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Techno-Economic Assessment of Municipal Natural Gas-Powered (Off Grid) Alternative Electric Power Supply in Lagos State, Nigeria

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Abstract

This study examined the techno-economic viability of natural gas-powered (off-grid) alternative electric-power infrastructure for municipalities in Lagos State, Nigeria, as a strategic model for regional/national power infrastructure development. Techno-economic data were obtained through literature, questionnaire and site inspection. An energy project foresight analysis framework was used. The study determined appropriate power-plant locations at Apapa, Ikeja and Festac-Town Divisions of Lagos State. Technical/economic requirements per power plant included a 15-MW power-plant design over 5.145 acres, annual natural-gas requirements of approximately 160 million scf, and investments of US$ 12.7 – 16.42 million. Profitability Indices include Net Present Value of US$ 5.03 million and 1-year break-even time per location, with payback period of 12 – 20 years. Techno-economic benefits/location/annum were 46,720 MWh of electricity, estimated profits of US$ 0.84 million, and fuel cost savings of US$ 1.87 million. The study concluded that the infrastructure was technically and economically viable, and a suitable template for Nigeria.

Keywords: Natural-gas power plants; Lagos Power Infrastructure; Energy planning; Project foresight analysis; Off-grid electric power systems.

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1.0 Introduction

Energy is a critical basic infrastructure for and fundamental to any nation's socio-economic and technological development; without it, modern life would cease to exist (OECD, 2011; Ogundari *et al.*, 2017). Electricity is a very important and extremely versatile form of energy; it is capable of being generated in many ways and from many different sources, can be easily stored, and can be transmitted almost instantaneously over long distances (Ajayi *et al.*, 2014; Taylor, 2017). Electricity is a major part of modern technology and it provides the necessary light, heat, and mechanical power, for phones, computers, other consumer electronics and domestic appliances (Taylor, 2017; Momodu *et al.*, 2011). Electricity availability makes industrial and commercial activities possible [2], and the electricity access by individuals in any country is one of the most clear and un-distorted indications of that country's energy security status (Sambo, 2008; OECD, 2011; Momodu *et al.*, 2011; Bergasse, 2013). Limiting electricity supply in any nation would restrict socio-economic growth and adversely affect the national quality of life as expressed in increased food production, increased industrial output, adequate shelter, healthcare and other human services, and the provision of adequate and efficient transportation (Jesuleye *et al.*, 2012; Taylor, 2017;). Momodu *et al.* (2011) observed that the countries on the list of largest economies in the world are also on the list of largest electricity producers.

According to the EIA (2020) and WEC (2020) the worldwide distribution of electricity generation by source, as at 2017/2018, was coal/peat/oil shale (38 – 38.5%), natural gas (23%), hydro (15.9 – 19%), nuclear energy (10 – 10.3%), solar PV and wind or non-hydro renewables and wastes (7 – 9%), and oil (3 – 3.3%). Thus, natural gas is the second largest source of world electricity generation. On an individual country basis, natural gas is either the largest source for electric power generation, or as one of the top-four contributors; country examples include the USA (35.2% in 2018), UK (42% in 2016), Germany (11% in 2018), Russia (62% in 2016), and Japan (23% in 2016). EIA (2020) and WEC (2020) further point out the growing global investment in natural gas as an electricity power source.

In Nigeria, natural gas is the leading source of electricity generation accounting for about 80% of the national power generation infrastructure, and consequently contributing significantly to national energy security (PwC (2016); FGN (2018). The Federal Government, in recognizing the huge gas deposits in the country (estimated reserves of 5.2 trillion cubic metres), has long advocated for the increased exploitation of this huge energy potential for power generation to meet the nation's acute energy shortfalls within national development aspirations FGN (2018). Inexplicably Nigeria, in spite of being energy-rich, exhibits a national electric power system in disarray: there are wide and daunting electricity demand and supply gaps, and recurrent power shortcuts[1]. The Residential sector consumes more electricity (59.6% of national electricity consumption) than the productive Industrial and Commercial sectors combined (11.3 and 29.1% respectively) (Ogundari *et al.*, 2017). Inadequate grid power supply is the leading cause for private (off-grid) power generation, mainly from environmentally-harmful petrol/diesel generators (Sambo, 2008; Ogundari *et al.*, 2017; FGN, 2018).

The Lagos State scenario is a reflection of the national malaise (Onochie *et al.*, 2015). 40% of Lagos residents do not have access to the national grid and 80% of residents rely on diesel generators (Atkins Limited, 2014; Ogundari and Otuyemi, 2019). National grid supply to Lagos State is estimated to be only 1000 MW with current power supply deficits amounting to 9,000 – 10,000 MW (Olurode *et al.*, 2018; Arowolo *et al.*, 2019; Africa Energy (2019). This raises strategic concerns as Lagos State is the economic powerhouse of the country, producing almost 65% of the national economy and having a population of 21

