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Techno-Economic Assessment of Liquefied Petroleum Gas-Powered Alternative Electricity Critical Infrastructure Development in Nigeria's Southwest Geopolitical Zone

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Abstract: The decentralization of electricity authority in Nigeria has made it expedient for the Southwest Geopolitical Zone to develop strategic power generation infrastructure. This study assessed the techno-economic viability of the liquefied petroleum gas (LPG)-powered (off-grid) alternative electricity infrastructure option in Southwestern Nigeria as a mitigation strategy to endemic inadequate grid power supply under the region's integrated electric power programmes. An energy project planning and foresight analysis methodology was used. The study showed that a 25 MW stand-alone LPG-based CHP power plant would require 8.567 acres of land and consume approximately 15.459 million kg of Liquefied Petroluem Gas (LPG) annually, while generating 210,240 MWh of electricity annually. This power plant initiative was considered acceptable risk (Payback period = 9 years 3 months; Return on Investment = 10.73%) and viability at the minimum tariff of $ 0.11/kWh. It also had considerable annual CO_2 emissions and fuel cost savings (255.75 metric kilotonnes and $ 137.58 million) relative to diesel-based alternative power generation. The study recommended that reductions improve the viability of the power initiative in terms of operations costs. The study concluded that the LPG plant initiative was technically feasible, economically viable, and environmentally friendly and was suitable for deployment in the study area.

Keywords: *Liquefied Petroleum Gas power plants; Southwest Nigeria Power Infrastructure; Energy planning; Project foresight analysis; Critical power infrastructure; Electric power supply; Off-grid electric power systems*

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1.0 Introduction

It is incumbent on governments to provide critical infrastructure, such as modern energy services, to their societies as a strategic input to sustainable economic growth and industrialization [1, 2, 3, 4]. Electricity, one of the critical modern energy services, is fundamental to reliable public critical infrastructure service delivery (residential power utilisation, agricultural productivity, transportation, healthcare, manufacturing/industrial development, entertainment/ infotainment, telecommunications, education, and learning services, and clean water/sanitation provision) [3, 4, 5, 6]. Consequently, modern States, development agencies, and geopolitical actors focus on improving societal access to sustainable electricity services by developing strategic electric power technologies (such as liquefied petroleum gas-to-power) as strategic energy policy and planning outcomes.

The governments of the six constituent States and the region's development agency have prioritized improving regional electricity access as a mechanism for socio-economic advancement. The vision is to achieve universal electricity access while attaining net-zero carbon emissions [7, 8, 9, 10, 11].

Strategic status assessments of the regional electricity sector indicate a significant electricity supply crisis, inadequate electricity generation to meet domestic demand, and very low electricity consumption per capita; the want for reliable, accessible electricity is palpable (7, 9, 12, 13, 14, 15]. Power supply to the region from the national grid is grossly insubstantial at a mere 2000 MW, severely stifling regional socio-economic development [10, 11, 16, 17, 18]. Persistent incidents of national grid failure further exacerbate inadequate regional power supply, compelling considerable private power generation to meet demand [10, 11, 16, 19, 20, 21]. Factors attributed to the region's suboptimal electric power scenario include inadequate power infrastructure, rapid and uncontrolled population growth, vandalism and poor maintenance of equipment, poor purchasing power of consumers, poor policy and management framework, poor financing of the sector, limited capabilities and ethics amongst sector operators amongst others [7, 13, 14, 22]. Further, the poor grid power supply is compounded by the geopolitical zone being under six different state administrations and within the distribution zones of four different electricity distribution companies with their individual planning and control structures. These distribution companies are Eko Electricity Distribution Company Ltd (Eko DISCO) for Lagos Island and its environs; Ikeja Electricity Distribution Company Ltd (Ikeja DISCO) for Lagos Mainland and parts of Ogun State; Ibadan Electricity Distribution Company Ltd (Ibadan DISCO) for Oyo/Osun States and parts of Ogun State, and Benin Electricity Distribution Company Ltd (Benin DISCO) for Ekiti/Ondo States and parts of Osun State [7, 9, 10, 11].

