Abstract

This study investigates the feasibility, community perception, and implementation potential of bottom-up hybrid solar photovoltaic (PV) microgrids in Esa Community, a peri-urban settlement in Isolo, Lagos, Nigeria. Despite being connected to the national grid, Esa experiences persistent and unreliable electricity supply, compelling residents to rely heavily on petrol-powered generators and rechargeable lamps, with substantial economic and environmental costs. Using a mixed-methods approach—comprising key informant interviews with a royal family member and a solar energy engineer—the research explores socio-technical dynamics, including community governance, affordability, energy behaviors, and technical challenges of solar deployment.

Findings reveal that while energy demand is high, income levels remain low, making affordability a central concern. Nonetheless, residents show strong willingness to adopt solar microgrids if introduced through trusted local institutions such as the palace or community cooperatives. Pay-as-you-go models are preferred over fixed monthly tariffs, as they offer flexibility and reflect actual usage. Technically, challenges like shading, battery degradation, and theft are major risks, particularly in dense, low-income housing types. However, with proper site selection, local technician training, and secure community-based management, these risks can be mitigated.

The study concludes that bottom-up solar microgrids are not only viable but essential for improving energy access in underserved Nigerian communities. It recommends integrating microgrid strategies into Nigeria's national electrification roadmap, investing in local capacity building, and encouraging policy reforms that support decentralized energy solutions. Community trust, affordability, and long-term sustainability must remain at the core of implementation strategies. The insights gathered contribute to the growing body of knowledge on distributed energy transitions in Sub-Saharan Africa and offer practical pathways for replicating successful models in similar socio-economic contexts.

Declaration

I, the undersigned, declare that this report is entirely my own written work, except where otherwise accredited, and that it has not been submitted for a degree or other award to any other university or institution.

Signed,

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Nwaogu, Onyinyechi Anita

Date: _______________

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Foreword

This is where you put the explanation of your own reason for writing the thesis, the basis of your interest in the subject, the purpose of the discussion, special features of organization, limitations on the content or completeness, and acknowledgements of aid.

Glossary of Terms

Abbreviation	Full Form / Definition
AI	Artificial Intelligence
BESS	Battery Energy Storage System
CAPEX	Capital Expenditure
CR	Community Representative
DeFi	Decentralized Finance
DG	Diesel Generator
DRE	Decentralized Renewable Energy
DRES	Decentralized Renewable Energy Systems
ETP	Energy Transition Plan
GHG	Greenhouse Gas
GDP	Gross Domestic Product
GHI	Global Horizontal Irradiance
HOMER	Hybrid Optimization of Multiple Energy Resources
HPP	Hybrid Power Plant
HRES	Hybrid Renewable Energy System
ICT	Information and Communication Technology
IPP	Independent Power Producer
IRR	Internal Rate of Return
ISO	International Standards Organization
kWh	Kilowatt Hour
kWh/m^2	Kilowatt Hour per Square Meter
LCOE	Levelized Cost of Energy
LV	Low Voltage
MW	Megawatt

Abbreviation	Full Form / Definition
MWh	Megawatt Hour
NEP	Nigeria Electrification Project
NERC	Nigerian Electricity Regulatory Commission
NGOs	Non-Governmental Organisations
NPC	Net Present Cost
NPV	Net Present Value
NREL	National Renewable Energy Laboratory (USA)
OPEX	Operational Expenditure
PAYG	Pay-As-You-Go
PESTLE	Political, Economic, Social, Technological, Legal, Environmental
PHCN	Power Holding Company of Nigeria
PV	Photovoltaic
R&D	Research and Development
RFM	Royal Family Member
REA	Rural Electrification Agency
RHMG	Renewable Hybrid Microgrid
ROI	Return on Investment
SERC	State Electricity Regulatory Commission
SE	Solar Engineer
SPP	Simple Payback Period
SDGs	Sustainable Development Goals
SME	Small and Medium Enterprise
SoC	State of Charge (battery)
ToU	Time of Use (tariff model)
TWh	Terawatt Hour
USD	United States Dollar
VAT	Value Added Tax

Abbreviation	Full Form / Definition
VRE	Variable Renewable Energy
WHO	World Health Organisation

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Chapter 1: Introduction

So imagine the world today in which millions of people do not have constant electricity. It is hard to believe but every day people in Nigeria experience power cuts and blackouts practically everywhere in a country of almost 92 million inhabitants [1]. Although the country is endowed with both fossil and green energy powers, the nation remains in a constant struggle with the widespread problem of energy shortage and poor consequences of climate change [2].