[1] The national power infrastructure (made up of 7 Thermal and 3 Hydro generation stations) has estimated total installed, transmission and distribution capacities of 12.5, 5.3, and 7.2 GW respectively. Actual generated, transmitted and distributed electricity were estimated to be 3.9, 3.6 and 3.1 GW respectively. Only 40% of Nigeria is connected to the national grid, average daily power supply is estimated to be four hours, and power supply is at best erratic (Momodu *et al.*, 2011). Problems in the sector have been attributed to institutional management failures, limited technical/technological know-how, insufficient gas supply, lack of energy efficiency and infrastructure maintenance, inadequate regulations, fraud and theft of equipment, gross incompetence of sector operators, poor funding, attacks on energy infrastructure, and low sectoral capacity utilization, amongst others (Ogunleye and Awogbemi, 2010).

million. Lagos State is estimated to require 16,000 – 27,000 MW of new generation capacity by 2030, with $14 – 33 billion energy generation investment required (Atkins Limited, 2014).

Limitations to public power supply in Nigeria in general and Lagos State in particular has been attributed to the Federal Government's sole control of power generation, transmission and distribution prior to electricity sector reforms in the mid-2000s (Ugwuanyi, 2018; Africa Energy, 2019). The Electric Sector Reform Act (2005) opened up opportunities for the decentralised public sector, non-state actors, and the organised private sector to engage meaningfully in critical electric power infrastructural initiatives for regional/national development (Ugwuanyi, 2018; Africa Energy, 2019).

In Lagos State, cognizance has been taken of these reforms and the limitations of the state to solely develop the power infrastructural initiatives needed to achieve domestic energy security. The Lagos State Electric Power Sector Reform Law (2018) was enacted by the State to boost domestic electricity supply through the establishment of an embedded power scheme and the creation of offences for energy theft (Caleb *et al.*, 2018). Private sector inculcation in state-based electric infrastructure and service provision has been actively encouraged premised on the notion that it would provide private capital as well as critical technological capabilities that would deliver better quality public services as well as free public funds for essential socio-economic programmes (African Renewal, 2017; World Bank Group, N. D.; Ogundari and Otuyemi, 2020).

Several sector-specific and alternative power supply options have been considered for Lagos State. In this study the burgeoning Residential sector was targeted consequent to its huge sectoral consumption of electric power supply, while the off-grid natural-gas powered power option was considered as a feasible environmentally-friendly alternate.

1.1 Statement of the Problem

Although the grid-connected gas-power system has been set up in Lagos State to augment electric power generation, the off-grid, mini-system natural-gas power station approach has not been deployed for residential sector utilization. The adoption of the natural gas-powered (off-grid) alternative power option in the Metropolitan Lagos State residential sector is limited by the non-availability of appropriate techno-economic assessments of the strategic option. This techno-economic assessment is an essential, effective planning/evaluation tool for the selection of critical energy infrastructure projects. This study thus provides a viable critical assessment of the natural gas-powered (off grid) alternative power option in Lagos State as a strategic template for interested stakeholders in the State and in Nigeria.

1.2 Objectives of the Study:

The objectives of the study were to:

i. Assess appropriate site locations for the natural gas plants in Lagos State;
ii. Determine the technical specifications and economic viability of the natural gas-powered system; and
iii. Examine the techno-economic and environmental benefits of the system.

1.3 Rationale for the Study

Nigeria's limited capacity to provide affordable, adequate, and environmentally-friendly electric power supply over many years has restricted techno-economic development across the country as a whole and in the economically-critical Lagos State in particular. This limitation is further exacerbated in Lagos State by an exploding population, weakening public infrastructure and services provision, the vagaries of international energy policy and economics, and the realignments of national economic policies. Reforms in the nation's electric power sector over the last 20 years, like the Science, Technology and Innovation (STI) Policy (2012), the National Renewable Energy and Energy Efficiency Policy (NREEEP) and the Electric Sector Reform Act (2005), have created opportunities for the development and deployment of strategic energy infrastructure initiatives to meet domestic electric power demand (FMST, 2012; FMP, 2015). At regional levels, policy initiatives include the Lagos State Embedded Power Programme and the Lagos State Infrastructural Development Initiative. These reform efforts however, are weakened by limited public capabilities to institute and/or maintain the strong institutions, infrastructure, policies and plans required for sustainable electricity supply (FMST, 2012).

The Lagos State's estimated population of 21 million is the largest in Nigeria. The State's urban agglomeration is the largest in Africa by population, and the seventh fastest-growing in the world. Its economy is the largest, most urbanised, most industrialised, and most complex in Nigeria, estimated to be about 65% of Nigeria's economy. These dynamics of technological and socio-economic advancement make it imperative for the State to overhaul its limited domestic power generation and supply capacity, and incorporate new, affordable, and environmentally-friendly electric power sources in the State's energy mix. The Lagos State power and gas sector reforms, the key interventions to correct the structural challenges in the power sector and position the State for 24-hour power supply, have considered the natural gas-to-electricity generation option as an appropriate intervention strategy due to the presence of gas infrastructure in the State. The State's ambitions of developing independent power project (IPP) programmes would enhance the provision of mini, off-grids systems within the national grid structure, and generate new gas-fired power capacity at strategic locations around the state. These natural gas-to-electricity initiatives may provide models for such other initiatives across the country, and their critical assessment may provide strategic intelligence on their development for other stakeholders in Nigeria.