Prior to 2005, measures to improve power supply to the Southwest geopolitical zone were under Federal authority and included strengthening the defunct national electric power authority through various policy and management reforms; provision of power infrastructure for generation, transmission, and distribution; financial mechanisms; capacity building and workforce enhancement; community engagement; technology and innovation; and international support amongst others [9, 19, 23, 24]. From 2005, power sector reforms entailed legislature and policy measures like the Electric Power Sector Reform (EPSR) Act of 2005 (which unbundled the national power authority and incorporated decentralized public and private sector participation), the National Renewable Energy and Energy Efficiency Policy (2015), the Climate Change Act (2021), the Energy Transition Plan (ETP) (2022), and the Nigeria Sustainable Energy for All Action Agenda (NigeriaSE4ALL) [9, 19, 23, 24]. The Electricity Act (2023) repealed the EPSR Act (2005) and, amongst other things, expanded the powers of the States beyond merely interfering in the areas not covered by the national grid system. The States were granted constitutional powers to establish state electric power authorities, create state electricity markets with full policy and regulatory powers in their areas of jurisdiction, and generate, transmit, and distribute power [9, 19, 23, 24].

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The limited timespan on executive authority in electric power development matters notwithstanding, the Southwest States and their regional development agency have been focused on integrating their individual energy policy and management measures and amalgamating and expanding the scope of distinct power infrastructure development initiatives. Regional energy policy considerations include attaining 50,000 MW of new power generation and US$ 100 billion in investments over the next decade and a half, encouraging dispersed power generation, and promoting significant devolved public and private sector investments in strategic energy infrastructure such as the liquefied petroleum gas (LPG)-based off-grid independent power system [8, 9, 10, 11, 25, 26]. LPG utilization for power generation is premised on it being a cost-effective, low-emissions alternative to polluting fossil fuel plants in off-grid situations [27]. Furthermore, LPG (made up of propane or butane) is easy to transport (as it is stored under pressure as a liquid), has a higher heating value, contains less sulfur (making it greener than other sources of energy like oil), burns consistently (making it more reliable than other energy forms), and is more environmentally friendly than other energy sources (LPG releases only 81% of the carbon dioxide that oil does) [27].

Despite the electric power sector restructuring efforts, policy measures to advance and deploy innovative distributed power technologies like the LPG-to-power system in the Southwest region's electricity market have been ineffectual [7, 25, 26]. The generation and supply of clean and affordable alternative LPG -based power as a mechanism for socio-economic advancement has had very limited success. These limitations have been attributed to ineffectual techno-economic assessments of the strategic LPG-to-power infrastructure initiative which is vital to its planning and development. Consequently, this study provided a viable assessment for the development of a proposed 25 MW off-grid LPG power plant for integration into Southwestern Nigeria's energy mix. Specific objectives were to determine the technological specifications for the proposed LPG power plant, assess its techno-economic viability, and analyze the possible technological, financial, and environmental advantages that may arise from its use as a strategic model for the region in particular and Nigeria in general.

2.0 Materials and Methods

Project investment decision-making is dependent on a robust project economic analysis. This study thus employed an energy planning and technology foresight analysis framework for a robust project investment analysis. Technology Foresight Analysis is a systematic, participatory process using collective intelligence for informed decision-making in exploring and shaping a strategic future for an organisation or society [28]. It is most suitable for planning a desired energy future in a region. The TFA methods are Quantitative (benchmarking, modeling-simulation, extrapolation etc.), Semi-quantitative (road mapping, gaming-simulation, Delphi Technique, strategic assessment, etc.), and Qualitative (backcasting, genius-forecasting, expert panels, SWOT scanning, etc.) [28]. These methods can be used independently or in combination.

2.1 Location of study area

According to the DAWN Commission [8] almost 22 percent of Nigeria's total population lives in the Southwest Geopolitical Zone, which is one of the country's six geopolitical zones. It is made up of six states: Lagos, Ogun, Oyo, Osun, Ondo, and Ekiti. Together, these states span 77,818 square kilometers of land. The zone extends along the Atlantic coast from the Benin Republic in the west to the South-South geopolitical zone in the east and the North-Central geographical zone in the north. According to Ajala [29], the Southwest is culturally part of Yorubaland, with the Yoruba ethnic group occupying the majority of the region.

The Southwest Geopolitical Zone contributes significantly to the Nigerian economy, with major activities in agriculture, education, banking, media & advertising, telecommunication, commerce, energy (power, oil & gas), manufacturing, and transportation. The Southwest has the most developed infrastructure in Nigeria and one of the country's most viable assets – the ports. Tin Can Island Port and the Lagos Ports Complex are the gateways to

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commerce in Nigeria. The industrial capacity of Southwest Nigeria is greater than that of the rest of Nigeria combined, and the region has enormous potential to generate electric power for development with the Papalanto, Olorunsogo 1 & 2, Egbin, and Omotosho 1&2 power stations. The region's Gross Domestic Product (GDP) is approximated to be US$ 235.4 billion (about 46.7% of national GDP), and Southwest Nigeria would be Africa's third largest economy were it to be a separate country [8, 30, 31].