Straddled in longitudes 3oE to 15oE and 4oN to 14oN [ON1], Nigeria enjoys tropical weather with ample energy availed to it by solar form of energy in form of extremely high solar radiation of about 5.55 kilowatt-hour per square meter [3] and moderate wind streams of an average between 3.0 to 7.5 meters per second at a height of 10 meters [4]. But even with these positive conditions, power outages are a persistent problem [1], especially in rural locales, whereas energy supply is nothing short of unreliable, in spite of the fact that sufficient renewable sources, such as solar, wind, hydro, and geothermal energy are available [3][4].

Critical statistics indicate that as at 2024, the national power grid had collapsed a dozen times within one year [5]. Being the most populous nation in the African continent, Nigeria is yet to adequately meet the standard requirements of power generation [5] thereby compelling citizens and business outfits to employ the use of petrol and diesel generators [6] immensely. The solution that has long been favored by the government is to implement the national grid expansion with centralized and top-down approaches. What is to say, however, is that this process has been both costly, lengthy, and disjointed, in many instances, with the circumstances facing communities on the ground [7].

Another model is on the rise: decentralized electrification with a solar microgrid and a photovoltaic-battery system [8]. Such systems are flexible, customizable, and scalable so that they address local energy requirements. But the success of these solutions further depends on their financial affordability, the support of people, and the government policy.

1.1 Problem Statement

Millions of people in Nigeria have to do without delivery of regular electricity [1]. In most peri-urban and rural areas, the electricity grid either does not exist or is very poor in quality. Consequentially, the households and businesses have to extensively depend on the use of expensive and emission producing generators to satisfy their power demands [9], [10]. The economic and environmental cost of such dependency is great, as families can easily spend up to 40 percent of the income to keep power generators operational exposing them to air pollution, breathing disease, and contributing to worldwide greenhouse gases, [11], [12]. There are still no evidence-based methods to the implementation of bottom-up energy solutions to challenge these issues at the local level in Nigeria as the country is being increasingly interested in decentralized energy technologies across the world. There are just some few attempts on trying to connect technical modeling with real stakeholder input like, Ndukwe and Iqbal [13] and Ukoima et al. [14] in the natural scenario of Nigeria. The gap in research perspectives this leaves is significant and requires the presence of context-sensitive models corresponding to the local realities. In the absence of these models, it is explained that policy recommendations are no longer related to the realities on the ground, and numerous energy projects are not able to achieve significant results.

Although governmental institutions such as Rural Electrification Agency (REA) have introduced programs in partnership with some business firms [15], a large number of them lack technical and strategic advancement. Others include the absence of true community participation, limited knowhow of local energy requirements and unrealistic pricing structures often interfere with scale-up and sustainability [16], [17]. This research will aim to fill these gaps by investigating the hybrid renewable decentralized system in a semi-urban area in Nigeria. It brings in economic, technical analysis and includes proper investigation of the social aspects such as the social acceptance of the products and their affordability along with the consequences the policy would have on the larger adoption into the country. Besides the technical feasibility, the study points at the necessity to meet the solutions to the energy with the lived realities..

1.2 Research Question

- To systematically address the identified challenges, this research has been structured around a set of focused objectives derived from two core investigative questions. These guiding questions define the scope and analytical framework of the study. The rationale for exploring these questions is as follows:

- To what extent can Nigeria's political, economic, social, technological, legal, and environmental (PESTLE) conditions support the implementation and scaling of locally managed Hybrid Solar PV microgrids as a viable solution to the national energy shortfall between 2025 and 2035?

- Within the context of Isolo, Lagos, what are the projected outcomes of transitioning from generator-dependent homes and small enterprises to a collectively operated hybrid solar microgrid, with regard to power availability, cost efficiency, carbon emissions, and user satisfaction over a ten-year period?

1.3 Aims and Objectives

This thesis aims to demonstrate the viability of a bottom-up approach to addressing Nigeria's electricity deficit through community-owned solar battery microgrids in Isolo over the next decade. The study assesses current electricity access, usage, and reliability in the area; models decentralized energy systems using HOMER Pro based on local solar data, technology costs, and fuel prices; and evaluates financial feasibility using metrics like LCOE and NPV. It also compares carbon emissions between solar systems and diesel generators, explores community attitudes, affordability, and policy knowledge through surveys, identifies adoption barriers, and concludes with policy recommendations to support scalable decentralized energy solutions.

