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Techno-Economic Assessment of Liquefied Petroleum Gas-Based Alternative Electric Power Generation in Selected Residential Estates in Oyo State, Nigeria

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Abstract

This study examined the technological and economic parameters for Liquefied Petroleum Gas (LPG)-to-Power generation in housing estates in Oyo State, Nigeria. Technological and economic data were obtained through literature, questionnaire and site inspection. An energy project foresight analysis framework was used. The results showed that the housing estates had daily grid electricity demand range from 1438.43 – 8209.98 kWh. The technological specifications revealed gas turbine generator specifications from 0.6 – 3.5 MW and LPG storage tank specifications for 30 days from 30 – 171 m^3. Environmental specifications showed CO_2 emission mitigation from 331 – 1888 kg. The alternate diesel generation option has storage tank specifications for 30 days from 19 – 109 m^3 while CO_2 emissions were from 1553 – 8867 Kg. Life Cycle Costs (LCC) for the LPG plant were ₦ 122.74– 132.35/kWh and ₦ 151.62–160.81/kWh for the diesel generator option. The LPG-to-diesel generator estimated annual fuel costs savings were ₦ 229.05 million. The study concluded that LPG option was technologically and economically viable and was a more appropriate alternative electricity option relative to the existing diesel alternative electricity generation option.

Keywords: Liquefied petroleum gas; CO_2 emission; Life cycle costs; Gas turbine generator

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1.0 Background to the Study

One of the key drivers of socio-economic development and economic growth in any society is steady access to affordable, reliable and modern energy. Not only does access to energy determine economic growth, it ultimately determines the ability of any country to meet basic human needs, access to amenities like proper transportation network, education, healthcare, and safe and reliable drinking water (World Energy Outlook, 2017). With the urgency to meet the energy targets for 2030 and by extension attaining the Sustainable Development Goals (SDGs), different countries have developed priorities and strategic plans aimed at transforming lives and ensuring better standards of living for their citizens. In Nigeria, one of the steps taken to address this was the approval of the National Gas Policy by the Federal Executive Council in June 2017, stating therein that the Liquefied Petroleum Gas (LPG) should be used for power generation apart from domestic cooking that was noted for (Natural Gas Policy, 2017).

Although Nigeria is considered the largest economy in Sub-Saharan Africa it has difficulties meeting the socio-economic aspirations of its people due to its inefficient and unreliable power generation. It is estimated that only 45% of Nigeria's population of 200 million people has access to electricity. In spite of this low electricity access, the residential sector electricity consumption is estimated to be 60% of the total national electricity consumption (Ogundari *et al.*, 2017). Due to the lack of reliable electricity supply, many people and companies supplement the grid electricity supply with self-power generation. Many households have acquired petrol/diesel generators for domestic power generation with its attendant environmental and cost consequences. The development of alternative fueled engines has become imperative due to recent environmental regulation. To address this and make electricity more accessible, Liquefied Petroleum Gas is considered a suitable source for electricity generation (WLPGA, 2017). This is premised on the fact that LPG powered generators release less carbon dioxide per unit of energy than petrol or diesel powered generators. An LPG power generator is considered an appropriate choice for residential electricity demand requiring a steady and reliable source of back-up energy.

2.0 Statement of Research Problem

Liquefied Petroleum Gas (LPG) is set to play an increasingly important role as a "bridging fuel" alongside natural gas in the long-term transition to a truly sustainable global energy system. The challenge is to set in motion a profound shift to low-carbon energy sources and technologies, while at the same time satisfying the growing energy needs of an expanding world economy and population, especially the billions of people in the developing world who are still deprived of access to modern energy services. As a fossil fuel, LPG would appear to have no significant part to play in the low-carbon energy system of the future, but its specific characteristics of the fuel and its advantages over other fuel-fossils and non-fossil mean that it is remarkably well-placed to help reconcile the world's environmental, economic and social goals during the long period that it will take to complete that energy transition.

For decades, despite consistent investment by the Federal Government, localised as well as nationwide power outages become a constant phenomenon in our country. Nigerians expected that power generation, transmission and distribution would significantly improve after the 2013 privatization, but unfortunately, the sector is currently in a state of uncertainty despite leaving the control of generation and distribution in the hands of private investors in order to ensure adequate, regular and stable electricity supply. It appears to most stakeholders that the challenges besetting the sector appear to have compounded more than they were when the government controlled the levers. Even though Nigeria has about 202 trillion Standard Cubic Feet (SCF) of gas reserves, harnessing the potential to power generation plants has remained a mirage, especially because of low investment, inadequate funding of projects, and huge indebtedness to gas suppliers (NNPC, 2015). The hindrances mentioned above have not helped in providing enough natural gas to power thermal plant in Nigeria. This has resulted in epileptic supply of electricity to many homes for use either to power their electrical appliances or lighting purposes.