According to the Dawn Commission [8] and LASG [32], Southwest Nigeria's major urban areas are Ibadan, Oyo State, and the Lagos Metropolitan Area. Other large cities in the zone include Ogbomoso (in Oyo State), Ikorodu (in Lagos State), Akure (in Ondo State), Abeokuta (in Ogun State), Ado Ekiti (in Ekiti State), Osogbo and Ilesha (in Osun State). The central industrial and economic axis in the area is the Lagos-Ibadan Corridor, and because of its rapidly expanding population, built-up areas and recently constructed residential complexes have proliferated. Lagos State is the most populated state in Nigeria, home to 21 million people, while having the smallest total size (3,577 sq. km). With about 30% of the country's GDP, 90% of its international trade, and 70% of all industrial investments, Lagos State is widely regarded as Nigeria's economic powerhouse [8, 32]. The conurbation, known as the Lagos Metropolitan Area, or the megacity region, accounts for 10% of the country's GDP, 85% of the state's population, and roughly 37% of the state's total land area [8, 32]. This megacity area has spread into adjourning Ogun State. The largest and capital city of Oyo State is Ibadan, which has a population of roughly 6 million people. Ibadan is one of the biggest cities in the region and all of Nigeria in terms of geographic size. It is the second most populated city in Southwest Nigeria, behind Lagos. Ibadan's economy, which is the second largest in Southwest Nigeria and the fourth largest in Nigeria, is supported by its proximity to Lagos, which is only 119 km to the northeast (8, 33, 34, 35, 36]. This proximity also helps the city's agricultural and industrial development.

Figure 1: Maps Showing Southwest Nigeria and Nigeria Geopolitical Zones
Source: Bakare [37]

2.2 Liquefied Petroleum Gas (LPG)-to-Electric Power Development

The Liquefied Petroleum Gas (LPG)-to-electric power development entails a distributed generation system that deploys decentralized mini-scale, modular, or renewable energy-based electric generation technologies close to their end users. In contrast to the traditional, centralized power system, the distributed generation power system has lower costs, higher efficiency, and reliability and poses fewer environmental consequences. As depicted in Figure 3, the process entails fuel (LPG) injection into an engine/turbine and generator for electricity production, which may be provided for a grid system or directly into a building or facility. Figure depicts a typical LPG power plant with the LPG tanks in the background and the power plant in the foreground.

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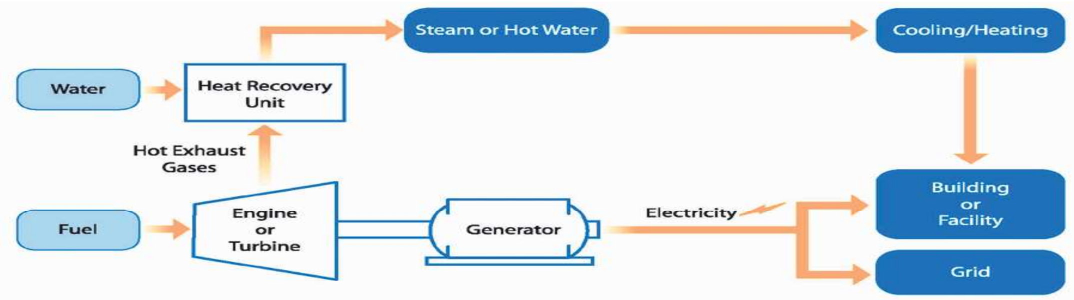

Figure 2: Combustion Turbine with Heat Recovery Unit (A DG LPG-to-Power Process) in the Combined Heat and Power System
Source: EPA [38], Bloomberg [39]

Figure 3: An LPG Power Plant
Source: EPA [38], Bloomberg [39]

2.3 Determination of Technological Specifications for the LPG Power System

To achieve the first specific objective (i.e. the determination of the technological specifications for the proposed LPG-power plant), data on the technical specifications for the power plant were obtained from secondary sources such as manufacturers manuals, equipment vendors, energy/engineering journal articles, estate agents' lists, electricity planning reports and tariff templates from the national electricity regulatory agency [40, 41, 42, 43]. Information obtained included daily uninterrupted electric power supply estimations, the LPG-to-electricity generation ratio, and LPG power plant land area requirements.

A 25 MW-Distributed Generation LPG power plant system was purposively selected for analysis. This is a standard modular electricity generation system [38, 39]. The power plant was estimated to have 60% energy efficiency [44].