1.4 Scope and Limitations

This study focuses on Esa, an urban area in Lagos, Nigeria, home to both low- and high-income residents. The research is structured around three core components: technical modelling using HOMER Pro, comparative analysis of hybrid solar systems versus diesel generators in terms of cost and environmental impact, and stakeholder engagement through surveys and interviews with residents, business owners, and local authorities. The HOMER Pro simulations use site-specific inputs to assess system performance. While the social research is limited to qualitative data from a single community, it aims to provide valuable insights that can inform localized energy planning and decision-making.

Limitations

One key limitation is the low granularity of field data, particularly demand profiles, due to access restrictions and the reluctance of electricity distribution companies to share real-time consumption data. Accurate population and load figures were also unavailable, requiring approximations. Additionally, findings may not be broadly generalizable across Nigeria due to regional variations in environment, economy, and infrastructure. While HOMER Pro assumptions are methodologically sound, they may not fully capture real-world complexities like maintenance issues or supply chain disruptions. Further uncertainties include exchange rate volatility, technology cost shifts, and limited time for in-depth stakeholder engagement, leading to reliance on secondary cost data.

1.5 Significance of the study

Both academically and practically, the research is of great importance as there is a great gap in the literature, and the proposed research will combine localized and community-based information in data with simulation-oriented optimization in decentralized renewable energy (DRE) planning [18], [19]. This study synthesizes technically-designed, fragmented, and socially-accepted ideas because most of the previous works appear in one of the above areas alone. The results will be applicable to the decentralized electrification in Nigeria, since it will contribute real-world evidence regarding cost-effectiveness, environmental, and stakeholder acceptance. These observations will be crucial to the country, as it seeks to achieve universal energy access by 2030 [20], [21], since they enable the planners and policymakers to factor the bottom-top approaches into the higher scaling of national and statewide energy strategies. The study also helps in this debate on energy justice by pointing to values of inclusivity, affordability and sustainability in system design. By so doing, it helps champion some of the most important Sustainable Development Goals, that is SDG 7 (Affordable and Clean Energy), SDG 11 (Sustainable Cities and Communities) and SDG 13 (Climate Action). In practice, the research presents a replicable model to energy developers and government departments, donor agencies, and in communities of Nigeria and other nations of sub-Saharan Africa, in principle. Scalable and community-based renewables are not just preferable following the rise in energy demands and the growing climate threats and associated fuel prices but vital to energy resilience in the future.

1.6 Dissertation structure

It consists of eight connected chapters that study decentralized renewable energy as a way out of the existing energy access problems in Nigeria. Chapter One defines the national energy crisis, the research problem, the research aims and the research scope. In Chapter Two, the review of the most recent international and domestic literature of decentralized electrification, hybrid solar systems, and policy, finance, and community are given. The mixed-methods of collecting information are described in Chapter Three, consisting of HOMER Pro simulation and other qualitative options such as questionnaires and interviews. Chapter Four provides context of the case study area which is Isolo by looking at demographics of Isolo and energy consumption. Chapter Five outlines technical outcomes, including performance, costs and emissions to the system and Chapter Six discusses perceptions of stakeholders with regard to energy access and decentralized systems. Chapter Seven compiles both technical and social information and brings in correlations to the literature and overall applicability. The final paragraph of Chapter Eight provides some major findings, policy implications, and future results and field trials.

Chapter 2: Literature Review

2.1 Overview

Recent global estimates show that about 750 million people, which is roughly 9 % of the world's population, still lack access to electricity, and nearly 80 % of them live in Sub-Saharan Africa while another 12 % live in South Asia [22]. Nigeria alone accounts for approximately 86.8 million of those unelectrified people, according to the World Health Organisation's (WHO) Tracking SDG 7 energy progress report (2025) [23].