In the light of above, LPG could provide part of the solution in the short term as a bridging fuel for power generation in our residential estates. In Oyo State, Nigeria, the government has established protocols to adopt LPG for off-grid electric power generation in housing estates across the state. Being the hub of the Development Agenda for Western Nigeria (DAWN), the regional development agency of Southwestern Nigeria, and having a population of over 5.5 million, Oyo State is set to provide leadership in the Southwest. The successful development of the LPG-to-power initiative would provide a template for the rest of Southwestern Nigeria. There is a dearth of information on the techno-economic viability of LPG-to-power development for housing estates in Oyo State; hence, this study is necessary as a strategic intelligence input to electric power development for the sub-region. The specific objectives of the study were to estimate the electricity demand in the six government-approved residential estates in Oyo State, assess technological and environmental specifications for LPG power generation in the selected estates; and determine the engineering-economic specifications of the LPG power generation option.

This study was limited only to three residential estates each in Ibadan and Ogbomoso cities in Oyo State. This is because those cities constitute about 65% of the population of Oyo State. The study went further to cover the energy demand, power load, assessment of technological and environmental specifications for LPG power generation, Life cycle cost analysis, sensitivity analysis, extent of awareness and sources of awareness in the six selected government- approved residential estates.

2.1 Liquefied Petroleum Gas (LPG)

According to WLPGA (2008), Liquefied Petroleum Gas (LPG) consists mainly of propane (C_3H_8), propylene (C_3H_6), butane (C_4H_{10}) and butylene (C_4H_8) in various mixtures. LPG is produced as a derivative of the crude oil refining process through the absorption of the gas streams emanating from the several stages of the process. The components of LPG are released at various stages of the refining of crude oil (like the atmospheric distillation stage, the reforming stage and the fluid catalytic cracking stage). Approximately 3 percent of a barrel (159 litres) may be refined into LPG. This estimation is dependent on the type of crude oil that is being processed, the sophistication (configuration) of the oil refinery, and the market value of propane and butane - derived products as opposed to that of other petroleum products such as Light Naphtha, Heavy Naphtha, Kerosene, Automotive Gas Oil (Diesel), Gasoline and Fuel Oil (WLPGA, 2008).

LPG has gone from being a traditional fossil fuel to a new form of renewable energy. Scientists have developed a new biosynthetic process to produce propane (LPG). This is done by indirectly converting sunlight to propane and a genetically engineered version of the common E. coli bacteria do the conversion. The bacterial consume sugar. With genetic modification, and with the help of a couple of enzymes, they make propane instead of their normal cellular material that they are noted for. The propane produced is chemically identical to regular propane and it is still carbon based. This renewable propane can be used exactly like the traditionally derived fossil fuel version and is known as bio-LPG. (www.elgas.com/au, 2018).

2.1.1 Overview: the energy crisis in Nigeria

Nigeria is a country with an estimated population of 200 million people with less than 40% of the population having access to the national grid (National Renewable Energy and Energy Efficiency Policy (NREEEP, 2015). In spite of electricity being an essential component of modern society, citizens in most parts of Nigeria receive only 6 hours supply of electricity daily on the average (Ogundari *et al.*, 2017). Majority of the rural areas in the country are yet to even have access to any electrical power grid, and their reliance on some other sources of electricity, especially those sources that are detrimental to the environment, has led to Nigeria being one of the world's largest producers of carbon emissions, closely associated with global warming (Sadiks, 2015). In order to enhance the energy security of the country and establish a sustainable energy supply system, it is necessary to promote the policy of diversifying the energy supply, so as to include alternative or renewable resources and technologies into the nation's energy mix. Non-renewable energy resources are coal, oil and gas while renewable energies include: wind, ocean waves and tides, solar, biomass, hydro, and geothermal (heat of the earth) (Maren *et al*, 2013).

2.1.2 The Nigerian power sector: Past and present

Electricity generation in Nigeria began in 1896 in Lagos. In 1950, The Electricity Corporation of Nigeria (ECN) was established, and the Niger Dam Authority (NDA) was established in 1962. In 1972, the National Electric Power Authority (NEPA) was established by the government by merging the ECN amd the NDA. NEPA operated as a government -controlled monopoly in the domain of generation, transmission and distribution (Table 1). In 2005, as a result of the power sector reform process, NEPA was restructured and renamed the Power Holding Company of Nigeria (PHCN). With the completion of reforms in 2013, PHCN ceased to exists, and the power sector unbundled into generation, transmission and distribution entities (Sambo, 2018).