1.4 Lagos State, Nigeria

Lagos State is located on the coast in Southwestern Nigeria with its capital at Ikeja. The State, with the smallest land area in Nigeria at 3,577 sq. km, has the country's largest population at an estimated 21 million people. Lagos State is Nigeria's most economically-viable state, accounting for 65% of national industrial output, 90% of foreign trade flow, and contributing almost 30% to national GDP (MEPB, 2015). With a gross domestic product (GDP) of $136.6 billion, Lagos State is a major financial centre in Africa, and would be Africa's fifth largest economy if it were a country (Oteri and Ayeni, 2016). Lagos State is divided into 5 Administrative Divisions (Ikeja, Lagos, Badagry, Ikorodu and Epe), 20 Local Government Areas (LGAs), and 57 Local Council Development Areas (LCDAs) (MEPB, 2013).

The City of Lagos, which with its adjoining conurbation, is Nigeria's largest urban area, largest city, chief port, and principal economic and cultural centre. Until 1991, the City of Lagos was the capital of Nigeria. The Lagos conurbation, known officially as the Lagos Metropolitan Area (or Metropolitan Lagos or Greater Lagos) is made up of 16 of the State's 20 LGAs, and is one of the fastest growing and most populous urban agglomerations in the world (PwC, 2015). This Metropolitan Area makes up 37% of the State's land area, has about 85% of the State's population, and generates about 10% of national GDP (PwC, 2015). It includes the islands of the former municipality of Lagos (Lagos Island, Ikoyi, and Victoria Island) and the mainland suburbs (e.g. Apapa, Ikeja, and Oshodi) (MEPB, 2013). The Lagos Metro Area has extended beyond Lagos State boundaries into neighbouring Ogun State (comprising Obafemi Owode, Sagamu, Ifo, Ado Oto/Ota, and parts of Ewekoro LGAs), acquiring a megacity status known as the Lagos Greater Metropolitan Area (GMA) (Campbell, 2012; Stiftung and Fabulous Urban, 2018). Not only have these developments strained urban planning in Lagos State, they have created imperatives for a strategic approach towards critical infrastructure development (Stiftung and Fabulous Urban, 2018; Ogunsanya *et al.*, 2016).

Figure 1: Map of Nigeria showing Lagos State in Red
Source: Lagos State Government (2009)

Figure 2: The 16 LGAs of Metropolitan Lagos
Source: Lagos State Government (2009)

1.5 Lagos State Critical Power Infrastructure Development Initiatives

The Lagos State Development Plan (LSDP) (2012–2025), with its vision to transform Lagos State to an African model megacity and leading business hub by 2025, has four identified pillars of development including sustainable power infrastructure development like integrated power projects and off-grid alternative energy systems (Ogunsanya *et al.*, 2016). The State detailed stable electric power provision as a priority policy area (demonstrated by the facilitation of Independent Power Projects (IPPs)) for enabling and promoting economic activities across the economy (agriculture, agro-industry, industry, commerce, tourism, and telecommunications) and facilitate the delivery of key social services (water, health, education, and communication) (MEPB, 2013). Lagos State is the largest consumer of power in Nigeria (approximately 30% of total national power distribution) with electric power demand estimates of 10,000 MW; albeit national grid power supply fluctuates from 900 – 1200 MW (MEPB, 2013; Ogunbiyi, N.D.; Ventures Africa, 2014, USAID, 2020). Lagos State is estimated to require 15,000 – 27,000 MW of new generation capacity by 2030, with estimated investment of $14 – 83 billion (MEPB, 2013; Ogunbiyi, N.D.; SPARC, 2014; World Bank, 2015; USAID, 2020). Challenges to power supply include obsolete transmission and distribution technology, equipment vandalism and the centralised grid system in the country (Ogunbiyi, N.D.; Ventures Africa, 2014; USAID, 2020).

An integral part of the State's electric power reform activities is the establishment of the Lagos State Embedded Power Programme (EPP) in 2018, with the target of generating 3,000 MW of electricity for the State over three to five years, and ultimately positioning Lagos State for 24-hour power supply and domestic electric power security (Caleb *et al.*, 2018). Other important expected outcomes include enhancing State gas-to-power development, enhancing gas supply to Lagos from 500 to 1.25 billion million standard cubic feet (scf) per day over 3 to 5 years, opening the Lagos gas market to local and international players, and ensuring reduction of State's reliance on gas from the Niger Delta region for economic development (Caleb *et al.*, 2018; USAID, 2020).