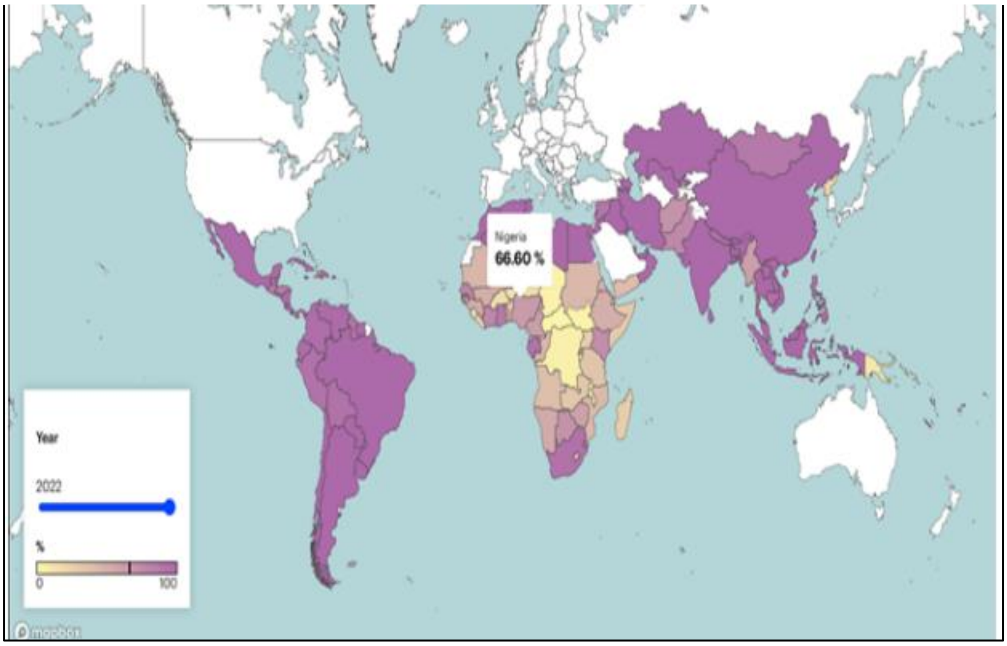


Figure 1: People without access to electricity by country in 2022[22]

Till date, Nigeria's electricity supply remains structurally inadequate [24]. About 90m out of its 230m citizens are left without access to energy[1], [25], [26]., and even electrified areas still experience frequent power outages leading to the use of heavy polluting generators [6], [20]

While official reports suggest an installed capacity exceeding 12,500 MW, actual transmission output rarely surpasses 4,000 MW due to systemic failures in gas delivery infrastructure, poor transmission networks, and decades of underinvestment [24] [19]. This energy deficit hampers socioeconomic development and has prompted exploration of decentralized solutions [9] [27]. In particular, community-scale hybrid solar PV microgrids which are small, localized grids combining solar panels with batteries and/or backup generators are gaining attention as a bottom-up approach to electrification [28], [29], [30], [14], [31]. Such microgrids can operate independent off the national grid, offering reliable and sustainable power to off-grid or underserved communities which align with global calls for clean energy access [32], [33] and Nigeria’s own ambitions to expand renewables. Nigeria in its Renewable Energy and Energy Efficiency Policy (2022) includes a "30:30:30" strategy that seeks to boost power capacity by 30 GW by 2030, with renewable sources accounting for 30% of the country's energy mix[34].

2.2 PESTLE Analysis of Nigeria’s Electricity Sector

Political Factors (NEW)

Nigeria’s energy governance is highly centralised, often dictated by federal ministries and agencies such as the Ministry of Power and the Nigerian Electricity Regulatory Commission (NERC). While political will exists through initiatives like the Energy Transition Plan (ETP, 2022), actual policy implementation is hampered by bureaucratic inefficiencies and frequent changes in leadership [34], [19], [63]. Political instability has historically discouraged foreign investment in infrastructure projects, especially in rural electrification. Corruption and policy inconsistency have further strained investor confidence, leading to delays in project delivery and uneven deployment of mini-grids across regions [43], [65]. In conflict-affected areas, such as the North East, electrification projects are hindered by insecurity and weak institutional capacity, resulting in an uneven energy access landscape [57], [62].

Economic Factors (Reorganise & Expand)

The economic implications of Nigeria’s power deficit are profound. According to the World Bank (2020), unreliable electricity costs the country approximately $28 billion annually, equivalent to 2% of GDP [47]. Businesses spend heavily on self-generation, with Okafor [48] estimating $600 billion in losses over 20 years due to reliance on diesel gensets. The removal of fuel subsidies in 2024 has exacerbated energy poverty, increasing costs for both households and enterprises [50]. Income disparities mean that decentralised solutions, while more sustainable, are often financially inaccessible without donor or government support. Affordability concerns also influence willingness to adopt new technologies and hinder scale-up, especially in peri-urban and rural communities [58], [61].

Social Factors (NEW Section – Extract & Expand Existing Content)

Social acceptance of renewable energy solutions remains relatively low in Nigeria due to lack of awareness, distrust in government-led initiatives, and insufficient community engagement. Public education on solar energy is limited, especially in rural areas where misconceptions about costs, reliability, and maintenance persist [58], [62], [63]. The top-down approach historically neglected local behavioural patterns, leading to mismatched solutions [21], [70]. Gender disparity and low female participation in energy decision-making are also prominent issues. Additionally, communities often lack the technical expertise to maintain decentralized systems, reinforcing dependency on external actors [20], [62]. Trust-building through community-led models and inclusive stakeholder engagement is crucial for long-term adoption and sustainability [76], [77].