2.3.1 Determination of maximum estimated power output for the LPG plant

The maximum estimated power output by the LPG power plant was determined by taking into cognizance the power plant's estimated energy efficiency and the potential power demand projections in Southwestern Nigeria. A slack or unused system productive potential of 1MW was provided for the power system design [40]. The determined power output would be the benchmark for design calculations. Eq, 2.1 presents the equation for the calculation:

$$Estimated\ power\ output = Installed\ Power\ Generation\ (W) - Slack\ (W) \quad \text{...... (Eq. 2.1)}$$

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2.3.2 Determination of total electricity generation

The estimated duration for uninterrupted electricity supply per day is 24 hours in conjunction with global best practices [7, 43]. Electricity generation per day and per annum were determined as the guaranteed electric power supply to the study area (See Eqns 3.2 and 3.3).

$$Electricity\ generation\ per\ day = Power\ (W) \times Time\ (h) = Wh/day \ldots \text{(Eq. 3.2)}$$

$$Electricity\ generation\ per\ annum = Power\ (W) \times Time\ (h) \times 365\ Days = MWh/\ year \ldots \text{(Eq. 3.3)}$$

2.3.3 Determination of the total Liquefied Petroleum Gas (LPG) requirement

The conversion factor for LPG to electricity was determined as 1 kg LPG (Propane) gives 13.6 kWh of electricity [38]. The total LPG requirement for the determined total electricity generation in 2.3.2 was estimated using Eqn 3.4.

$$Total\ LPG\ requirement = \frac{Annual\ electricity\ generation}{13.6\ kWh}\ x\ 1\ kg \ \ldots \text{Eqn 3.4}$$

2.4 Choosing the Site and Acreage for the LPG Power Plant Complex

An industrial plant's location is important in analyzing its viability [43]. The authors note that factors critical to industrial plant location include raw materials accessibility, end-user proximity, availability of labor, infrastructure and finance, and government regulations and policies.

The Lagos – Ibadan Corridor is the major industrial, commercial, and residential axis in Southwest Nigeria with a combined population of 28 million people. New residential complexes springing up in the Corridor are mostly unconnected to the public grid and are the impetus for developing off-grid power systems. A newly developed residential complex at the Ibadan end of the Corridor was purposively selected for this study as a model for the Southwest region.

An average gas power plant requires approximately 0.343 acres per MWe produced (Strata, 2017). The total acreage for the purposively selected 25 MW LPG power station was estimated using Eqn 3.6.

$$Total\ acreage\ requirement = 0.343\ \times Total\ ouput\ of\ Power\ station \ldots \text{Eqn 3.6}$$

2.5 Techno-Economic Analysis of the LPG-to-electric power system

The second specific objective, which entailed assessing the techno-economic viability of the LPG-to-electric power system, required determining the total initial investment (costs for the LPG power complex, building and facilities, transformers and electrical features, land, and cash-in-hand) and the annual operational costs (costs for LPG feedstock, personnel, depreciation, maintenance and repairs, administration, insurance, and taxes, as well as research and analysis). An energy project financial management template detailing the percentage of each cost item relative to the total initial investment and annual operations costs was developed premised on data sources such as technical reports, expert opinion, price lists from estate agents, manufacturers, and equipment vendors, and project financial analysis reports [40, 41, 42, 43]. Engineering economics and project management specialists under the Nigerian Society of Chemical Engineers and the Nigerian Society of Engineers (Obafemi Awolowo University, Ile-Ife, branches) verified this energy project financial management template. Other data obtained included average residential electricity tariffs from the region's electric distribution companies as well as project economic viability specifications for determining levelised costs of LPG-based energy, Present Value (PV),

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Payback Period, and Return on Investment. The techno-economic viability analysis also included determining comparative fuel costs for the LPG-powered and diesel-powered (off-grid) alternative power supply systems.

2.5.1 Determination of the initial investment (fixed capital and cash-in-hand)

i. The power plant cost was determined from the conversion factor detailing average costs for a combined cycle unit at US$ 520/kW [45].
ii. Land costs were determined from conversion factors detailing the cost of commercial land in the selected study area in Ibadan, Oyo State, at $ 2,250.00 per plot of land and 1 acre of land equivalent to 6 plots [46].
iii. The cost estimates for ancillary structures (the buildings and facilities) in the study area were based on the engineering economics and project management experts' advice and determined at 10% of the cost of the LPG power plant.
iv. The cash-in-hand is a form of working capital required to meet current, short-term obligations [47, 48]. Cash-in-hand estimates were assumed at annual operating costs for 1 year premised on the engineering economics and project management experts' advice.