The major constraints of the Nigerian Power Sector have been found to include: gross inadequate electricity generation, transmission and distribution; poor demand side management, limited access to infrastructure, poor organizational management, and limited government support, amongst others (Sambo, 2018; Ogundari *et al.*, 2017).

Table 1: Generation and Distribution Companies in Nigeria

Generation Companies	Distribution Companies
Afam Power	Abuja Electricity Distribution Company
Geregu 1	Benin Electricity Distribution Company
Sapele Power	Eko Electricity Distribution Company
Ughelli Power	Enugu Electricity Distribution Company
Kainji/Jebba Hydro Power	Ibadan Electricity Distribution Company
Shiroro Hydro Power	Ikeja Electricity Distribution Company
	Jos Electricity Distribution Company
	Kaduna Electricity Distribution Company
	Kano Electricity Distribution Company
	Port Harcourt Electricity Distribution Company
	Yola Electricity Distribution Company

Source: Nigerian Electricity Regulatory Commission (NERC)

Some countries, for example, Japan, France, South Korea and Singapore, have adopted a set of successful strategies for enhancing domestic electric power supply, and these strategies include: increasing the number of fuels and technologies that are in the energy mix (for example, oil and gas, solar, wind, biomass, nuclear, geothermal and tidal), increasing the number of suppliers for each fuel, developing strategic reserves of fuel types, and increasing energy efficiency and conservation (Maren *et al*, 2013; Sadik, 2015).

The integration of LPG in the electric power supply mix globally has gained momentum in recent years, and being one of the cleanest conventional fuels available, LPG has become a highly desirable fuel alternative for the generation of off-grid electricity. LPG enables highly efficient, decentralized generation through self-containing generator and combined heat and power systems (WLPGA Final Report, 2015). LPG as a highly versatile energy source is used in all the major energy end-use sectors – residential, agriculture, commercial, industry, and transport – albeit the residential sector is the largest consumer of LPG (WLPGA Final Report, 2015). In distributed power generation, LPG emits less greenhouse gases than diesel and Liquefied Natural Gas (LNG) and its use has been acknowledged to bring environmental benefits, including greatly reducing indoor and outdoor pollution, and helping mitigate deforestation – a major cause of global warming.

In Nigeria, the government policy for LPG is to ensure the development of a strong and rapidly growing LPG market, and promote its wider use in the domestic sector, power generation, and auto-gas and industrial applications towards the attainment of Five Million (5,000,000) MT utilization by 2022 (National Gas Policy, 2017). It is anticipated that increased LPG use could spur increased government revenue, reduce government costs on fuel, create thousands of skilled jobs in the various segments of the LPG supply value chain, as well as generate positive outcomes for the environment and public health sectors (National Gas Policy, 2017).

3.0 Research Methodology

A three-stage multi-sampling technique was used to select housing units from government-approved housing estates in Oyo State, Nigeria. In the first stage, two towns namely Ibadan and Ogbomoso were purposively selected amongst the towns in Oyo State. Ibadan (population: 3.65 million) and Ogbomoso (population: 577,000) constitute about 53.9% of Oyo Sate (estimated population: 7.84 million). In the second stage, three government-approved residential estates were purposively selected from Ibadan and Ogbomosho cities respectively, while in the third stage, 30 housing units were randomly selected from each of the selected residential estates taking into consideration the categories of buildings in each estate. Thus, a total of 180 housing units were sampled across the six housing estates in the two cities. The residential estates selected in Ogbomoso were, namely, the Federal Mortgage Bank (FMB) Housing Estate, Samade, with 50 housing units (Estate 1); the Oyo State Housing Corporation Estate, Ajilete, with 120 housing units (Estate 2); and the Federal Low Cost Housing Estate, Adeniran Area, with 100 housing units (Estate 3). In Ibadan, the estates selected were, namely, Olubadan Housing Estate, off New Ife Road, Opposite New Gbagi market, with 180 housing units (Estate 4); Resettlement Housing Scheme, New Olubadan Palace Road, Yemetu, with 60 housing units (Estate 5); and Aerodrome GRA Housing Estate, Samonda, with 90 housing units (Estate 6).

