Mgmt. Res. Vol.184, pp.21-25.

[16] Eduardo, F. (2015). Hybrid energy scenarios for Fernando de Noronha archipelago. Energy Procedia. Vol.75, pp.2833-3838.

[17] Ajao, K. R., Oladosu, O. A., and Popoola, O. T. (2011). Using HOMER power optimization software for cost benefit analysis of hybrid-solar power generation relative to utility cost in Nigeria. Int. J. of Res. Rev. Appl. Sci. Vol.7(1), pp.96-102.

[18] Dufo-Lopez, R., and Bernal-Agustín, J. L. (2008). Multi-objective design of PV-wind-diesel-hydrogen-battery systems. Renew. Energy. Vol.33(12), pp.2559-72.

[19] Hassanzadehfard, H., Moghaddas-Tafreshi, S. M. and Hakimi, S. M. (2011). Optimal sizing of an Islanded micro-grid for an area in north-west Iran using particle swarm optimization based on reliability concept. World Renew. Energy Congr., Linkoping, Sweden, 8-13 May, 2011, pp.2969-2976.

[20] Oko, C. O., Diemuodeke, E. O., Omunakwe, N. F. and Nnamdi, E. (2012). Design and economic analysis of a photovoltaic system: a case study. Int. J. Renew. Energy. Dev. Vol.1(3), pp.65-73.

[21] Shokati, N., Mohammadkhani, F., Yari, M., Mohmoudi, S. M. and Rosen, M. A. (2014). A comparative exergoeconomic analysis of waste heat recovery from a gas turbine modular helium reactor using organic Rankine cycles. Sustainability. Vol.6(5), pp.2474-2489.

[22] Manmidi, T. and DSuryarunshi, J. G (2012). Investigation on S.I engine using liquefied petroleum gas (LPG) as an alternative fuel. Int. J. Eng. Res. Appl. Vol.2(1), pp.262-367.

[23] Aydin, M., Irgin, A. and Çelik, M. B. (2018). The Impact of Diesel/LPG Dual Fuel on Performance and Emissions in a Single Cylinder Diesel Generator. Appl. Sci. Vol.8(5), pp.825-839.

[24] Kalra, D., Babu, V. A. and Kumar, V. (2014). Effects of LPG on the performance and emission characteristics of SI engine - An Overview. Int. J. Eng. Dev. Res. Vol.2(3), pp2997-3003.

w York: McGraw-Hill Book Co.,2007.