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Project Planning Analysis for Off-grid Municipal Water Desalination Critical Infrastructure Project Development in Metropolitan Lagos, Nigeria

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Abstract

This chapter examines the project planning specifications for an off-grid water desalination critical infrastructure project in Metropolitan Lagos, Nigeria taking into cognisance the State's critical infrastructure planning limitations. Technological, financial and socio-economic data for the water desalination project were obtained and the Technology Foresight Analysis (TFA) methodology was used for analysis. The results determined a 100 million litres a day (MLD) water desalination plant design requiring an initial investment of N 70.82 billion. Estimated levelized cost of desalinated water was N 0.89 per Litre of water. With an assumed retail price of N 1.00 per Litre of water, annual revenue and profits were estimated at N 24.13 and 3.638 billion respectively. Profitability indices showed Net Present Values of N 16.15 billion, break-even time of 1 year, payback period of 13 to 20 years, and Return on Investment of 122.8% over the 25-year life span of the project. Socio-economic benefits were determined to be a regular supply of desalinated water provided at a quarter of the extant price charged by water vendors supplying the area and having a daily cost savings of N 100.56 – 201.12 million (N 36.72 – 73.42 billion annually). The study concluded that an off-grid water desalination infrastructure project for the area would be technically feasible, economically viable, and socio-economically worthwhile, and recommended same as adequate and appropriate to be deployed as a strategic municipal water supply alternative for Metropolitan Lagos, Nigeria.

Keywords: *Desalinated water, Critical infrastructure; Technology foresight analysis (TFA); Project planning and management; Metropolitan Lagos; Nigeria*

1.0. Background to the Study

It is imperative for a modern State to provide the critical infrastructure essential for the effective functioning of their societies and economies, and one such critical infrastructure is the water supply system (Ait-Kadi, 2016; Adeniran *et al.*, 2021). Water is an important natural resource for human existence, and it is essential for every industrial and natural process (Fletcher *et al*., 2017). The water industry provides drinking water and waste water services to the industrial, commercial and residential sectors of the economy. The operations of the water industry in modern states are usually executed by public utilities which are subject to public control and regulation (Vanbriesen *et al*., 2013; OECD, 2021). The water supply system typically includes water sources, collection location, purification facilities, storage facilities, pumping stations, distributions systems, and municipal disposal systems (Sultana and Sultana, 2019). Developed countries tend to exhibit advanced water supply systems, and in these countries, it is normal to open a tap and get drinkable (or potable) water on demand (National Academies of Sciences, Engineering, and Medicine, 2006). Many developing countries however lack potable water as their governments are deficient in the capacity to develop water treatment or distribution systems (Akpor and Muchie, 2011; Naik, 2016). Potable water supply is therefore a major challenge, and developing-country water supply systems face problems of technical inefficiencies, limited funding, population increase, water scarcity, environmental pollution, and non-existence of basic modern water supply infrastructure (Balogun *et al.*, 2017; Ngene, 2021).

In Nigeria, the responsibility of water supply is shared between the three tiers of government – the Federal Government takes responsibility for water resource management, the State Governments are primarily responsible for municipal water supply, while the local governments take charge of rural water supply (Federal Republic of Nigeria, 2004; FMST, 2011; Federal Ministry of Water Resources, 2016). Public water provision is however beset with a myriad of technical and economic challenges. In 2019, approximately 60 million people (about 30% of Nigeria's estimated population of 200 million) were living without access to basic drinking water, and majority of the population relied on informal water sources comprising of wells, rivers and rainwater (Adeniran *et al.*, 2021; World Bank, 2021a). Some of the reasons for the water limitations include inadequate water supply policy, limited public capabilities to plan and implement water supply operations, poor infrastructure investment and maintenance, deficiencies in pipe distribution networks, and inadequate power supply (Aderogba, 2014; Ohwo, 2016; Adeniran *et al.*, 2021; World Bank, 2021b).

In Lagos State, access to formal clean water is abysmally low, and the State has found it difficult to meet the millennium development goal (MDG) on water (Balogun *et al.*, 2017; Danert and Healy, 2021, World Bank, 2021a). In the State, daily demand for potable water is estimated to be 540 million gallons, while public water supply is only 210 million gallons (or 38.9% of demand), creating a daily shortfall of about 330 million gallons (Momoh, 2019; World Bank, 2021a). It is also estimated that only 35% of the urbanite population is provided public water supply with the other 65% left to fend for themselves in any way possible, most especially via private wells, boreholes, protected springs, rainwater collections and water vendors (Balogun *et al.*, 2017; Danert and Healy, 2021; World Bank, 2021a). The Lagos State public water supply network is dependent on 3 major waterworks (Iju, Ishasu and Adiyan waterworks, constructed in 1910, 1976 and 1991 respectively), 27 mini-waterworks, and 10 micro-waterworks with a combined production capacity of 240 million of gallons per day (MGD) (Balogun *et al.*, 2017; Ayeni *et al.*, N. D.; Lagos State Water Corporation, N. D). The limited public water distributed (210 MGD) is plagued by loss due to pipeline leakages, illegal connections, and excessive water use (Ohwo, 2016; Balogun *et al.*, 2017; Danert and Healy, 2021; World Bank, 2021). Furthermore, there are heightened concerns on the quality assurance of the public water supplied, even at times exceeding the quantity concerns (Oteri and Ayeni, 2016; Ayeni *et al.*, N. D.).