Data were obtained from both primary and secondary sources. Primary data was obtained from a questionnaire administered to the residential housing units. The questionnaire elicited information on the electricity consumption in each housing unit through the types of electrical gadgets in the housing units, their electric power ratings, and their hourly use. Socio-demographic characteristics of the estate dwellers as well as their level of awareness of LPG-based power generation were obtained. A total of 33 household appliances and provision made to specify others were identified. Different types of bulbs for lighting used in each housing unit were included in the questionnaire. Secondary data on the technical specifications of the LPG and diesel power generating systems were collected from the catalogues and manuals of the manufacturing companies, equipment vendors and energy researchers. Data such as capital cost, operating cost, maintenance cost, replacement cost and life cycle of the generation system, amongst others, were obtained. Data were analysed using Energy Planning Analysis, Life-Cycle Cost Analysis, CO_2 emission mitigation calculations, and statistics.

In order to achieve Objective 1 (estimation of the energy demand in the six (6) government-approved residential estates in Oyo State), the energy demand for each housing unit was extracted using the questionnaire, and the energy demand for each residential estate, and consequently the six housing estates, determined.

In order to achieve Objective 2 (assessment of technological and environmental specifications of LPG and Diesel power generation in the selected estates), the sizes of the LPG and Diesel power generators needed for each residential estate were determined from the power consumption obtained in Objective 1, the LPG and diesel fuel consumptions were calculated per day and per month from the energy demand, the volume of the LPG and Diesel storage tanks were calculated, .the design specifications of the thickness of the cylindrical shell and hemispherical heads of LPG storage tanks for each residential estate as well as the wall thickness of the diesel vertical cylindrical storage tanks were determined, and the total CO_2 emission mitigation calculations for the LPG and Diesel fuels were determined.

In achieving Objective 3 (determination of the engineering-economic specifications of the LPG and Diesel power generation), the cost-benefit analysis of LPG relative to diesel fuel per day and per annum were determined, and the Life-Cycle Cost Analysis of gas turbine generators using LPG and Diesel fuels was estimated.

4.0 Results and Discussion

4.1 Power Load and Electricity Consumption Demand in the Selected Estates

Table 2 shows power loads and electricity consumption estimates for the six (6) selected residential estates. The table reveals that the power loads of appliances and lighting sources used in the selected estates were in the range 288.16 – 1718.04 kW, with total power load estimates of 5221.68 kW. Estimated electricity consumption in the estates was from 1438.43 – 8209.98 kWh with total electricity consumption of 24,241.49 kWh). Electricity consumption in the estates was split between household appliances and lighting sources, with the household appliances being the major electricity consumers (85 – 93% of total electricity consumption) and the lighting sources accounting for 6.80 – 14.68%. Residential lighting share of total residential electricity consumption was found to be higher than the reported industrial lighting share of total industrial electricity consumption (2 – 10%) (Bureau of Energy Efficiency India, 2009).

Table 2: Power Load and Electricity Consumption in the Selected Housing Estates

Residential Estate	Total Power Load (kW)	Total Electricity Consumption (kWh)	Total Household Appliance (kWh)	Total Lighting (kWh)
Estate 1	396.52	1825.63	1688.55 (92.49%)	137.08 (7.51%)
Estate 2	745	3938.80	3593.16 (91.22%)	345.64 (8.78%)
Estate 3	288.16	1438.43	1227.33 (85.32%)	211.10 (14.68%)
Estate 4	1209.12	5217.36	4556.58 (87.33%)	660.78 (12.67%)
Estate 5	864.86	3611.02	3365.34 (93.20%)	245.68 (6.80%)
Estate 6	1718.04	8209.98	7206.99 (87.78%)	1002.99 (12.22%)
TOTAL	5221.70	24,241.22		

4.2 Technological and Environmental Specifications for LPG Power Generation in the Selected Estates

The technological and environmental specifications for the LPG and diesel generator alternative systems were determined and this section shows the results.

4.2.1 Energy demand, generator load size and fuel consumption requirements for the alternative LPG and diesel power supply options

The determination of the power loads and electricity consumption profiles of each of the estates is critical to the estimation of (gas turbine) generator load size and fuel consumption requirements for the alternative power system options. Table 3 reveals that the estimated power loads and electricity demands for the housing estates would require gas turbine generators with size ranges from 0.6 – 3.5 MW. Estimated daily LPG supply of between 400 – 2,304 Kg or a total daily LPG demand of 6,767 Kg for the six estates were obtained if the LPG power system was adopted as the stand-alone alternative power generation option. In like fashion, daily diesel demand was estimated to be between 575 – 3,284 litres (a total daily diesel demand estimation of 9,696 litres) if the diesel alternative power supply system was chosen as the stand-alone alternative power generation option. These fuel consumption estimates were the input variables for the designs of the fuel storage tanks required in each estate.