1.6 Challenges to sustainable power infrastructure development in Lagos State

The development of sustainable power infrastructure projects in Lagos State has been hampered by many of the same challenges identified to affect electricity generation and distribution problems in Nigeria, but also general infrastructural development in the State in particular and Nigeria in general. Ogundari *et al.* (2017) citing Adegbulugbe and Adenikinju (2011), FMST (2012), and Ajayi (2013) noted that acute electric power generation challenges in Nigeria were attributable to institutional management failures, technical limitations, insufficient gas supply, fraud and theft of equipment, gross incompetence of sector operators, poor funding, non-installation or very poor maintenance of purchased electric power equipment, high prevalence of accidents and incidents at electric power facilities, very low human capabilities for power generation, and low sectoral capacity utilization, amongst others. Ogundari and Otuyemi (2019) listed several challenges to infrastructural development in Lagos State which are pertinent to the electric power sector. Atkins Limited (2014), SPARC (2014), Olurode *et al.* (2018), Ugwuanyi (2018), Stifting and Fabulous Urban (2018), Arowolo *et al.* (2019), and USAID (2020) have also reported challenges to power infrastructure development in Lagos State. These include:

i. conflicts over national, state and private power generation rights under the energy reform era, and high propensity for litigation;
ii. inadequate electric power project planning, design and implementation, including rushed nature of project designing and implementation, high number of project variations and incomplete designs, inefficient and poor service delivery, and the inability to complete projects on time, within cost and to the required quality;
iii. limitations to project financing and financial management;
iv. lack of innovation and the inability to manage energy innovation and technological change;
v. high costs of energy project execution including high construction wastes;
vi. lack of skilled manpower for power infrastructure development; and
vii. poor management of electric power projects, among others.

1.7 Justification for Natural Gas as Electric Power Generation Option in Lagos State, Nigeria

The world's electric power demand is estimated to increase from 25 trillion kWh to 45 trillion kWh from 2018 to 2050. Natural gas-based infrastructure is expected to be the bedrock of power industry supply, generating in excess of 22% of the future power demand (EIA, 2020; WEC, 2020).

Nigeria is considered to be in a vantage position for natural-gas electric power production – the country has the world's 9th largest proven natural gas reserves of 5,475 – 5,627 Billion m^3 (193.35 – 198.72 trillion cubic feet (tcf)) and estimated unproven reserves of about 600 tcf. Given these vast natural gas reserves, it is only natural that natural gas would be integrated into the national energy mix (BP, 2018; Biose, 2019). Currently Nigeria produces about 2.920 tcf of natural gas per year, with 41% exported, 48% used domestically, and 11% flared (BP, 2018; Biose, 2019).

Natural gas deployment in the provision of clean, dependable supply of electricity in Lagos State is premised on a number of factors (CBN, 2015; GIZ, 2015; Orogun, 2015; Occhiali and Falchetta, 2018; Tahir and Sheriff, 2018).

i. cleaner environmental performance of natural-gas usage relative to other fossil fuels (e.g. reducing CO_2 emissions by up to 60% relative to coal, 80% less NOx (Nitrogen Oxide) and virtually no mercury or particulate emissions),
ii. the improved efficiency of natural gas-fired technologies has resulted in a greater volume of electricity per unit of natural gas burned,
iii. the stable and low price of natural gas in the international market has made natural gas readily available for use in power generation,
iv. The reliability of the resource supply thus reducing or eliminating erratic power generation,
v. high energy conversion efficiency when used for power generation in combined cycle gas turbines, and
vi. significant potential to create jobs through development projects.

Furthermore, natural gas power plants feature low capital cost to power ratio, high flexibility, high reliability without complexity, compactness, early commissioning and commercial operation, and fast starting-accelerating and quick shutdown (Economides and Wood, 2009; Oyedepo *et al.*, 2014)

Reforms in the national electric power sector have enabled Independent Power Producers (IPPs), such as the Lagos State-owned 270-301.5 MW AES gas power station, to obtain licenses from government regulators for electricity generation. This power station consists of nine (9) barges (9 x 31.5 MW) mounted frame-6B gas turbines connected to the national grid. The units are situated at the Egbin Thermal Station premise, in Ijede-Ikorodu, Lagos (Oyedepo *et al.*, 2014). This power plant is inadequate to meet the demands of the Metropolitan Lagos market, thus creating the imperative to build new gas power plants, preferably distributed generation or independent electric distribution networks, in the strategic economic area.

1.8 Natural Gas-to-Power Technologies

Natural gas can be used to generate electricity in a variety of ways. These include large, centralized power plants and individual, smaller sized electric generation units, namely Virginia Technology (2007) and NaturalGas.org (2013):

i. Steam Generation Units: the most basic natural-gas-fired electric generation methods which entail burning fossil fuels in a boiler to heat water and produce steam which then turns a turbine to generate electricity. They have fairly low energy efficiency, as only 33 – 35 % of the thermal energy used to generate the steam is converted into electrical energy.

ii. Centralized Gas Turbines/Combustion Engines: These units use hot gases from burning fossil fuels, rather than heated steam, to turn the turbine and generate electricity. These units are used primarily for peak-load demands, as they can be quickly and easily turn them. Their popularity has increased due to advances in technology and the availability of natural gas, although they are still slightly less efficient than large steam-driven power plants.