2.5.2 Determination of the annual operating costs

The annual LPG feedstock costs and depreciation were determined by calculation, while other cost items were determined using the financial template discussed in the study methodology (See Table 6 for details).

i. The total annual Liquefied Petroleum Gas (LPG) costs were determined from the unit cost of LPG as obtained from LPG retail outlets in the study area at $ 0.8/kg multiplied by the total estimated LPG requirements as determined in sub-section 2.3.3. This is represented in Eqn 3.5.

$$Total\ LPG\ costs = Total\ LPG\ requirements\ x\ \$\ 0.8/kg \quad \text{…Eqn 3.5}$$

ii. Depreciation was determined using the Straight-Line method [49, 50]. The study assumed that the LPG power plant, administrative buildings, and facilities had a salvage value of 10% of their initial investment premised on the engineering economics and project management experts' advice.

Salvage value = 10% of Initial Investment….Eqn 3.6

$$\text{Annual Depreciation} = \frac{Initial\ Investment - Salvage\ Value}{Number\ of\ Years} \quad \text{…Eqn 3.7}$$

$$\text{Annual Depreciation (\%)} = \frac{Annual\ depreciation}{Initial\ Investment} \text{ X 100\% …Eqn 3.8}$$

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iii. The annual operating costs template as developed for this study:

Costs	(%)
Liquefied Petroleum Gas (LPG) 49.9%	49.9
Depreciation (2.1%)	2.1
Operations & Maintenance	41.0
Utilities (Electricity, Water)	3.9
Other costs (insurance, taxes, etc)	3.1
Total Operating Costs (Annual)	*100*

2.5.3 *Determination of levelized cost of LPG-based electricity*

The levelized cost of LPG-based Electricity (LCOLE) is a suitable tool for policymakers and investors to assess the economic viability of energy projects. It represents the minimum average revenue per unit of LPG-based electricity generated that would be required to recover the average costs of producing a unit of electricity during an LPG-power-generating plant's assumed financial life and duty cycle [43, 49, 50]

$$\text{Levelized Cost of LPG-based Electricity} = \frac{sum\ of\ costs\ over\ lifetime}{sum\ of\ electricity\ produced\ over\ lifetime}$$ ….Eqn 3.9

OR

$$\text{Levelized Cost of LPG-based Electricity} = \frac{Initial\ investment + Lifetime\ Operations\ costs}{electricity\ produced/year\ x\ Project\ lifespan}$$ … Eqn 3.10

The study assumed that the value of the annual operating costs would be the same over the 25-year project lifespan and be equal to the first-year costs [43, 49, 50. Eqn 3.9 details the total value of operating

$$Total\ value\ of\ operating\ costs\ over\ project\ lifespan = 25\ years\ \times First\ year\ costs$$ …Eqn 3.11

The Present value of a future sum of money is determined by discounting it at some chosen compound interest rate [43, 49, 50]. The equation is:

$$Present\ Value\ (PV) = F(P/F\ , I, N)$$ …Eqn 3.12

Where F is the future cash flow, and (P/F, I, N) is the discounting factor that is multiplied by the future cash flow to discount it to the present value (Sullivan et al., 2000). The number of years (N) was determined as one year, and the Interest Rate (I) is 20% (Loan interest rate obtained from the Central Bank of Nigeria (CBN) as of September 13, 2023)

2.5.4 Determination of the estimated minimum annual revenue for the power project

To justify its establishment, the LPG-based Electric Power Initiative would need to generate, each year over time, revenues equivalent to the first year's revenue [43, 49, 50]. The appropriate equation is provided in Eqn 3.13.

$$Estimated\ minimum\ annual\ revenue = Electricity\ produced\ per\ year\ X\ Price\ per\ unit$$ …Eqn. 3. 13

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2.5.5 Determination of Payback Period and Return on Investment for the LPG Power Plant

i. The Payback Period is the amount of time required to recover the cost of an investment. Shorter payback periods infer more attractive investments. Knowledge of the payback period enables businesses to understand when their investments will become profitable and is thus used for risk assessment and as a planning tool [49, 50].

$$Payback\ Period = \frac{Initial\ Investment}{Annualized\ expected\ cash\ inflow} \quad \text{………………………Eqn. 3.14}$$

ii. The Return on Investment (ROI) is a performance measure used to evaluate the profitability or efficiency of an investment. The ROI is also used risk assessment and as a planning tool [49, 50]

$$Annual\ Return\ on\ Investment\ (ROI) = \frac{Annual\ Net\ Profit}{Initial\ Investment} \text{ X } 100 \quad \text{……………Eqn. 3.15}$$

2.5.6 Viability analysis of the LPG-based electric power system scenarios

Extant average electricity residential tariffs in Southwestern Nigeria are $ 0.06 per kWh for the 12-16 hr tariff regime. However, this tariff regime has tariff projections for $1.00 per kWh by December 2023. The Premium Power Initiative (PPI) or 'Willing Buyer, Willing Seller' policy plan in the region provides for uninterrupted power supply at rates which are approximately 31.25% more than the extant tariff regime. Consequently, PPI rates are projected at ₦200 per kWh under the new price regime.