Technological Factors

Nigeria's energy sector is marked by significant technological shortcomings, particularly in power generation and distribution. Although the country has over 13 GW of installed generation capacity, actual output rarely exceeds 4 GW due to poor maintenance, inadequate gas infrastructure, and ageing transmission networks [24], [19]. This has led to widespread reliance on small-scale diesel generators, which are inefficient, costly, and polluting. In contrast, decentralized renewable technologies—particularly solar PV microgrids—are gaining traction as a feasible solution for off-grid communities [14], [28], [30]. Technological advancements in battery storage and hybrid systems have improved the reliability of such microgrids, especially in rural or peri-urban settings. However, the expansion of these technologies is limited by high initial costs, lack of technical expertise, and weak grid integration [58], [60]. There is also a gap in local innovation and manufacturing capacity, which increases dependence on imported components and restricts the scalability of clean energy technologies.

Environmental Factors

The environmental impact of Nigeria’s energy practices is increasingly concerning. Widespread use of petrol and diesel generators contributes significantly to air pollution and greenhouse gas emissions, releasing approximately 33 million tonnes of CO_2 annually [52]. These generators not only degrade air quality but also contribute to noise pollution and health issues, particularly in densely populated areas. The associated particulate matter is linked to thousands of premature deaths due to respiratory and cardiovascular diseases [53]. Additionally, improper disposal of generator waste, such as used oil and batteries, contaminates soil and water sources. In contrast, renewable energy sources like solar offer a cleaner, more sustainable alternative with minimal emissions. Nigeria’s Energy Transition Plan aims to increase renewable energy capacity while reducing the country’s carbon footprint [34]. However, achieving these goals will require stronger policy enforcement, greater public awareness, and sustained investment to replace fossil-fuel systems with environmentally friendly technologies.

2.3: Global Best Practices in Decentralized Electrification

Decentralized electrification, especially via community-scale microgrids and solar home systems (SHS), has already been successfully replicated in some developing nations and can provide useful experience for Nigeria's own electrification initiative. Successful implementations in Bangladesh, Kenya, India, and Nepal illustrate how specific policy interventions, creative financing, and local level engagement can reconcile with the constraints of central energy distribution.

Bangladesh is generally considered a world leader in SHS rollout, which was primarily motivated by the Infrastructure Development Company Limited (IDCOL) scheme initiated in 2003. Concessional lending from the World Bank, Asian Development Bank, and bilateral donors complemented the microfinance institutions in-country, enabling IDCOL to deploy more than 4.5 million SHSs, reaching about 20 million people by 2020 [88]. The success of the program relied on its pay-as-you-go (PAYG) approach to making systems accessible to poor households and the creation of a countrywide network of trained installers and maintenance personnel [89]. Most importantly, Bangladesh established strong quality standards for imported solar equipment, thus gaining the confidence of consumers [90]. For Nigeria, this lesson points to a convergence of financing models and quality control systems to facilitate mass rural electrification.

Kenya is also becoming a regional champion of decentralized renewable energy, led by the use of solar mini-grids and off-grid solutions. Kenya's supportive regulatory framework, such as the Energy Act (2019) and tariff guidelines for mini-grids, has stimulated private sector engagement [91]. Businesses like M-KOPA and Powerhive used mobile money platforms like M-Pesa to increase PAYG solar services in rural areas [92]. By 2023, Kenya's off-grid solar industry had penetrated more than 1.5 million homes, and the nation planned to install another 150 mini-grids by 2026 [93]. Kenya's experience can be seen to project that combining mobile payment systems with renewable energy services has the capacity to significantly enhance financial inclusion and lower transaction costs, a strategy that can be emulated in Nigeria considering the acceptance of mobile banking platforms across the country.

India has developed a range of decentralized electrification programs to supplement its national grid extension. The Deendayal Upadhyaya Gram Jyoti Yojana (DDUGJY) and follow-on Saubhagya scheme have united government subsidies with private sector and community-based microgrid projects [94]. In Bihar and Uttar Pradesh states, firms such as Husk Power Systems have rolled out hybrid biomass-solar mini-grids, powering households as well as small businesses [95]. India's strength is developing business models that bring productive applications of energy, such as to power farm processing equipment, that increase economic benefits and local acceptance [96]. For Nigeria, integrating productive-use applications into microgrid design may make systems more affordable, drive local economies, and enhance system resilience.