iii. Combined-Cycle Units: These are natural-gas-fired power plants combining steam unit and gas turbine technologies in a single unit. In combined-cycle plants, apart from the gas turbines generating electricity, the waste heat from the gas-turbine process is used to generate steam like a steam unit, which is then used to generate electricity. Combined-cycle plants efficiently use the heat energy released from natural gas (thermal efficiencies up by 50 – 60 %), and thus are much more efficient than steam units or gas turbines alone

iv. Distributed Generation (DG): this is an approach that deploys individual (decentralized), small-scale electric generation technologies close to the end users they serve. DG technologies may be modular or renewable-energy based, have capacities up to 10 MW, and range from small, low-output, back-up generators to support centralized electric utilities, to larger, independent generators. DG technologies can provide lower-cost, higher-reliability, higher-efficiency, higher-security with fewer environmental consequences electricity relative to the traditional, centralized power utility. DG also enables increased local control over the electricity supply, and reduces transmission electricity losses. Various forms of on-site, natural gas-fired distributed generation include fuel cells, gas-fired reciprocating engines, industrial natural gas-fired turbines, micro-turbines, and Combined Heat and Power (CHP) systems.

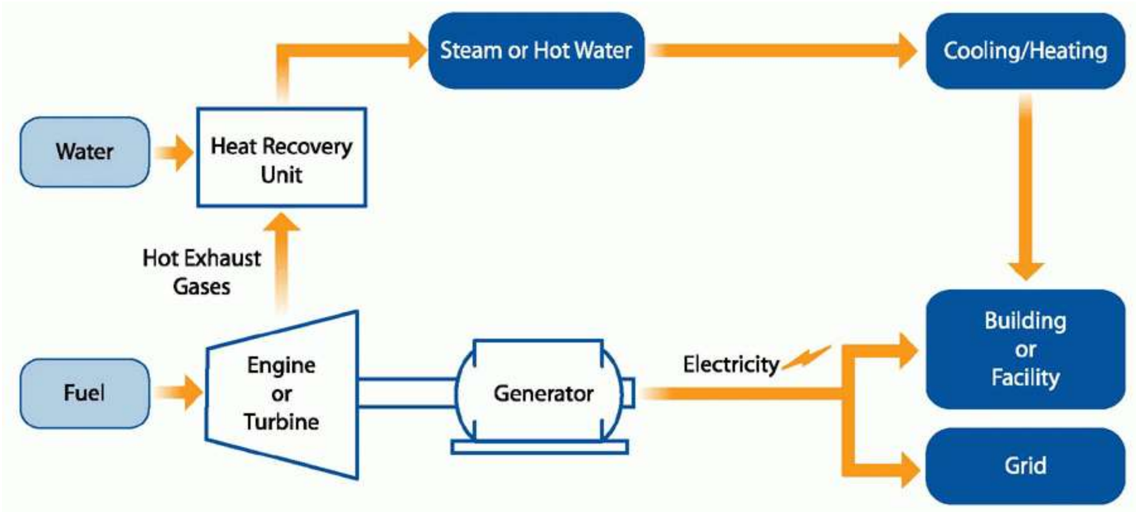

Figure 3: Combined Heat and Power System – Combustion Turbine, or Reciprocating Engine, with Heat Recovery Unit (A DG Natural Gas-to-Power Process)
Source: EPA (N. D.)

2.0 Methodology

The study was carried out across Lagos State, Nigeria, comprising five Divisions, namely Lagos, Ikeja, Badagry, Ikorodu and Epe. Information on the electricity demand and supply projections in, as well as location specifications of each Division was obtained from technical reports of the Lagos State Ministry of Power and personal interviews with policy leaders in the Ministry. This information included the number, types and occupant-characteristics of residential complexes in the Divisions. The technical and economic specifications for the development of the natural gas-powered (off-grid) alternative electric power plants were obtained from manuals and technical reports of manufacturers and equipment vendors; as well as information from energy planners, estate surveyors and literature. A Distributed Generation CHP system with an 8 MW-provision target was purposively selected for analysis. The study utilized an energy project foresight analysis framework.

To achieve objective (i), Plant Location Analysis was carried out to determine three out of the five Divisions in Lagos State as sites for the natural gas-powered (off-grid) plants. Parameters of the plant location analysis include accessibility to raw materials (natural gas), nearness to the market, availability of labour, transport facilities/services, availability of fuel and power, availability of water amongst others. After the determination of appropriate site Divisions, the specific site town in each division was purposively selected.

To achieve objective (ii), a natural-gas (off-grid) electric power system design calculation was conducted. This entailed using the presumed power rating and energy consumption data of the Divisions as input to determining the power consumption demands, natural gas requirements and site area demands. Parameters for the engineering economic assessment of the alternative energy system included initial investment costs – cost of the combined cycle unit, land costs, building costs, transformer and electric features costs and working capital; annual operation costs – natural gas procurement costs, personnel costs, utilities, depreciation, insurance and taxes, maintenance and repairs, administrative costs, research, development and analysis costs; and annual estimated revenues from projected electricity sales. Profitability indices (Net

Present Value, Break-even and Payback Period) were determined using Net Present Value (NPV) and Payback Period methodologies. The techno-economic viability analysis also included determining comparative fuel costs for the natural-gas powered and diesel-powered (off-grid) alternative power supply systems.