2.6 Examination of Potential Techno-Economic and Environmental Benefits of the LPG Power System

This specific objective entailed obtaining diesel-to-kWh, diesel-to-CO_2 emission, LPG-to-kWh, LPG-to-CO_2 emission conversion ratios from technical & research reports. The data were used to determine total diesel consumption and CO_2 emissions from alternative off-grid diesel power generation. The environmental advantages of the proposed LPG power system were ascertained by the comparisons of CO_2 emissions from the LPG and diesel power systems. Fuel cost specifications for LPG and diesel power systems were also obtained from fuel retail outlets. These were used to determine the comparative fuel cost savings between the LPG- and diesel-powered (off-grid) alternative power supply systems.

2.6.1 Comparison of carbon dioxide emissions by the LPG-power system with the alternative diesel power system

i. The diesel required by the diesel-based alternative power option to generate the calculated annual electricity consumption was determined using the conversion factor of one litre of diesel produces 10 kW of energy [51].
ii. The carbon dioxide (CO_2) emission by the estimated diesel consumption for electricity generation was determined using the conversion factor of one litre of diesel utilisation for electricity emits 2.68 kg of carbon dioxide (CO_2).
iii. The carbon dioxide (CO_2) emission by the estimated LPG consumption for electricity generation was determined using the conversion factor of one kg of LPG utilisation for electricity emits 2.983 kg of carbon dioxide (CO_2).

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2.6.2 Comparison of estimated annual and lifecycle fuel requirements, CO_2 emissions and fuel cost savings for LPG- and diesel-based electricity generation

i. As shown in Eqn 3.16, the estimated annual and lifecycle electricity generation, fuel requirements, and carbon dioxide emissions for the LPG and diesel-based power systems were used to determine the carbon dioxide emission savings.

$$Carbon\ dioxide\ emission\ savings = carbon\ dioxide\ emissions\ from\ diesel\ system - carbon\ dioxide\ emission\ from\ the\ LPG\ system\ \ldots$$ Eqn. 3. 16

ii. The estimated annual and lifecycle electricity generation, fuel requirements and fuel costs for the LPG and diesel-based power systems were used to determine the fuel cost savings as shown in Eqn 3.17

$$Fuel\ savings = fuel\ costs\ from\ diesel\ system - fuel\ costs\ from\ the\ LPG\ system$$
…………………………..Eqn. 3. 17

2.7 Analytical Tools

The study utilised energy planning and project foresight analysis framework. For section 2.3 (Technological specifications for the LPG Power Plant), analytical tools were used for industrial and energy process calculations. For Section 2.4 (Site and acreage of LPG power system), acreage calculations were used. For Section 2.5 (Techno-economic Analysis), Engineering economic analysis methods entailing the Straight-line method, Present Value analysis, Levelized cost method, Payback Period and Return on Investment analyses, descriptive statistics, and comparative costs analysis were used. For Section 2.6 (Examination of Potential Techno-Economic and Environmental Benefits of the LPG Power System), industrial and energy process calculations and comparative cost analysis were used. The equations are presented in the Materials and Methods sections.

3.0 Results and Discussions

Technological specifications for the 25-MW distributed generation LPG power plant

The LPG power plant template is estimated to have a maximum power outlet of 24 MW. This is because a slack of 1MW was incorporated into the design. The expected annual uninterrupted electricity supply is 210,240 MWh. This significantly improves the extant annual electricity supply to most of Nigeria, estimated at only 78,840 MWh [20, 43]. The estimated annual LPG requirement, at 15,459 tonnes, offers a huge opportunity for the development of the domestic LPG industry in the Southwest region. This amount of LPG is equivalent to the cooking gas needs for LPG 103, 058 households Southwest Nigeria in a year [26]. The total land required to build the LPG plant is estimated at 8.575 acres. An industrial plant of this size would be an industrial pull for many skilled workers. This should bring significant socio-economic advancement to the region in which it is cited [8].