Although much of metropolitan Lagos is surrounded by or adjourning water, there are many residential areas in the region where access to potable water is a luxury – such as the urban developments of the Eti-Osa Local Government Area which are highbrow Lagos neighbourhoods housing several recent gated residential developments (Aderogba, 2014; Balogun *et al.*, 2017). The potable water limitations in the area have been attributed to its geography and the inadequacies of the State public water services (World Bank, N. D.; World Bank, 2019; Balogun *et al.*, 2017). The Lagos State Water Corporation has a very limited water supply network in the Eti-Osa Local Government Area. Consequently, residents in the area have adopted the use of wells and boreholes to meet their water needs (Aderogba, 2014; Balogun *et al.*, 2017; World Bank. 2021a). This strategy has proved inadequate, and the water produced in the area, especially in the Lekki axis, has been shown to be salty and contaminated, thus proving unsuitable for drinking (Aderogba, 2014; Balogun *et al.*, 2017; Danert and Healy, 2021). The costs for digging a deep borehole (250 – 300 metres) to alleviate the water scarcity have been deemed prohibitive at ₦ 8 – 10 million (World Bank, 2021a; 2021b). It has become a norm, therefore for many residents to use the services of water vendors for their domestic water needs, notwithstanding the resulting punitive costs (Aderogba, 2014; Balogun *et al.*, 2017; Danert and Healy, 2021). A private-public partnership (PPP) may be advocated as a suitable means to address the water supply challenges in the area, and with such a high demand for water in the area, a pre-investment assessment could likely indicate community willingness to pay for water at a reasonable rate (Ogundari and Otuyemi, 2020).

In Lagos State, water supply limitations have been attributed to poor governance and regulatory framework, fragile planning and operations, insufficient funding, inadequate number of waterworks and the poor performance of the existing ones, high pipe leakages, and lack of adequate infrastructure (Aderogba, 2014; Balogun *et al.*, 2017; Danert and Healy, 2021; World Bank, 2021). This situation is further exacerbated by specific dynamics such as exploitation in the polity, climate change, erratic electricity supply, inadequate enforcement of policies and regulations, and water leakages and theft from the public water system (Aderogba, 2014; Balogun *et al.*, 2017; Danert and Healy, 2021). The State's high (and rapid) population growth rate has caused an over-abstraction of water resources, and indiscriminate sinking of wells and boreholes in many parts of the State not covered by the public water supply network (NASEM, 2006; Akpor and Muchie, 2021; Ngene *et al.*, 2021). National and regional efforts to mitigate the disconcerting public water supply system include instituting reforms into the public water sectors at the various governmental levels, and strengthening federal, state and local governments' responsibilities for water provision. Furthermore, encouraging decentralized government tiers, the organized private sector, non-governmental/donor organizations as well as other non-state actors to contribute to the critical technological and investment is necessary to achieve improvements in the water supply system (NASEM, 2006; Ogundari and Otuyemi, 2020; Akpor and Muchie, 2021; Ngene *et al.*, 2021).

These reforms are to institute a water supply program with robust plans and strategies that are vigorous enough to take care of current and future demand, reduce wastes and losses, ensure improved service delivery and enhanced potable water access, and guarantee appropriate investment recouping within a dependable, and secure governance and regulatory framework (Ohwo, 2016; Oteri and Ayeni 2016; Ayeni *et al.*, N. D., OECD, 2021). Specific reform activities in Lagos State over the years include the institution of the Lagos State Water Supply Project (LSWSP) and establishment of the Lagos State Water Regulatory Commission (Lagos State Government, 2017; World Bank, N. D.). The LSWSP aimed to increase access to and improve the efficiency of public water supplies by expanding water supply facilities (the production, transmission and distribution systems), rehabilitating existing systems, and strengthening administrative infrastructure and institutional support systems. The Lagos State Water Regulatory Commission has the role of regulating water supply vendors, issuing licenses for boreholes, and ensuring the provision of safe potable water at reasonable rates throughout the State (LSWC, N. D.; Lagos State Ministry of Economic Planning and Budget, 2013; Balogun *et al.*, 2017). The Lagos Water Supply Master Plan (2011), and other water supply schemes in the State have been initiated to bridge the State's water deficit by 2020 and beyond, and improve water supply through extensive infrastructure development. These water supply infrastructure developments have been supported by regional development banks and other financial institutions (Lagos State Ministry of Economic Planning and Budget, 2013; Ohwo, 2016; Lagos State Government, 2017).