Table 3: Energy Demand, Generator Load Size and Fuel Consumption Requirements for the Alternative LPG and Diesel Power Supply Options in the Estates

Residential Estate	Power Load (kW)	Energy Demand (kWh)	Generator Load Size (MW)	Daily LPG Requirements (kg)	Daily Diesel Requirement (litres)
Estate 1	396.52	1825.63	0.80	507	730
Estate 2	745	3938.80	1.50	1094	1576
Estate 3	288.16	1438.43	0.60	400	575
Estate 4	1209.12	5217.36	2.50	1449	2087
Estate 5	864.86	3611.02	1.80	1013	1444
Estate 6	1718.04	8209.98	3.50	2304	3284
TOTAL	**5,221.70**	**24,241.22**		**6767**	**9696**

4.2.2 Fuel requirements and the storage tank design specifications per estate

Monthly generator fuel requirements were determined, and the corresponding storage tank design specifications for each estate were detailed for each fuel type (see Table 4 and 5). The monthly LPG requirements were between 12 – 69.12 Metric Tonnes (MT); leading to LPG storage tank capacities of 30 – 171 m^3, and estimated storage tank nominal diameters of 180 – 330 cm, cylindrical shell lengths of 850 – 1890 cm, cylindrical shell thickness of 9 – 14 mm, and hemispherical head thickness of 5 – 8 mm. The monthly diesel requirements were estimated to be between 21,900 – 98,520 Litres; leading to diesel storage tank capacities of 19 – 109 m^3 (with 10% freeboards), and estimated storage tank nominal diameters of 270 – 500 cm, heights of 335 – 555 cm, wall thickness of 2.60 – 3.60 mm.

Table 4: Monthly LPG Requirement and Design Specifications for LPG Storage Tanks in the Selected Estates

Residential Estate	LPG Monthly Requirement (MT)	Capacity 08 storage Tank (m^3)	Nominal Diameter (cm)	Cylindrical Shell Length (cm)	Cylindrical Shell Thickness (mm)	Hemispherical Head Thickness (mm)
Estate 1	15.21	38	230	850	10	6
Estate 2	32.82	81	280	1222	12	7
Estate 3	12	30	180	1119	9	5
Estate 4	43.47	108	320	1236	14	8
Estate 5	30.39	75	300	960	14	8
Estate 6	69.12	171	330	1890	14	8

Table 5: The Monthly Diesel Requirement and Design Specifications of Diesel Storage Tanks in Different Estates

Residential Estate	Diesel Monthly Requirement (Litres)	Including 10% Freeboard Capacity of Storage Tanks (m^3)	Nominal Diameter (cm)	Height (cm)	Wall Thickness (mm)
Estate 1	21,900	24	285	380	2.60
Estate 2	47,910	52	365	500	3.0
Estate 3	17,250	19	270	335	2.50
Estate 4	62,610	69	400	550	3.20
Estate 5	43,320	48	360	475	3.0
Estate 6	98,520	109	500	555	3.60

4.2.3 Carbon dioxide emissions from the LPG and diesel power generation systems

Determining the appropriate alternative power system (APS) to use in the estates requires comparing their carbon dioxide emissions. Table 6 shows these results. The daily LPG demand of 400 – 2304 Kg across the six estates would have a daily total LPG demand of 6,767 kg. This daily LPG demand is estimated to emit between 331 – 1888 kg of CO_2 (total daily emission of 6,424 kg or 6.42 Tonnes). The daily diesel demand of 575 – 3284 litres (total daily diesel demand of 9,696 litres) was estimated to emit 1553 – 8867 Kg of CO_2 (total daily emission of 26,181 kg or 26.18 Tonnes). Comparatively, the LPG APS would emit approximately 5 times less (20% less) carbon dioxide than the Diesel APS. This is critical to evaluating the comparative carbon footprints of the alternative options. The results indicate that LPG is less hostile to the environment relative to diesel, and its influence on global warming is minimal in comparison with diesel fuel. Interestingly, the United Nations International Panel on Climate Change (IPCC) does not list Liquefied Petroleum Gas (LPG) as a greenhouse gas (GHG), meaning that LPG is assigned a Global Warming Potential (GWP) factor of zero.