Nepal has shown progress in ensuring long-term microgrid sustainability through community-based governance. Nepal has helped more than 3,000 micro-hydro and solar mini-grids in rural communities through the Alternative Energy Promotion Centre (AEPC), many of which are controlled by local electricity user committees [97]. These local committees set tariffs, do maintenance, and handle disputes, so they are accountable and owned at the local level. Nepal's strategy emphasizes the significance of capacity-building schemes and participatory planning procedures to ensure that electrification solutions are embedded socially and maintained locally [98]. Nigeria, where widespread distrust of central governments and narrow technical capability impede renewable energy adoption, might find these kinds of community governance arrangements useful as well.

Various cross-cutting lessons for Nigeria can be derived from the experiences in these countries. First, creative financing arrangements like PAYG, microcredit, and performance-based grants are key to surmounting high initial costs [88]–[90], [92]. Second, policy consistency and regulatory clarity are essential to private sector investment attraction, illustrated in Kenya and India [91], [94]. Third, productive energy use integration improves system use rates and economic feasibility and lowers the risk of project failure [95], [96]. Fourth, community ownership and participation are essential for long-term system sustainability, illustrated by Nepal's experience [97], [98]. Lastly, quality assurance structures and post-sale service networks are needed in order to establish user trust and avoid early system failure [89], [90]. For Nigeria, these lessons mean that decentralized electrification must not be viewed as a technical solution in isolation but as a component of an overall socio-economic development plan. Through the integration of lessons in financing, regulation, community engagement, and productive-use integration, Nigeria can make faster gains toward its electrification goals while decreasing reliance on dirty diesel generators.

2.4 Bottom-up electrification theory

Prina et al. [67] indicate that the main paradigms of electrification planning models entail top-down on the one hand as well as the bottom-up paradigm on the other hand. Top-down model: Centralised efforts by the government paved the way to the top-down model, which was usually facilitated by a macro level objective, a ubiquitous planning template and national grid expansions, in contrast to bottom-up model; which focuses on decentralisation, local ownership, and community involvement in designing and undertaking energy systems[18], [68].

2.4.1 Historic Top-Down Approaches to Electrification

Traditionally, in the Nigerian context, top-down has been most common, where grid extension projects have occupied pride of place in federal roadmaps and electrification masterplans, at times civilly without sufficient consultation, and alignment to local energy behaviour patterns [69]. Expressly involving the setting up of major electrical power generation energy infrastructure, for example, hydropower dams and thermogenic plants, this model also encompassed the provision that even the rural and peri-urban populace would get electrical energy sometime in the future as the grid expanded incrementally [70]. This practice can be seen through the creation of the Niger Dams Authority (NDA) in 1960s and the government tried to exploit the hydropower potential of Nigeria in the form of large and centrally constructed dam projects. Although these interventions are intended to respond to the increasing need in electricity supply and to promote economic growth, Ogunleye et al.[21], Jia [50] and Ukoima et al. [14] claim that the said centralised model ignores the context specificities of rural and peri-urban communities especially regarding their socio-cultural situation and potential to pay and prioritisation of energy usage.

In practice, large-scale grid extension plans frequently bypass the poorest and most remote settlements due to high investment costs, rendering millions of Nigerians reliant on self generation or informal electricity networks [72]. Moreover, centralised schemes rarely build sufficient local capacity for operations, maintenance, and governance, key elements for system sustainability and long-term adoption [20]. Another critical shortcoming of historic top-down approaches is their limited adaptability to local environmental and socio-economic conditions. Centralized planning often fails to account for the diverse geographic, climatic, and cultural contexts found across Nigeria, resulting in solutions that are poorly suited to local realities [58] For instance, while Nigeria's tropical location offers substantial potential for renewable energy resources such as solar, hydro, and biomass, centralized grid-based strategies have not effectively leveraged these resources at the community level. Instead, the focus has remained on large-scale infrastructure, which is less responsive to the specific needs and capacities of rural populations. Key to this is the need to have more comprehensive, country-focused analyses of the correct sizing of electricity services to health facilities and in isolated or off grid systems where central grid extension is insufficient to support desirable health facilities which has both a deleterious effect on the health of a population and the well-being of communities is raised by Lammers et al. [73]. This model has been met with disappointments that have largely induced a growing interest in alternative, bottom-up strategies that focus on community participation, use of local resources and decentralized renewable energy options. It is clear that the shift to more participatory and context-focused strategies is now considered a key to the achievement of sustainable and equitable access to energy in Nigeria [60], [74].