In spite of the various reforms in the water supply system to mitigate the deplorable water supply options in the State generally and the Eti-Osa Local Government Area in particular, evidence shows that the water supply infrastructure is grossly inadequate (Lagos State Ministry of Economic Planning and Budget, 2013; Oteri and Ayeni, 2021). The development of critical water supply infrastructure, and the specific deployment of off-grid water supply technologies by the Lagos State and Local governments on the one hand, and the Organized and unstructured private sector on the other, to ameliorate the State's inadequate water supply in spite of the huge financial and material investments, could have been ineffectual due to the limitations in the capabilities of state agencies and private sector developers to adequately analyse the municipal water demand, and comprehensively plan and deliver an alternative water supply system for successful water project implementation.
In this study, a techno-economic assessment of the water desalination technology option as an innovative off-grid water supply system for Eti-Osa LGA suburban residential complexes was explored as a strategic input to the State water infrastructure development programme using appropriate engineering project management methods for successful delivery (Eti-Osa LGA is the appropriate location consequent to its direct access to seawater). The specific objectives of this study are to assess the water consumption in a selected residential complex; determine the technological specifications for a robust off-grid water supply initiative; and ascertain the techno-economic parameters for the water supply system's installation. The study is significant as it provides strategic information on the technological, economic and socio-economic viability of water desalination infrastructure development for Lagos State in particular and other Nigerian coastal states in general.

1.1. Overview of Lagos State and Eti-Osa Local Government Area

Lagos State is the smallest of Nigeria's 36 states and is situated on the coast in the country's South-west geopolitical zone. The state covers a landmass of about 3,474 km², has 20 local government areas, and an estimated population of 21 million with a strong urban presence. Ikeja is the capital city (Lagos State Ministry of Economic Planning and Budget (LSMEPB), 2015; Lagos State Government, 2018)). Although the Yoruba constitutes the State's principal ethnic group, the State is a socio-cultural melting pot (LSMEPB, 2013, 2015). Lagos State is a major financial centre and the economic hub of Nigeria, accounting for about 65% of the Country's economy and with an estimated Gross Domestic Product (GDP) of US$84 million. The State would be the fifth largest economy in Africa if it were a separate country. Lagos State has the highest Human Development Index in Nigeria (Ogundari and Otuyemi, 2019). Metropolitan Lagos, consisting of 16 of the State's 20 LGAs, is the dominant section of Lagos State, and is located on four principal islands (Lagos Island, Apapa, Victoria Island, and Iddo Island) and important mainland suburbs including Yaba, Surulere, Shomolu, Agege, Mushin, and Ikeja (LSMEPB, 2015).

The LSMEPB (2015) report presents that Eti-Osa Local Government Area (LGA) is one of the five LGAs in the Lagos Division of the State with a population estimated to be 3.11% of the State's population. Eti-Osa is situated on a narrow piece of land that juts out into an area of water, and is bounded by the Lagos Lagoon to the North, and the Atlantic Ocean to the South. Lagos, the former capital of Nigeria, is situated in Eti-Osa and Lagos Island LGAs. Consequent to this, Eti-Osa is home to many large domestic and international businesses. Eti-Osa is made up of several important areas, affluent neighborhoods, and some of the most exclusive and expensive residential areas and wealthiest communities in Lagos State in particular and Nigeria in general, including Victoria Island, Lekki, Ajah, Obalende and Ikoyi (LSMEPB, 2015). Figure 1 depicts Eti-Osa LGA of Lagos State, Nigeria.

Figure 1. Eti-Osa Local Government Area of Lagos State, Nigeria
Source: Lagos State Ministry of Economic Planning and Budget (LSMEPB) (2015)

1.2. The Water Desalination Process

The quest for adequate municipal water supply is not limited to Metropolitan Lagos. Globally rapid population growth has put significant pressure on global freshwater resources, thereby depleting supply, limiting access, and making it imperative for humanity to seek alternative sources of sustainable freshwater supply; of which the earth's oceans are being considered a strategic solution (Fletcher *et al.*, 2017; Sultana and Sultana, 2019). The conversion of seawater to freshwater is a process called desalination (Sydney Desalination Plant, N. D) and several different desalination processes have been developed including distillation, electrodialysis, reverse osmosis, and direct-freeze evaporation (Vanbriesen *et al.*, 2013; Sultana and Sultana, 2019).

In this study, the chosen seawater desalination process is seawater reverse osmosis. This is because it is considered the most economical and efficient method for salt water purification (Sydney Desalination Plant, N. D). Osmosis, is a process by which molecules of a solvent pass through a semipermeable membrane from a less concentrated solution into a more concentrated one until equilibrium is reached (Sultana and Sultana, 2019). Reverse osmosis is when the opposite occurs. That is, by pressurizing the concentrated solution, the flow is forced through the membrane to the less concentrated solution (Sydney Desalination Plant, N. D).

Sydney Desalination Plant (N.D) and Sultana and Sultana (2019) report that the seawater desalination process starts by extracting water from the ocean by using an intake structure located in the ocean (Step 1 of Figure 2). This seawater (a concentrated solution) is pressurized and water molecules are forced from the salty seawater solution through the membrane into the freshwater. The seawater is screened (Step 2) and filtered (Step 3) so as to protect the reverse osmosis membranes from being clogged by solid particles that can be suspended in the seawater. This screening and filtration is done using multimedia filters which are tanks or vessels containing a series of layered granular materials such as anthracite, garnet, sand, pebbles, and/or gravel. The filters remove sand, twigs, seaweed, and other particles from the seawater. The next level of filtration is the cartridge filter which removes even smaller particles from the seawater such as fine sand and clay before the seawater proceeds to the reverse osmosis membranes (Step 4). High pressure pumps increase the seawater pressure up to 1000 psi. The pressure needs to be sufficiently high to overcome the naturally occurring osmotic pressure and force water from the saltwater side through the reverse osmosis membranes to the freshwater side. The salt particles in the seawater are rejected from passing through the membrane to the freshwater side and remain behind on the concentrated saltwater side. The desalted water emerges at low pressure where it is collected in a tube (about 40% of the seawater that enters the system is converted into potable water during the reverse osmosis process). The desalted water further undergoes treatment to drinking water standard in a treatment tank (Step 5) – calcium carbonate is added to improve the taste and bring the pH to the neutral range, and Chlorine is injected to provide disinfection properties. The treated water is finally pumped into the community's drinking water supply, while the concentrated saltwater stream is sent back to the ocean through a brine disposal well (Step 7).