From the perspective of technology foresight, these technological specifications further clarify the planning premises for constructing an LPG power plant in the Southwest geopolitical zone in line with regional energy policy. Each State in the region may provide the necessary land resources for private-sector players to invest in the sector. The total landmass of the Southwest geopolitical zone (47,405,437.7 acres) and its unoccupied or underdeveloped space (About 60% of this landmass) [8] offers ample land for the development of many LPG power stations in the region to achieve universal access to electricity.

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Table 1: Technological Specifications for the 25-MW Distributed Generation LPG Power Plant

Technological Specification	Quantity
Maximum estimated power output	24 MW
Total (uninterrupted) electricity Generation	
Daily:	
Annual:	576 MWh/day
	210,240 MWh/year
Total Annual LPG Requirement	15,458,823.53 kg or 15,459 tonnes
Total Land Requirement	8.575 acres or 52 plots

Techno-economic Analysis of the LPG-Fuelled Power Plant Project

The study determined that the total investment in the project was almost \$39.2 million, comprising capital costs of \$ 14.4 million and cash-in-hand of \$ 24.8 million. Total annual operating costs were estimated at \$24.8 million. Table 2 reveals that the two highest operations expenses were the purchase of the LPG feedstock (\$ 12.4 million) and the operations and maintenance costs (\$ 10.2 million). The reduction in the operations and maintenance costs could, therefore, lead to a decrease in operational costs and, consequently, improve the viability of the power initiative. Measures to reduce operations and maintenance costs of the power initiative are thus advised.

The analysis of these costs revealed that the minimum cost at which the LPG–based electricity could be sold would be \$0.11/kWh. Table 3 clearly shows that the extant and extant Premium tariffs in Southwest Nigeria (\$0.06/kWh and \$0.08kWh, respectively) would make the LPG power plant initiative non-viable. The development of the power initiative would, therefore, depend on subsidy provisions by the States or regional development agency. Even the proposed increase in electricity tariff (to \$ 0.10/kWh) would still not be enough to make the power plant project viable. Once again, a subsidy would be demanded from the State.

Project viability was dependent on a minimum annual revenue of \$26.65 million. In the scenario where the electricity tariff was assumed to increase to \$0.13/kWh, a profit margin of \$0.02/kWh was estimated. In actual terms, this is \$4.2 million dollars on an annual electricity output of 210,240 MWh. If this can be achieved, universal access to electricity would be guaranteed, and the State would be free of providing a subsidy. However, this template needs to take into consideration the purchasing power of the electricity consumers in the region. The payback period of 9 years, three months, and 25 days out of a useful lifespan of 25 years indicates that the project would have acceptable risk. The return on investment of 10.73% also supports this assertion. Therefore, the techno-economic analysis concludes that the project would be viable at the electricity tariff rate of \$0.13 kWh, with an acceptable risk in which the project would pay back its investment in less than ten years.

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Table 2: Techno-Economic Assessment of an LPG-Fuelled Power Plant Project

Costs	**($ Thousand)**
Capital Costs	
25 MW Combined Cycle Unit	13,000.00
Land	117.00
Administrative Building + Facilities	1,300.00
Cash-in-Hand	24,772.79
Total Investment	*39,189.79*
Operations Costs (Annual)	
Liquefied Petroleum Gas (LPG) (Raw Material)	12,367.05
Depreciation	514.80
Operations & Maintenance	10,156.84
Utilities (Electricity, Water)	966.14
Other costs (insurance, taxes)	767.96
Total Operating Costs (Annual)	*24,772.79*
Salvage value of LPG Power Plant	$ 1,430,000
Levelized cost of LPG-based electricity	$ 0.11/kWh
The Estimated Minimum Annual Revenue	$26.654 million
Estimated Annual Revenue from Scenario 4	$ 0.02/kWh
Estimated Annual Profits from Scenario 4	$4.205 million
Payback Period	9.32 years (9 y 3m 25 d)
Return on Investment	10.73%

Comparative estimated annual and lifecycle fuel requirements, CO_2 emissions, and fuel cost savings for LPG- and diesel-based electricity generation

The LPG-based electric power generation was determined to be more environmentally friendly relative to diesel-based power generation. At an estimated annual electricity generation of 210,240 MWh, CO_2 emissions savings were 10.23 metric kilotonnes. Over a 25-year lifecycle and total electricity generation of 5,256 GWh, these emissions savings were estimated at 255.75 metric kilotonnes (See Table 4).