To achieve objective (iii), Diesel-to-kWh and diesel-to-CO_2 emission conversion factors were obtained from literature. The data were used to determine total diesel consumption and CO_2 emissions if diesel generator-based off-grid alternative power supply had been employed. The comparison between diesel-to-CO_2 emissions by the natural-gas powered and diesel-powered (off-grid) alternative power supply systems were used to determine the Environmental benefits of the natural-gas powered (off-grid) alternative power supply system.

3.0 Results

The calculations of the study are presented in this section.

3.1 Determination of the Locations for the Municipal Natural-Gas Powered (Off-Grid) Alternative Power Systems in Lagos State

The analysis of plant location parameters (Table 1) indicate that Lagos, Ikeja and Badagry Divisions of Lagos State are the 3 most suitable Divisions for the siting of the natural gas plants in Lagos State. The Lagos Division with ratings of 8.55 out of a possible 10 was ranked 1st, the Ikeja Division (ratings: 8.18) was ranked 2nd while the Badagry Division (ratings: 7.91) was ranked 3rd. The towns Apapa (Lagos Division), Ikeja (Ikeja Division) and Festac Town (Badagry Division) were purposively selected for the large number of residential estates situated in and around them.

Table 1: Plant Location Analysis of Municipal Natural-Gas Powered (Off Grid) Alternative Power Systems Development in Lagos State

	Ikeja (Ikeja)	**Lagos (Apapa)**	**Badagry (Festac Town)**	**Ikorodu (Ikorodu)**	**Epe (Epe)**
Accessibility to raw materials (natural gas)	7	8	7	8	7
Nearness to the market	10	10	10	6	5
Availability of labour	10	10	10	7	6
Transport facilities/services	8	9	7	9	6
Availability of fuel and power	9	9	9	8	6
Availability of water	7	9	6	8	7
Nature of climatic conditions	7	7	7	7	7
Government policies and influences	8	8	7	7	6
Availability of finance	9	9	9	8	7
Availability of Infrastructural facilities	8	8	8	6	5
Disposal of waste	7	7	7	7	6
Weighted Average	8.18	8.55	7.91	7.36	6.18
Location Decision Ranking	2nd	1st	3rd	4th	5th

*(On a Scale of 1 – 10 where 1 is lowest Rate and 10 highest Rate**)**

3.2 Technical and Cost Specifications for the Natural Gas-Powered Stations in the Selected Areas in Lagos State

The purposively selected natural-gas power station for analysis is a Distributed Generation CHP system to provide 8 MW of electricity. This power station is estimated to have 60% energy efficiency.

a. Minimum estimated size for the power station

$$MinimumEstimatedinstalledpowergeneration = \frac{Power(W)}{EnergyEfficiency(\%)} \quad \text{Eq. 4.1}$$

Thus,

$$MinimumEstimatedinstalledpowergeneration = \frac{8MW}{0.6} = 13.3MW$$

Based on this calculated minimum estimated installed power generation (13.3 MW), an appropriate planning design for the natural gas power plant would be 15 MW.

b. Total electricity consumption

The estimated duration for uninterrupted electricity supply per day is 16 hours.

$$Electricityconsumptionperday = Power(W) \times Time(h) = Wh/day \quad \text{Eq. 4.2}$$

Thus,

$$Totalelectricityconsumptionperday = (8MW \times 16hours)/day = 128\,Wh/day$$

$$Annualelectricityconsumption = Power(W) \times Time(h) \quad /day \times 365days = Wh/year$$

$$Annualelectricityconsumption = \frac{8MW \times 16hours}{day} \times 365days = 46{,}720\,MWh/year$$

c. Natural gas requirement:

1 kWh of electricity requires 3.41 cubic feet of Natural Gas (EPA, N. D.)

Thus, Daily electricity consumption would require:

$$1kWhofelectricity \equiv 3.41cubicfeet(cf)ofNaturalGas$$
$$128MWhofelectricity \equiv (128000 \times 3.41)cubicfeet(cf)ofNaturalGas$$
$$128MWhofelectricity \equiv 436{,}480cubicfeet(cf)ofNaturalGas$$

Annual electricity consumption:

$$46{,}720MWhofelelctricity \equiv (436{,}480 \times 365)cubicfeet(cf)ofNaturalGas$$
$$46{,}720MWhofelelctricity \equiv 159{,}315{,}200cubicfeet(cf)ofNaturalGas$$

This is approximately 160,000,000 scf of Natural Gas.

d. Cost of Natural Gas

Natural gas costs US$ 1.76 per 1000 standard cubic feet (scf)

$$AnnualNaturalgascosts = \frac{160{,}000{,}000}{1000} \times 1.76 = US\$281{,}600$$

e. Cost of electricity consumption

Electricity in the study area costs US$ 0.064 per kWh

$$Electricityconsumptioncostsperday = 128{,}000 \times 0.064 = US\$8{,}192$$
$$Annualelectricityconsumptioncosts = 46{,}720{,}000 \times 0.064 = US\$2{,}990{,}080$$

f. Total land area required for the Natural Gas plants

An average natural-gas power plant requires approximately 0.343 acres per MWe produced (Strata, 2017).