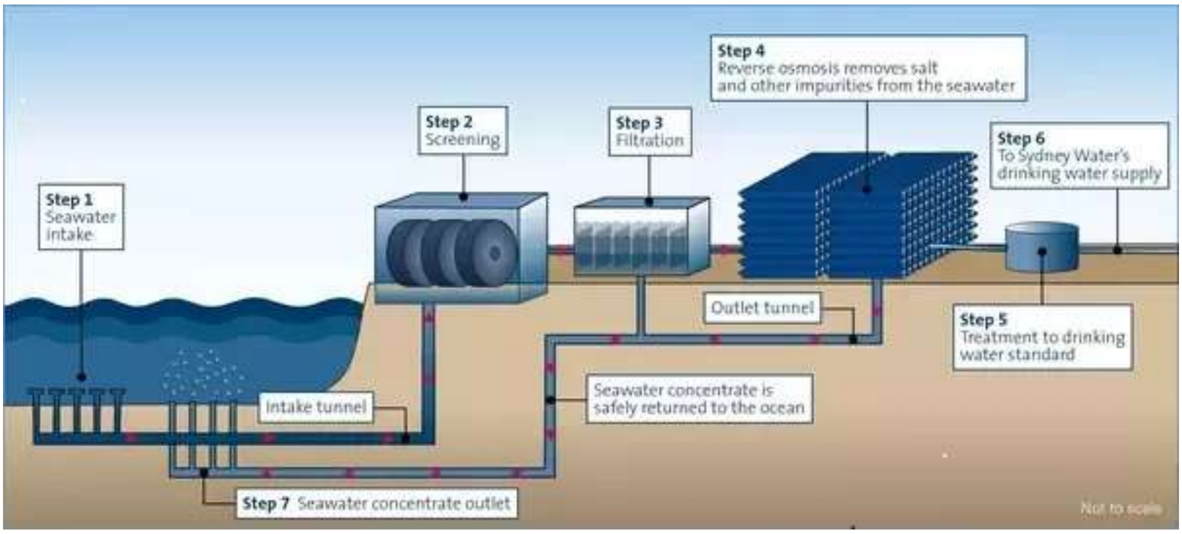

Figure 2: The Reverse Osmosis Process for Saltwater Desalination
Source: quora.com (2020)

2.0. Methodology

This study is a technology strategic analysis investigation premised on a Technology Foresight Analysis (TFA) framework for critical municipal water infrastructure development in a developing economy. Technology foresight is defined as a process that systematically examines the future for intelligence, as well as research and emerging technologies as a critical input for policy setting and strategic planning (Miles, 2010; Gibson *et al.*, 2018). Thus, Technology foresight is a lot more than just the ability to predict the future. It is the process for creating a future desired. Technology Foresight studies provide strategic intelligence for policy makers grappling with complex socio-technical challenges in critical industries such as food and beverages, healthcare, energy and public utilities (power and gas, telecoms, water supply, transport) (Na, 2015; Gibson *et al.*, 2018).

Technology Foresight Analysis (TFA) utilizes Qualitative (Back casting, literature reviews, expert panels, genius forecasting, strategic assessment, etc), Semi-quantitative (road mapping, game-simulation, Delphi Technique, System/Structural analysis etc), and Quantitative (benchmarking, extrapolation, modelling simulation, bibliometric analysis etc) techniques individually or in a multifaceted combination of methods (Yim, 2010; Ogundari and Otuyemi, 2020; Ogundari *et al.*, 2021).

The study entailed the following steps:

i. Determination of estimated water demand in Eti-Osa Local Government Area of Lagos State.
ii. Collection and analysis of data on the technological specifications for the water supply infrastructure (the off-grid water desalination technology option). The technological specifications include the pre-investment parameters for water supply system project management; the project scope, time and cost parameters of the water supply systems; and the socioeconomic benefits of the systems.
iii. Collection and analysis of the economic viability parameters of the water supply infrastructure.

The determination of the potable water demand in the study area, Eti-Osa Local Government Area of Metropolitan Lagos, Nigeria, entailed several steps which include: (i) obtaining average domestic water consumption per day per person from literature; (ii) determining the population of the study area by calculating 3.11% of the extant estimated population of Lagos State; (iii) estimating total domestic water demand per day in the LGA by multiplying (i) and (ii); (iv) estimating total domestic water demand per month and per year in the LGA by using appropriate conversion factors; and (v) determining demand reserves for the water supply infrastructure by assuming 25% excess demand on monthly water use in the first instance plus an addition of one month water demand reserve per year.