Table 6: Carbon Dioxide Emissions from the LPG and Diesel Power Generation Systems

Residential Estate	Electricity Demand (kWh)	LPG Demand (kg)	CO_2 Emissions (kg)	Diesel Demand (Litres)	CO_2 Emission (kg)	LPG CO_2 Emissions: Diesel CO_2 Emissions (kg)
Estate 1	1825.63	507	420	730	1971	1:4.69
Estate 2	3938.80	1094	906	1576	4255	1:4.7
Estate 3	1438.43	400	331	575	1553	1:4.69
Estate 4	5217.36	1449	1048	2087	5635	1:5.38
Estate 5	3611.02	1013	831	1444	3900	1:4.69
Estate 6	8209.98	2304	1888	3284	8867	1:4.7
TOTAL	24,241.22	6,767	5,424	9,696	26,181	1:4.83

4.3 Determination of the Engineering-economic Specifications of the LPG Power Generation Option

Table 7 shows the cost parameters and life cycle cost analysis of the LPG APS in comparison with the diesel APS over a 25-year project life-cycle. The results show that the capital costs of the LPG APS across the selected estates were ₦ 151.39 million – 849.98 million. Life operating/maintenance costs were ₦ 93.87 million – 517.13 million, life fuel costs were ₦ 1,085 million – 6,233 million, life replacement costs were ₦ 172.67 million – 991.05 million, and the life cycle costs were ₦/kWh 122.76 – 132.9. For the diesel APS option, capital costs across the selected estates were ₦ 146.67 million – 826.48 million. Life operating/maintenance costs were ₦ 87.13 million – 483.58 million, life fuel costs were ₦ 1.441.9 million – 8.219.3 million, life replacement costs were ₦ 166.81 million – 961.98 million, and the life cycle costs were ₦/kWh 151.69 – 160.81. The comparison between these two alternative power supply options shows that the capital costs of diesel APS option were between 96.9 – 97.5% of the capital costs of the LPG APS option. For the life operating/maintenance costs and life replacement costs, diesel APS option costs were around 92.8% and 97% of the capital costs of the LPG APS option respectively. For the life fuel costs, LPG APS costs were around 75% of diesel APS costs. The Life Cycle Cost (LCC) analysis revealed that the LPG APS costs ₦127.83±5.07/kWh across the six estates was lower than that for diesel APS costs of ₦156.25±4.56/kWh.

Table 7: Life Cycle Cost (LCC) Analyses on the LPG and Diesel Alternative Power Systems

	APS	Estate 1	Estate 2	Estate 3	Estate 4	Estate 5	Estate 6
Capital Costs (₦)	LPG	199,012,010.70	369,066,120.00	151,392,776.90	607,242,943.70	438,983,731.60	849,732,840.40
	Diesel	193,549,399.30	357,840,156.70	146,667,292.30	591,992,366.50	427,893,425.20	826,478,085.70
Life Operating/ Maintenance Costs (₦)	LPG	123,429,201.4	227,953,219.40	93,874,576.78	370,262,383.10	267,362,444.90	517,133,759.80
	Diesel	114,470,126.1	210,279,575.50	87,129,887.32	346,830,114.90	251,132,533.70	483,575,154,80
Life Fuel Costs (₦)	LPG	1,375,789,333	2,963,556,125	1,085,522,284	3,923,507,506	2,743,509,628	6,233,152,333
	Diesel	1,829,705,490	3,946,227,698	1,441,926,599	5,224,647,140	3,615,990,190	8,219,300,902
Life Replacement Costs (₦)	LPG	228,235,960.6	427,874,310.80	172,668,657.00	706,508,613.70	509,431,524.60	991,052,982.20
	Diesel	221,648,450.5	414,062,536.00	166,812,753.90	687,619,732.20	495,666,975.30	961,979,037.40
Life Cycle Cost (₦/kWh)	LPG	**127.91**	**122.76**	**126.69**	**130.28**	**132.90**	**126.84**
	Diesel	**156.65**	**151.69**	**155.26**	**159.17**	**160.81**	**154.89**

Table 8 presents the sensitivity analysis of fuel cost with Value-Added Tax (VAT) on LPG and without VAT on LPG. This study showed that the cost per kilowatt hour with VAT on LPG ranged from ₦ 122.74 – 132.35 but without VAT on LPG, it ranged from ₦ 118.20 – 127.77. This amounted to a saving of about ₦ 4.54 per kilowatt hour.