For the proposed 15MW Natural-Gas power plant,

$$Totallandrequirements = 0.343 \times 15 = 5.145acres$$

Since 1 acre is approximately 6 plots of land,

$$Totallandrequirements(5.145acres) = 5.145 \times 6 = 30.87 \vee \ 31plotsofland$$

g. Cost of land in the selected areas of Lagos State:

Lagos Division (Apapa)

5820 sq metres (1.438 acres) of industrial land cost US$ 1.41 million

5.145 acres will cost = US$$\left(\frac{1{,}410{,}000}{1.438} X5.145\right) = \ US\$5.05million$

Ikeja Division (Ikeja)

22000 sq metres (5.436 acres) of Industrial land cost US$ 3.08 million

5.145 acres will cost = US$$\left(\frac{3{,}080{,}000}{5.436} X5.145\right) = \ US\$2.92million$

Badagry Division (Festac Town)

15 acres of mixed-purpose land cost to US$ 3.85 million

5.145 acres will cost = $US\$\left(\frac{3{,}850{,}000}{15} X5.145\right) = US\$1.32million$

h. Cost of Distributed Generation CHP system (Combined cycle unit)

Average cost for combine cycle unit = ~ US$ 614/Kw (Strata, 2017)

$$Estimatedcostsfora15MWcombinedcycleunit = 614 \times 15000 = US\$9.21million$$

3.3 Techno-economic analysis of the natural gas-powered (off-grid) alternative power systems in the selected divisions of Lagos State

It is imperative to determine the viability and payback period of the natural gas power supply system project as an input to project investment decision making by critical stakeholders. Table 2 reveals the cost and revenue estimates for the natural gas-powered (off-grid) alternative power systems in the determined areas of Lagos Division (Apapa), Ikeja Division (Ikeja) and Badagry Division (Festac Town).

A. Payback Period Analysis for the natural gas-powered systems

The Payback Period Calculation was used for analysis [57]. The electricity rates for IKEDC and EkEDC[2] are US$ 0.064/kWh.

$$Payback\ Period = \frac{InitialInvestment}{Annualizedexpectedcashinflow} \qquad \text{Eq. 4.3}$$

Thus,

Payback Period for Apapa Station = $\frac{16{,}420{,}000}{838{,}162.94}$ = 19.5 years or Approx. 20 years.

Payback Period for Festac Town Station = $\frac{12{,}690{,}000}{838{,}162.94}$ = 15 years

Payback Period for Ikeja Station = $\frac{14{,}290{,}000}{838{,}162.94}$ = 17 years

[2] IKEDC and EkEDC are the Ikeja and Eko Electricity Distribution Companies respectively. These DISCOs distribute power across Lagos State.

Table 2: Techno-Economic Assessment of the Natural Gas-Powered (Off-Grid) Alternative Power Systems in Selected Divisions of Lagos State

Costs	Lagos Division (Apapa) (US$)	Badagry Division (Festac Town) US$)	Ikeja Division (Ikeja) (US$)
Capital Costs			
15 MW Combined Cycle Unit	9,210,000	9,210,000	9,210,000
Land	5,050,000	1,320,000	2,920,000
Administrative Building	642,000	642,000	642,000
Transformers + electrical features	218,000	218,000	218,000
Working Capital	1,300,000	1,300,000	1,300,000
Total Investment	*16,420,000*	*12,690,000*	*14,290,000*
Operations Costs (Annual)			
Natural Gas (Raw Material)	281,600	281,600	281,600
Personnel	100,300	100,300	100,300
Utilities (Electricity, Water)	89,300	89,300	89,300
Depreciation	400,000	400,000	400,000
Various costs (insurance, taxes)	952,900	952,900	952,900
Maintenance & Repairs	280,000	280,000	280,000
Administrative costs	26,000	26,000	26,000
Research, Development & Analysis	26,200	26,200	26,200
Total Operating Costs (Annual)	*2,156,300*	*2,156,300*	*2,156,300*
Estimated Revenue (Annual)			
Projected Electricity Sales of 46,720 MWh @ US$ 0.064/kWh	2,990,080	2,990,080	2,990,080
Estimated Profit (Annual)	838,162.94	838,162.94	838,162.94
Profitability Index			
Net Present Value (US$)	5,028,977.66	5,028,977.66	5,028,977.66
Break-even time (Years)	1	1	1
Payback Period (Years)	12 – 20	12 – 15	12 – 17

The estimated difference in capital costs is in the various costs of land. Annual operating costs (US$ 2, 156, 300) were estimated for each location. With estimated annual revenues of US$ 2,990,080 per location, the estimated profits US$ 838,162.94 per location. The profitability index showed Net Present Value of US$ 5,028,977.66, break-even time of 1 year, and payback period of 14 years per location. Thus the adoption of natural gas-powered (off-grid) alternative power systems in Lagos (Apapa), Ikeja (Ikeja) and Badagry (Festac Town) Divisions of Lagos State were determined to be viable projects which would break even in 1 year. Payback period for the investments were estimated to be 12 – 20 years for Lagos Division (Apapa), 12 – 15 years for the Badagry Division (Festac Town) and 12 – 17 years for the Ikeka Division (Ikeja). It is important to note that land appreciates over time, thus it is reasonable to deduct the cost of land and the working capital from the estimation of payback period. If this is taken into consideration, the Payback Periods for each Station would be the same as all other capital costs are uniform.