2.4.2 Rationale for a Bottom-Up Approach

Bottom-up electrification becomes an attractive alternative due to the consideration of local needs, which promotes energy equity and solution that mirrors the live realities of the target population [75]. The need to adopt such an approach in dealing with the energy crisis in Nigeria can be attributed to the fact that all technical, economic, and social factors involved in this complex situation complicate the success of traditional directly-achieved approaches. The weakness of centralized planning and diesel driven generators can be seen in the continued deficiency in energy provision especially in rural and semi urban societies. This is enabled by awareness gaps and a lack of involvement of the local stakeholders in addition to an overlay of policies that in many cases are distant and do not consider the facts and needs of those experiencing the worst effects of energy poverty [37]. Higher adoption, higher system resilience, and community satisfaction have been reported in the countries where participatory electrification processes have been carried out (e.g., Kenya and Bangladesh) [76], [77]. They are embedded into the local financing arrangements, gender-sensitive outreach, and responsive tariffs based on which they are more affordable and transparent.

In Nigeria, however, participatory frameworks are still underdeveloped, often existing only as pilot initiatives rather than national policy norms. While the REA has introduced mechanisms like Performance based grants and community consultations for mini-grid deployment, the extent of genuine bottom-up engagement remains limited [9], [19]. Consequently, Ugwoke et al. [19] posits that decentralisation efforts sometimes face community resistance, low uptake, or mismatches between system design and user needs. This underscores the critical need for integrated feasibility assessments, such as this study, that combine technical simulation with stakeholder perspectives, thereby contributing to more grounded, inclusive electrification pathways. For instance, the integration of multiple energy sources and technologies, tailored to the specific conditions of a region, requires flexible and adaptive modelling strategies that are best informed by local data and stakeholder input [73], [78].

Benchmarking studies tailored to the Nigerian context are essential for setting realistic goals and policies that reflect both the opportunities and constraints of alternative energy generation [79] The techno-economic feasibility of solar and battery technologies in Nigeria’s humid tropical climate further underscores this need. Variability in solar irradiance, temperature, and humidity can significantly impact system performance and cost effectiveness[80], [81]. Economically oriented strategies that balance supply and demand, while minimizing expenses, are most successful when grounded in site-specific data and community priorities[82]. Social acceptance and the equitable distribution of benefits are also central to the rationale for a bottom-up approach. Community led initiatives are more likely to gain trust and participation, as they align with local values and address specific needs [83]. Mosetlhe [84] indicates that business models that include customer and market needs, rather than imposing external solutions, are more appropriate and sustainable, although it should be noted that certain changes might need to be made in order to suit individual use. Furthermore, decentralized energy systems can enhance transparency and reduce corruption, particularly when supported by innovative financial mechanisms such as tokenized energy markets and decentralized finance (DeFi) platforms [85].

2.5 Techno-Economic Feasibility

2.5.1 Renewable energy potential in Nigeria

Nigeria possesses vast renewable energy resources, including solar, wind, hydro, and biomass, offering a diverse portfolio of options for decentralized power generation [44][ON5]

2.5.2 Solar Resource in Nigeria and The Humid Tropics

Solar irradiance in humid tropical regions such as Nigeria is characterized by high levels of solar energy potential, yet it is also subject to unique site specific challenges that influence the techno-economic feasibility of solar photovoltaic (PV) systems. The country's geographical location ensures substantial solar resource availability, with average annual global horizontal irradiance (GHI) values often exceeding 5 to 6 kWh/m2 in many regions, including the northern and central zones [38], [59], [80]. This abundance of solar energy is a fundamental driver for the deployment of decentralized renewable energy systems, particularly in rural and semi-urban communities where grid access is limited or unreliable [56], [74] .

However, the humid tropical climate introduces complexities that must be addressed in system design and performance assessment [80], [81]. High ambient temperatures, while indicative of strong solar resource, can adversely affect the efficiency of PV modules[80]. The semiconductor properties of solar cells are sensitive to temperature, hence extreme increases in temperature can lead to reduced conversion efficiency, as elevated temperatures increase the intrinsic carrier concentration in the semiconductor, thereby enhancing recombination losses and reducing the open-circuit voltage of the cells [86]. In practice, many locations in Nigeria experience moderate to high temperatures, but some sites maintain conditions that are sufficiently moderate to avoid significant efficiency losses, supporting reliable PV operation. The assessment of solar resource quality in these regions requires detailed analysis of multiple irradiance parameters[87].