Calculating the technical specifications for the off-grid water infrastructure entailed obtaining information on water desalination systems from literature and determining industrial/natural material and energy balances to match the domestic potable water demand (actual water demand use and slack or reservoir system potential) in the LGA. Furthermore, the comparative technical specifications for water supply from existing delivery modes were obtained from equipment vendors.

In analyzing the engineering economic parameters for the water desalination infrastructure installation, project definition information such as time (time of infrastructure installation and lifecycle in years), costs (capital costs, land costs, operations and maintenance costs, energy costs etc, measured in Naira), and technical scope (equipment size and landmass requirements, measured in appropriate dimensions like litres and square metres) were obtained from manufacturers/equipment vendor and estate agents' price lists, project financial analysis reports, and other relevant literature. An engineering project financial management template detailing the percentage of each capital and operational cost item relative to the total capital and operations cost respectively was also utilized from literature (Panneerselvam, 2012; Towler and Sinnott, 2013; PMI, 2013). The costs for administrative building and facilities and the working capital were elicited from a purposively selected private industrial/structural engineering firm based on the engineering project financial management template provided by literature. Furthermore, thirty heads of households in a purposively selected estate in the study area were chosen randomly. The information elicited from them included water usage per household per month and the cost of the water delivered to them.

The data obtained were analysed using different analytical methods including material and energy project foresight/analysis techniques, descriptive statistics and Life Cycle Cost Analysis. Profitability indices (minimum potable water selling price, Net Present Value (NPV), Break-even and Payback Period, and return on investment) were determined using appropriate infrastructure project financial management methods. The techno-economic viability analysis also included determining comparative costs for the traditional water vendor supply option.

3.0. Results

The calculations of the study are presented in this section.

3.1. Technological and Cost Specifications for the Water Desalination Infrastructure in the Eti-Osa Local Government Area of Metropolitan Lagos

This section analyses the project definitions for the water desalination infrastructure project. The TFA methods were Qualitative (Back casting, literature reviews, genius forecasting, strategic assessment), Semi-quantitative (road mapping, system analysis), and Quantitative (benchmarking).

a. **Estimated Population of Eti-Osa Local Government Area**
   The Eti-Osa Local Government Area of Lagos State is estimated to have 3.11% of the State's population (LSMEPB, 2015).
   Thus,
   Estimated population = 3.11% of 21,000,000 = 653,100 people
b. **Estimated domestic water consumption per person per day is 50 to 100 litres (OECD, 2021)**

   Thus,
   Estimated Domestic water demand in Eti-Osa LGA:
   Per day: (50 – 100 litres) * 653,100 persons = 32,655,000 – 65,310,000 litres
   Per week: (32,655,000 – 65,310,000 litres) * 7 days = 228,585,000 – 457,170,000 litres
   Per month: (228,585,000 – 457,170,000 litres) * 4 weeks = 914,340,000 – 1,828,680,000 L
   Per year: (914,340,000– 1,828,680,000 L) * 12 months = 10.97 – 21.94 billion litres

c. **Estimated Water Reserves or Slack (assumed 20% excess monthly water demand plus one-month domestic water demand as standby per year):**

Table 1: Estimated Water Reserves (Slack)

	Estimated water reserves or slack (litres)
20% excess monthly water demand	182,868,000 – 365,736,000
1-month domestic water demand	914,340,000 – 1,828,680,000
TOTAL	**1,097,208,000 – 2,194,416,000**

Water Demand Design Specifications for the Water Desalination Infrastructure:
Estimated water demand per year + estimated water reserves or slack
(10.97 – 21.94 billion litres) + (1,097,208,000 – 2,194,416,000 litres)
= 12.067 – 24.13 billion litres per year (3,017 – 6.033 billion gallons/year)
or 1.01 – 2.01 billion litres per month (251.4 – 502.8 million gallons/ month)
or 33,519,444.44 – 67,040,044.43 litres per day (8.38 – 16.76 million gallons/day)

d. **Input Saltwater Determination:**
   It is estimated that the desalinated water produced would be 40% of total input saltwater (Sultana and Sultana, 2019; Sydney Desalination Plant, N. D). Thus, the production of 33,519,444.44 – 67,040,044.43 litres of desalinated water per day would require input saltwater estimates:

   Lower limits of 33,519,444.44 litres per day:
   33,519,444.44 litres = 0.4 X, where X is the input saltwater

$$X = \frac{33{,}519{,}444.44}{0.4} = 83{,}798{,}611.10 \text{ Litres of saltwater}$$

   Upper limits of 67,040,044.43 litres per day:

67,040,044.43 litres = 0.4 Y, where Y is the input saltwater

$$Y = \frac{67,040,044.43}{0.4} = 167,600,111.10 \text{ Litres of saltwater}$$

e. **Costs of Desalinated Water Production:**

The capital costs for a desalination plant were estimated to be US$ 1.07 to produce 1 Litre of potable water per day (Sultana and Sultana, 2019; Sydney Desalination Plant, N. D). At the exchange rate of US$1 to ₦416.15 (official bank rates as at the time of this study), capital costs for the desalination plant would be:

Upper and lower rates of water demand per day measured in Litres multiplied by the costs
= (33,519,444.44 – 67,040,044.43) * ₦ 416.15 = ₦ 13.95 – 27.90 billion
Thus, estimated capital costs for the desalination plant would range from ₦ 13.95 billion to ₦ 27.90 billion.