Thus,

$$\text{Payback Period} = \frac{10{,}070{,}000}{838{,}162.94} = 12 \text{ years}$$

Consequently, payback period for the Apapa, Festac Town and Ikeja Stations may be estimated to be in the ranges 12 – 20 years, 12 – 15 years, and 12 – 17 years respectively.

B. Comparative Fuel Costs for the Electric Power Systems
Annual Fuel Costs:
In Each Division, with Annual Electricity Generation of 46,720 MWh
a. Estimated diesel required = 4,672,000 Litres
b. natural gas required = 160,000,000 Scf (approximation)
c. Cost of diesel @US$ 0.46/litre = 4,672,000 x 0.46 = US$ 2,149,120
d. Cost of natural gas @ US$ 0.00176/scf = 160,000,000 x 0.00176 = US$ 281,600
e. Cost differences in fuel supply = US$ (2,149,120 – 281,600) = US$ 1,867,520

Life Cycle Fuel Costs:
(The natural-gas powered off-grid system is estimated to have a 20 year lifespan)
Thus,
In Each Division (Using annual data for consideration):
a. Total electricity generation = 46,720 MWh X 20 = 934,400 MWh
b. Estimated diesel required = 4,672,000 Litres X 20 = 93,440,000 Litres
c. Natural gas required = 160,000,000 scf X 20 = 3,200,000,000 scf
a. Cost of diesel = US$ 2,149,120 X 20 = ₦ 16,819,200,000 US$ 42,982,400
d. Cost of natural gas = US$ 281,600 X 20 = US$ 5,632,000
e. Cost differences in fuel supply = US$ 1,867,520 X 20 = US$ 37,350,400

In each of the Lagos State’s Divisions analysed in this study, with an annual electricity generation of 46,720 MWh, cost differences in fuel supply was estimated to be almost US$ 2 million. This translates to an estimated annual electricity generation of 140,160 MWh across the 3 Divisions, and a cost difference in fuel supply would be slightly more than US$ 5.6 million.

Across the life cycle of the gas-powered electric power plant (20 years), in each Lagos State Division, annual electricity generation was estimated to be 934,400 MWh, and cost differences in fuel supply estimated to be about US$ 37.35 million. This translates to an estimated annual electricity generation of 2,803,200 MWh across the 3 Divisions and a cost difference in fuel supply slightly more than US$ 112.05 million.

4.0 Summary and Conclusion

This study examined the natural gas-powered (off-grid) alternative electric power supply option for municipal residential complexes in Lagos State, Nigeria, as a mitigation strategy to erratic power supply under the State’s embedded power programme and a strategic template for other stakeholders in Nigeria in general and Lagos State in particular. An energy project foresight analysis framework was used. The study established that Lagos (Apapa), Ikeja (Ikeja) and Badagry (Festac Town) Divisions of Lagos State were the most appropriate locations for the gas power plant initiatives in the State. The energy project technical specifications analysis determined an individual natural gas power plant planning design of 15 MW over 5.145 acres of land, with estimated annual electricity provision of 46,720 MWh and annual natural gas requirements of about 160 million scf in each of the established locations in the State. The economic analyses established that each 15 MW combine-cycle natural-gas power plant would cost an estimated US$ 9.21 million. Furthermore, annual gas prices were estimated to be US$ 281,600, annual electricity costs estimated to be US$ 3 million, and estimated land prices of about US$ 5.95 million, US$ 2.92 million, and US$ 1.32 million for Lagos (Apapa), Ikeja (Ikeja) and Badagry (Festac Town) Divisions respectively. For the power plant initiatives, additional the economic analyses established capital costs of an estimated US$ 16.4 million, US$ 12.69 million, and US$ 14.29 million for Lagos (Apapa), Ikeja (Ikeja) and Badagry (Festac Town) Divisions respectively; estimated annual operations costs of US$ 2.16 million, estimated annual revenues from electricity sales of US$ 2.99 million, and estimated annual profits of US$ 0.84 million per location. Profitability Indices indicated Net Present Value of US$ 5.03 million and break-even time of 1 year per location, and payback period ranges of 12 – 20 years across locations. Annual fuel cost differences across the 3 Divisions were estimated to be slightly more than US$ 5.6 million and US$ 112.05 million over the lifecycle of the natural gas plant system.

From the results, it can be concluded that the municipal natural gas-powered (off-grid) alternative electric power initiative for Lagos State electric power supply is technically feasible and economically viable, and suitable to be deployed as a strategic template for other stakeholders in Nigeria in general and Lagos State in particular.

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