4.3.1 Extent of awareness of the respondents to the usage of LPG for power generation.

From Table 9, the study revealed that only 47.22% of the respondents indicated they were aware of the use of LPG for power generation as against the 52.78% who were not aware. This indicates that a majority of the respondents were not aware of LPG use as power fuel. At level of confidence ∝ of 5% (i.e. ∝ = 0.05) and degree of freedom of 5, the calculated value is 3.59. Thus the study concluded that the response did not vary significantly from estate to estate.

Table 8: Sensitivity analysis of fuel cost (LPG)

Residential Estate	With VAT on LPG (₦/kWh)	Without VAT on LPG (₦/kWh)	Diesel (₦/kWh)
Estate 1	127.91	123.37	156.65
Estate 2	122.76	118.20	151.69
Estate 3	126.69	122.15	155.26
Estate 4	130.28	125.22	159.17
Estate 5	132.90	127.77	160.81
Estate 6	126.84	122.26	154.89

Table 9: Extent of Awareness of LPG as Fuel for Power Generation in the Selected Estates

Residential Estate	Extent of Awareness		Total
	Yes	No	
Estate 1	14 (46.67)	16 (53.33)	30
Estate 2	13 (43.33)	17 (56.67)	30
Estate 3	11 (36.67)	19 (63.33)	30
Estate 4	18 (60.00)	12 (40.00)	30
Estate 5	15 (50,00)	15 (50.00)	30
Estate 6	14 (46.67)	16 (53.33)	30
Total	**85 (47.22%)**	**95 (52.78%)**	**180**

Note: Figures in parentheses are percentages

4.3.2 Sources of awareness

From Table 10, the major sources of information were: Publication (31.76%), Internet (27.06%) and Friends (27.06%). Other sources were: Advertisement (2.35%) and Neighbours (2.35%) are the lowest sources of awareness. This implied that newspapers would be a better option to create awareness on the use of LPG for power generation. This was followed by the Internet and friends' sources.

Table 10: Sources of awareness

Sources	Frequency	Percentage
Publication	27	31.76
Internet	23	27.06
Friend	23	27.06
Place of Work	8	9.42
Advertisement	2	2.35
Neighbour	2	2.35
TOTAL	85	100

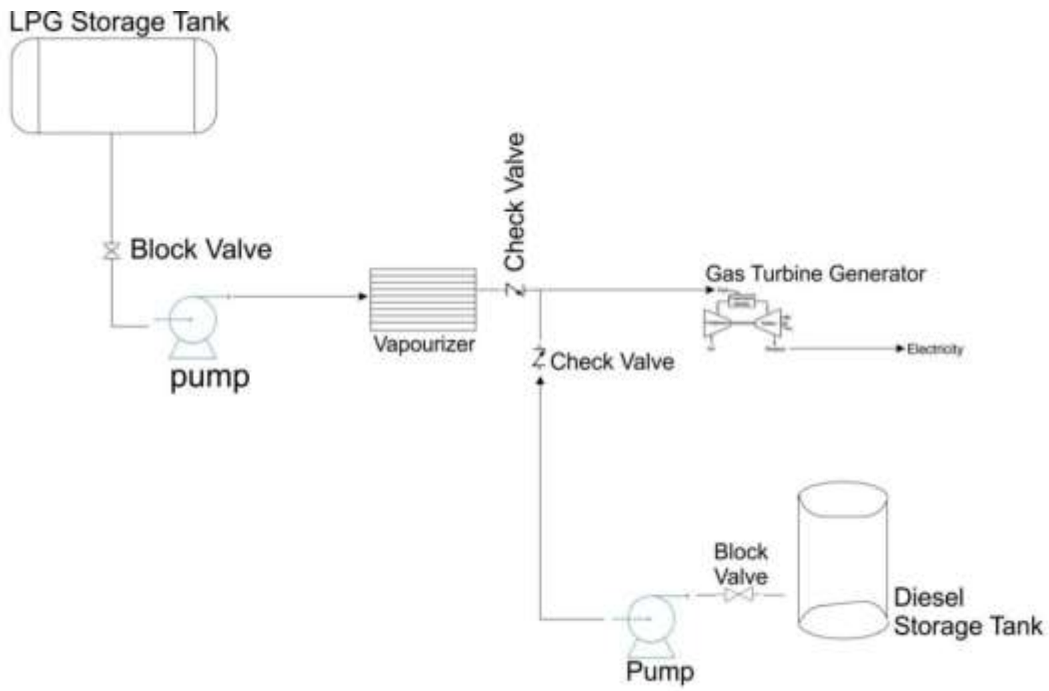

Figure 1: Process Flow Diagram of Electricity Generation (Used in the life cycle cost analysis calculations)