The Operations and Maintenance (O&M) costs for a desalinated plant was estimated to be US$ 0.00135 to produce 1 Litre of potable water per day ((Sultana and Sultana, 2019; Sydney Desalination Plant, N. D). At the exchange rate of US$1 to ₦416.15 (official bank rates as at the time of this study), O&M costs would be:
US$ 1≡ ₦416.15
Thus US$ 0.00135 ≡ ₦416.15 * 0.00135 = ₦ 0.56
Thus, O&M costs for the desalinated plant would be ₦ 0.56 for the production of 1 Litre of desalinated water per day.
Total O&M costs per day = (33,519,444.44 – 67,040,044.43) * ₦ 0.56
= ₦ 18.771 – 37.542 million

f. **Energy demand for Water desalination**

The energy demand to produce 1000 gallons of desalinated water was estimated to be 14 kWh of energy (Sultana and Sultana, 2019; Sydney Desalination Plant, N. D). Thus, the production of 1 Litre of desalinated water per day would require:

1000 gallons of desalinated water ≡ 4000 Litres
4000 Litres of desalinated water require 14 kWh of electricity.
1 Litre of desalinated water would require = 0.0035 kWh of electricity
Thus, total electricity demand for the production of 33,519,444.44 Litres to 67,040,044.43 Litres of desalinated water per day is estimated to be:
(33,519,444.44 – 67,040,044.43) * 0.0035 kWh of electricity
= 117,318.06 – 234,640.16 kWh of electricity

Cost of electricity at Eko Electric Distribution Company (EkEDC) rates are ₦ 60 per kWh (grid electricity costs provide the minimum attractive rate for electricity (Salu, 2021), while off-grid natural gas generation promise stable power supply and has levelized cost of electricity comparative to gas-powered grid electricity (Nigerian Economic Summit Group and Heinrich Böll Stiftung Nigeria, 2017)

Thus, the production of 1 Litre of desalinated water per day would cost
₦ 60 * 0.0035 kWh = ₦ 0.21

Estimated costs of electricity for the determined total electricity consumption would be:
117,318.06 – 234,640.16 kWh of electricity * ₦ 60 = ₦ 7.039 – 14.078 million

Thus, total Operations Costs for the desalination plant to produce 1 Litre of desalinated water per day would be:

O&M costs + electricity costs
= ₦ 0.56 + 0.21 = ₦ 0.77

Upper and lower rates of operating costs to produce 1 Litre of desalinated water per day
= (33,519,444.44 – 67,040,044.43) * ₦ 0.77 = ₦ 25,809,972.22 – 51,620,834.21

g. **Total land area required for the water desalination plant**
An average water desalination plant requires approximately 0.15 acres per Million Litres per Day (MLD) produced (Sultana and Sultana, 2019; Sydney Desalination Plant, N. D).

In this study, taking into cognizance rapid population growth in the study area, it was deemed appropriate to adopt the specifications for water desalination plants existing globally. Thus, the 100 MLD water desalination plant specifications were adopted:
For the proposed 100 MLD water desalination plant,
$Total\ land\ requirements = 0.15\ \times 100 = 15\ acres$ (or 90 plots @1 acre ≡ 6 plots of land)

h. **Cost of land in Lekki, Eti-Osa LGA, Lagos State** (Nigeria Property Centre, 2021)
1 acre of industrial land costing ₦ 1.31 billion was found in the area
15 acres (90 plots of land) thus cost = ₦ 1.31 billion X 15 = ₦ 19.65 billion

i. **Cost of the Water Desalination Plant**
Average cost for the water desalination plant is approximately ₦ 445.45/Litre per day (Sultana and Sultana, 2019).
$Estimated\ costs\ for\ a\ 100\ MLD\ plant = ₦\ 445.45\ \times 100{,}000{,}000$ = ₦ 44.55 billion

3.3. Techno-economic analysis of the water desalination system in Lekki, Eti-Osa LGA of Lagos State

This section presents the estimated economic parameters of the water desalination infrastructure project. Specifically, a Table was presented (Table 2) which showed the Investment and operating costs of the project. The determination of the viability and payback period of the water desalination infrastructure project are also critical inputs to project investment decision-making From Table 2, the levelized cost of desalinated water production was estimated to be ₦ 0.89 per Litre. Assuming a retail price of ₦ 1.00 per Litre, the study determined annual revenue and profits to be ₦ 24.13 and 3.638 billion respectively. The study further determined the profitability indices of the water desalination infrastructure project at the assumed retail price of ₦ 1.00 per Litre. The profitability index showed Net Present Value of ₦ 16.15 billion, break-even time of 1 year, and payback period of 13 to 20 years.

3.3.1. Determination of depreciation

The value of the depreciation was assumed to be the same over the project lifespan and be equal to the first year Depreciation. The study assumed that the water desalination plant, administrative buildings and facilities could be sold at a salvage value equal to 10.267% of the initial investment (Ogundari *et al.,* 2021).