Similarly, the LPG-based electric power generation was determined to have lower fuel costs relative to diesel-based power generation. At an estimated annual electricity generation of 210,240 MWh, fuel cost savings were $5.5 million. Over a 25-year lifecycle and total electricity generation of 5,256 GWh, these fuel cost savings were estimated at $137.58 million (Table 5).

The potential fuel cost savings over the 25 years ($137.58 million) could be used in futures trading as funds for the construction of 3 more LPG power stations. Furthermore, the strategic implication of these emissions and cost savings is that the development of LPG power systems in the Southwest geopolitical zone could eliminate the use of environmentally harmful and financially expensive fossil-fuel-based power generation systems in the region. This would not only improve the air quality in the region, but it could also significantly impact cases of respiratory ailments in the region.

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Table 3: Viability Analysis of the LPG-based Electric Power System Scenarios

Scenario 1	
Levelized Cost of LPG-based Electricity (LCLE) ($/kWh)	0.11
Extant tariffs ($/kWh)	0.06
Profit or Loss	Loss
Viability Status	Not Viable
Scenario 2	
Levelized Cost of LPG-based Electricity (LCLE) ($/kWh)	0.11
Extant Premium Power Initiative (PPI) tariffs ($/kWh)	0.08
Profit or Loss	Loss
Viability Status	Not Viable
Scenario 3	
Levelized Cost of LPG-based Electricity (LCLE) ($/kWh)	0.11
Projected tariffs ($/kWh)	0.10
Profit or Loss	Loss
Viability Status	Not Viable
Scenario 4	
Levelized Cost of LPG-based Electricity (LCLE) ($/kWh)	0.11
Projected Premium Power Initiative (PPI) tariffs ($/kWh)	0.13
Profit or Loss	Profit
Viability Status	Viable

Table 4: Comparative Annual and Lifecycle Fuel Requirements and CO_2 Emissions Estimates for LPG- And Diesel-Based Electricity Generation

Annual Estimates for Fuel Requirements and CO_2 emissions for LPG- and Diesel-based Electricity Generation		
	LPG generation	Diesel generation
Electricity generation (MWh)	210,240	210,240
Fuel requirement	15,458,823.53 kg	21,024,000 Litres
CO_2 emissions (Metric Kilotonnes)	46.11	56.34
CO_2 emissions savings (Metric Kilotonnes)	10.23	
Lifecycle Estimates for Fuel Requirements and CO_2 emissions for LPG- and Diesel-based Electricity Generation		
	LPG generation	Diesel generation
Electricity generation (GWh)	5,256	5,256
Fuel requirement	386,470,588.30 kg	525,600,000 Litres
CO_2 emissions (Metric Kilotonnes)	1,152.75	1,408.50
CO_2 emissions savings (Metric Kilotonnes)	255.75	

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Table 5: Comparative Fuel Costs for LPG- and Diesel-Powered Electric Power Systems

Annual Estimates for LPG vs Diesel-based Electricity Generation		
	LPG generation	Diesel generation
Electricity generation (MWh)	210,240	210,240
Fuel requirement (Million)	15.459 kg	21.024 Litres
Cost of fuel ($ million)	12.367	17.870
Fuel Costs Savings ($ million)	5.503	

Lifecycle Estimates for LPG vs Diesel-based Electricity Generation		
	LPG generation	Diesel generation
Electricity generation (GWh)	5,256	5,256
Fuel requirement (Million)	386.47 kg	525.60 Litres
Cost of fuel ($ million)	309.18	446.76
Fuel Costs Savings ($ million)	137.58	

Cost of diesel = $ 0.85/litre; Cost of LPG = $ 0.80/kg (As at September 2023)

4.0 Conclusion and Recommendation

The study assessed the techno-economic viability of the liquefied petroleum gas (LPG)-powered (off-grid) alternative electricity infrastructure option in Southwestern Nigeria as a mitigation strategy to endemic inadequate grid power supply under the region's integrated electric power programmes. An energy project planning and foresight analysis methodology was used. The study provided information on the technological specifications and economic viability of the proposed LPG power system and determined a 25 MW stand-alone LPG-based CHP power plant would require 8.567 acres of land, consuming approximately 15.459 million kg of Liquefied National Gas (LPG) annually while generating annually 210,240 MWh of electricity. This power plant initiative was considered to have acceptable risk and viability at the minimum tariff of $ 0.11/kWh. It also had considerable CO_2 emissions and cost savings relative to diesel-based power generation. The study recommended that the viability of the power initiative could be improved with reductions in operations costs. The study concluded that the LPG plant initiative was technically feasible, economically viable, environmentally friendly, and suitable for deployment in the study area.

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