4.4 Discussion of Results

The Nigeria National Gas policy (2017) is advocating the use of LPG as fuel for power generation. The identified problem is that there is no techno-economic assessment of the implementation of this policy. The project definitions have not been determined to aid strategic policy implementation. The results of this study provide a strategic assessment. The estimations of power loads and electricity demand provide evidence that electrical appliances in the estates consume more electricity (85 – 93%) of total electricity consumption) relative to the lighting sources. This is important because it shows that the utilization of low voltage devices should lead to a reduction of power loads or electricity consumption in buildings. The estimated LPG fuel demand for use in the gas turbine generators (6.78 Tonnes per day) is considerably huge and it shows that a market exists for LPG in Nigeria. From this study, LPG consumption in only six estates of 600 housing units (6.78 Tonnes) is 0.86% of total LPG production in Nigeria). Sonibare *et al.*, (2006) had argued that expanding access to gas in Nigeria via the state capitals would enhance the development of a robust domestic gas consumption industry in the country. The adoption of LPG-based electricity generation could strengthen the use of LPG in place of other dirty fuels and foster the elimination of carbon dioxide emissions in the country. The design for the required storage tanks were carefully detailed from the demand specifications of each fuel type. The storage tanks were designed for 1-month fuel stock for each fuel type. This is the standard tank storage size (Guohua, 2012).

Carbon dioxide emissions per day from diesel fuel usage were between 4 to 5 times the emissions calculated for the LPG fuel usage. This study confirms previous literature that diesel –based electricity generation was not environmentally friendly. Carbon dioxide emissions from diesel generator sets are known to increase health challenges in rural and urban settings. Specifically, ailments attributed to carbon dioxide emissions include, various types of Respiratory Tract Infections, amongst others (Orifah *et al*,2016). The adoption of the LPG APS should reduce the totality of carbon dioxide emitted into the environment and help save lives (Louis, 2008). Then techno-economic analysis indicates that the capital costs for the two fuel types are very close to one another. The major cost differences are in the life fuel costs. The amount of diesel required would lead to fuel expenditures far in excess of that for LPG. This is a major advantage for LPG fuel adoption. The life cycle costs for LPG is far less than that for diesel (approximately N30 less per kWh of electricity. This cost differential is a major incentive for the adoption of LPG for electricity generation in the country. Furthermore, the LCC provides critical, evidence-based input to the implementation of the Nigeria National Gas Policy.
For the sensitivity analysis of fuel cost (LPG), it was not compared with diesel fuel because diesel has been deregulated. LPG is the only petroleum product with Value-Added Tax (VAT) and the rate in Nigeria is 5 per cent. For Nigerians to embrace the National gas policy which would encourage the use of LPG for power generation, it would be advisable to remove VAT imposed on LPG for further price reduction.

5.0 Conclusion

The study has provided information on the use of LPG as an alternative fuel to power generators in the residential estates in Oyo State by determining energy demand required by each residential estate, quantity of LPG and diesel requirements, CO_2 emission for both LPG and diesel fuels, bulk storage tanks design specifications, Life-Cycle Cost Analysis (LCCA) for LPG and diesel and the extent of awareness among households in the residential estates. To this end, the following conclusions are drawn from this study:

(i) LPG is a promising alternative fuel being environmentally friendlier and it is more cost-efficient than diesel.
(ii) Being environmentally friendly, makeing LPG kinder to the planet.
(iii) People are not as aware of LPG as they are of traditional fuels such as petrol or diesel.
(iv) LPG powered generators release less carbon dioxide per unit of energy than petrol or diesel powered generators.
(v) Inaccurate belief that LPG is more expensive than traditional fuels such as petrol or diesel is also impeding the progress of its usage.
(vi) The energy demand increases with the level of income. The extent of energy usage for household purposes is linked to population, household formation and size, income and the degree of urbanisation. From the survey, it could be established that the energy demand increases with the level of income.
(vii) As household income rises, an increasing share of energy is used for other purposes other than basic cooking and lighting; largely for appliances such as refrigerators, freezers, air conditioners which is the main reason for use of electricity.

5.1 Policy Recommendations

The study made the following policy recommendations:

(i) Government is encouraged to further tap LPG as an alternative power source for residential needs.
(ii) The private sector is encouraged to invest in LPG-based electric power generation as it has been proven that it is economically viable.
(iii) Financial institutions are encouraged to provide necessary funds for inculcation of LPG –based power generation in Nigerian energy mix.
(iv) Further studies are needed to reduce LPG costs and incentivize its use in the energy mix.

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