Thus, salvage value = 10.267% of Initial Investment
= 10.267% of (₦ 44,550,000,000 + 1,420,000,000)
= 0.10267 * ₦ 45,970,000,000 = ₦ 4,720,000,000

Annual depreciation is thus estimated to be:

Annual Depreciation = $\frac{Initial\ Investment - Salvage\ Value}{Number\ of\ Years} = \frac{45,970,000,000 - 4,720,000,000}{25}$

= ₦ 1,650,000,000

Annual Depreciation (%) = $\frac{Annual\ depreciation}{Initial\ Investment}$ X 100% = $\frac{1,650,000,000}{45,970,000,000}$ X 100% = 3.59%

3.3.2 Levelized Cost of Desalinated Water (LCODW)

The levelized cost of desalinated water (LCODW) represents the average revenue per unit of desalinated water generated that would be required to recover the costs of building and operating a generating plant during an assumed financial life and duty cycle.

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 of ₦ 20,492,000,000.

Total value of operating costs over the 25-year project lifespan = ₦ 20,492,000,000 X 25
= ₦ 512,300,000,000

Present value of operating costs over lifetime = F(P/F, I, N)
Where,

F = ₦ 512,300,000,000
Number of years (N) = 1 year.
Interest Rate (I) = 10% (Commercial loan rate obtained from the CBN as at July 2021)

Thus,
Present value of lifetime operating costs = ₦ 512,300,000,000 (0.9091) = ₦ 465,731,930,000

Levelized Cost of Desalinated Water = $\frac{sum\ of\ costs\ over\ lifetime}{sum\ of\ desalinated\ water\ produced\ over\ lifetime}$

$= \frac{Initial\ investment + Operations\ costs\ over\ lifetime}{24,130,000,000\ x\ 25}$

$= \frac{70,820,000,000 + 465,731,930,000}{24,130,000,000\ x\ 25} = \frac{536,551,930,000}{603,000,000,000}$

Levelized Cost of Desalinated Water = ₦ 0.89 per Litre

3.3.1 Determination of Profitability Indices

Table 2 reveals the techno-economic assessment of the water desalination infrastructure project indicating capital costs and annual operating costs of ₦ 70.82 and 20.49 billion respectively. The Net Present Value over a 25-year lifespan was estimated to be ₦ 16.15 billion, Pay-back period estimated to be 13-20 years, Return of Investment estimated to be 122.8%, and socio-economic savings estimated to be ₦ 100.56 – 201.12 million per day (₦ 36.72 – 73.41 billion per year) indicating the water desalination project would be viable and justified for implementation.

Assuming retail price of desalinated water at ₦ 1.00 per Litre,
Annual revenue = 24.13 billion litres * ₦ 1.00 per Litre = ₦ 24.13 billion
Annual profit = ₦ 24.13 billion – ₦ 20.492 billion = ₦ 3.638 billion

Table 2: Techno-Economic Assessment of the Off-Grid Water Desalination

Infrastructure in Lekki, Eti-Osa LGA of Lagos State

Costs	(₦ million)
Capital Costs	
100 MLD plant	44,550
Land	19,650
Administrative Buildings + facilities	1,420
Working Capital	5,200
Total Investment	***70,820***
Operating Costs (Annual)	
Operations + Maintenance	13,703
Utilities (Electricity)	5,139
Depreciation	1,650
Total Operating Costs (Annual)	***20,492***

A. Net Present Value Analysis for the water desalination infrastructure project

The Net Present Value (NPV) is determined by the net cash flow over the project lifespan (25 years) discounted to the present less the Initial Investment (Blank and Tarquin, 2012; Shah, 2012).
The study assumed that the value of the annual revenues would be the same over the 25-year project lifespan and be equal to the first-year revenues of ₦ 24.13 billion.

NPV = Total revenues – Total costs
= (Total project Annual Revenues discounted to the Present + Salvage Value discounted to the Present) – Sum of costs over lifetime
NPV = ₦ (24,130,000,000*25) (0.9091) + 4,720,000,000 (0.9091) – 536,551,930,000
= ₦ 548,414,575,000 + 4,290,952,000 – 536,551,930,000
= ₦ 552,705,527,000 – 536,551,930,000
= ₦ 16,153,597,000

The Break-even time is the period (in Years) in which the gains from an economic activity equal the costs incurred in pursuing it (Blank and Tarquin, 2012; Shah, 2012). This study shows that the break-even time would occur in the first year of operation.

B. Payback Period Analysis for the water desalination infrastructure project

The Payback Period Calculation was used for analysis (Blank and Tarquin, 2012; Shah, 2012).

$$Payback\ Period = \frac{\textbf{Initial Investment}}{\textbf{Annualized expected cash inflow}} \ldots\ldots\ldots\ldots\ldots\ldots \text{(Eq. 4.3)}$$

$$= \frac{70{,}820{,}000{,}000}{3{,}638{,}000{,}000} = 19.5 \text{ years or Approx. 20 years.}$$

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 Period would be:

$$\text{Payback Period} = \frac{45{,}970{,}000{,}000}{3{,}638{,}000{,}000} = 12.6 \text{ years or Approx. 13 years.}$$

Consequently, payback period for the water desalination infrastructure project was estimated to be in the range of 13 – 20 years.

C. Return on Investment (ROI) Analysis for the water desalination infrastructure project

The Return on Investment (ROI) Calculation was used for analysis (Sullivan *et al.*, 2000; Nagarajan, 2010; Blank and Tarquin, 2012).

Return on Investment (ROI) = $\frac{\textbf{Net Profit}}{\textbf{Cost of Investment}}$ X 100 **……………………………** (Eq. 4.3)

Return on Investment (ROI) = $\frac{86,973,597,000}{70,820,000,000}$ X 100 = 122.8%

This is the ROI over the 25-year period.

Annual ROI would be = $\frac{\mathbf{122.8}}{\mathbf{25}}$ X 100 = 4.91%

3.4. Socio-economic benefits of the desalinated water infrastructure project in Eti-Osa LGA, Lagos State

The socio-economic benefits of the water desalination infrastructure project were analyzed in this section. In Lagos, individuals and households (and in many cases, private enterprises) rely on water vendors or private wells/boreholes for alternative water provision. The pumping of water from private wells/boreholes may require the use of petrol/diesel generators which have environmental and costs consequences (Ogundari *et al*., Forthcoming). The survey of households in the selected estate revealed average water consumption of 2,000 litres per adult at an average price of ₦4 per litre.

Comparatively, calculations on the water desalination infrastructure project showed desalinated water provision at the levelised cost of ₦0.89 per litre or 4.49 times lower than as provided by water vendors. Even at estimated desalinated water provision of ₦1 per litre, the desalinated water scheme would provide water at a price equivalent to one quarter the extant price of the water vendors in the area. Thus, as shown in Figure 3, ₦100.56 – 201.12 million could be saved daily (₦36.72 – 73.42 billion annually) by the Eti-Osa populace by the planning and execution of the off-grid water desalination infrastructure project. Furthermore, the project would guarantee constant desalinated-water supply which would be of strategic relief to the populace.

Table 3: Comparative Costs of Water Consumption: Water Vendor vs Water Desalination Plant

Source of Water	Water Consumption	Cost of Water (₦/Litre)	Total Costs (₦)
Water Vendor	33.52 – 67.04 mil.L/day	4	134.08 – 268.16 mil.
Water desalination plant	33.52 – 67.04 mil.L/day	1	33.52 – 67.04 mil.
Savings		**3**	**100.56 – 201.12 mil.**
Water Vendor	12.24 – 24.47 bil.L/year	4	48.96 – 97.88 bil.
Water desalination plant	12.24 – 24.47 bil.L/year	1	12.24 – 24.47 bil.
Savings		**3**	**36.72 – 73.41 bil.**

4.0. Summary and Conclusion

This study analysed the techno-economics of off-grid water desalination infrastructure development in Eti-Osa Local Government Area of Lagos State, Nigeria as a mitigation strategy to inadequate potable water supply in the LGA in specific and Lagos State in general. A Technology Foresight Analysis framework for critical municipal water infrastructure development comprising planning and strategic analysis methods was used.

This study, being a futures analysis, is subject to uncertainties and factor constraints. Consequently, for a reasonable strategic assessment of the project definitions (time, cost and scope), assumptions were made and project conversion factors obtained from literature. These assumptions and project conversion factors were design constraints, controlling the creation of the plan, project specifications and the prediction of the financial outcome following the plan implementation (Towler and Sinnott, 2013). These design constraints include estimation of the LGA's population, potable water consumption per person per day, estimated water reserve (Slack), estimated total saltwater input, desalination plant capital and operations and maintenance costs, energy demand for desalinated water production, and water desalination plant land requirements,

The study established the upper limits of daily, monthly and annual water demand for the estimated population of 653,100 people in the LGA to be 65.31 million, 1.83 billion, and 21.94 billion litres respectively. The water desalination plant was estimated to have a design capacity of 67.04 billion litres per day, demanding saltwater input of 167.6 billion litres, consuming 234.64 MWh of electricity for production at a cost of ₦14.078 million. Taking into cognizance population growth, the study adopted a 100 MLD water desalination plant design costing ₦44.55 billion, and requiring 15 acres of land costing ₦19.65 billion. Techno-economic considerations determined levelized cost of desalinated water to be ₦0.89 per Litre. With an assumed retail price of ₦1.00 per Litre, annual revenue and profits were estimated at ₦24.13 and 3.638 billion respectively. Profitability indices showed Net Present Values of ₦16.15 billion, break-even time of 1 year, payback period of 13 to 20 years, and Return on Investment over the 25-year life of the project of 122.8%. The study finally determined that the proposed water desalination infrastructure project would provide socio-economic benefits by not only guaranteeing regular supply of desalinated water, this water would be provided at a quarter of the extant price charged by water vendors supplying the area, and with cost savings of ₦100.56 – 201.12 million daily (₦36.72 – 73.42 billion annually).

The study determined techno-economic specifications for desalinated water provision in Eti-Isa LGA of Metropolitan Lagos, Nigeria. The study concluded that an off-grid water desalination infrastructure project for the area would be technically feasible, economically viable, and socio-economically worthwhile. Thus, the off-grid water desalination infrastructure project is adequate and appropriate to be deployed as a strategic municipal water supply alternative for Metropolitan Lagos, Nigeria.

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