2.6 Health Impacts of Diesel Generator Dependence

Diesel generators remain a dominant backup and off-grid electricity source in many developing countries, including Nigeria, due to unreliable grid infrastructure. However, their operation releases a complex mix of air pollutants that have well-documented health consequences. Key emissions include **fine particulate matter ($PM_{2.5}$)**, nitrogen oxides (NOx), and sulfur dioxide (SO_2) [99]. $PM_{2.5}$ refers to airborne particles with a diameter of 2.5 micrometers or less, which can penetrate deep into the respiratory tract and enter the bloodstream, triggering cardiovascular, respiratory, and systemic health issues [100].

Air Pollution Profile of Diesel Generators

The combustion of diesel fuel produces **high concentrations of $PM_{2.5}$** — often exceeding World Health Organization (WHO) ambient air quality guidelines by several folds [101]. NOx emissions contribute to the formation of ground-level ozone and secondary particulate matter, aggravating respiratory illnesses such as asthma and chronic obstructive pulmonary disease (COPD) [102]. SO_2 emissions are linked to respiratory tract irritation, increased hospital admissions, and the exacerbation of cardiovascular disease [103].

In Nigeria, measurements in generator-dense urban areas such as Lagos have shown $PM_{2.5}$ concentrations frequently exceeding 100 $\mu g/m^3$ during peak generator usage, more than four times the WHO daily guideline of 25 $\mu g/m^3$ [104]. Studies have found that small diesel generator clusters, common in residential and commercial neighborhoods, can elevate localized NOx levels by over 200% during outages [105].

WHO-Linked Health Risks

The WHO classifies diesel engine exhaust as a **Group 1 carcinogen** due to its established link to lung cancer [106]. Long-term exposure to $PM_{2.5}$ increases the risk of ischemic heart disease, stroke, and chronic bronchitis [107]. NOx exposure is associated with the development of asthma in children and worsened symptoms in adults with pre-existing respiratory conditions [108]. SO_2 exposure can cause bronchoconstriction, particularly in individuals with asthma, and is correlated with increased emergency room visits for respiratory issues [109].
A study conducted in Port Harcourt, Nigeria, linked generator-related air pollution to increased cases of respiratory infections, particularly in children under five [110]. Similarly, evidence from India and Bangladesh indicates that households relying heavily on diesel generators face higher incidences of respiratory hospitalizations compared to grid-reliant households [111].

Economic Burden of Health Impacts

The health consequences of diesel generator dependence also carry a significant **economic burden**. These include direct medical costs, productivity losses due to illness, and premature mortality costs. A World Bank assessment estimated that air pollution-related health damages in Nigeria cost the economy about **$2.1 billion annually**, with diesel generators being a major contributor [112].

In addition, the economic cost of premature deaths linked to air pollution — measured via the Value of Statistical Life (VSL) is substantial. In urban centers, generator-related pollution contributes to an estimated **10–15% of total air pollution mortality costs** [113]. Household-level expenses also rise due to frequent medical treatment for generator-induced ailments, imposing disproportionate burdens on low-income families [114]. Given these impacts, addressing diesel generator dependence through decentralized renewable energy systems could yield not only environmental but also major public health and economic benefits. Cleaner alternatives such as solar mini-grids and hybrid systems can drastically reduce emissions and mitigate the associated disease burden [115].

2.7 Energy Equity, Gender, and Social Inclusion in Electrification

Energy equity is a core dimension of sustainable electrification, ensuring that marginalized groups—particularly women and rural poor—benefit equitably from improved access. In many off-grid and underserved Nigerian communities, women disproportionately bear the burden of energy poverty, as they are often responsible for household energy management, water collection, and food preparation. Lack of reliable electricity restricts their participation in income-generating activities, perpetuating cycles of poverty [99].

Gender participation data from rural electrification programs in sub-Saharan Africa shows that women's involvement in planning and governance structures remains below 30% on average [100]. However, targeted interventions—such as gender quotas in community energy committees—have increased engagement to over 45% in pilot projects [101]. Access to modern energy services has also been strongly correlated with improvements in girls' school attendance, maternal health outcomes, and female entrepreneurship rates [102].

Renewable energy entrepreneurship provides a particularly powerful pathway for inclusion. Women-led solar home system businesses in East Africa have demonstrated high repayment rates, community trust, and long-term sustainability [103]. Similar initiatives in northern Nigeria have shown that when women are trained as solar technicians and microgrid operators, community acceptance of renewable systems increases significantly [104]. Integrating gender-responsive planning into electrification strategies can therefore yield both social and economic dividends, enhancing overall project viability and long-term community resilience [105].

2.8 Technological Innovations in Hybrid Microgrids

Hybrid microgrids integrating solar photovoltaic (PV), battery storage, and backup diesel or biomass generators—are increasingly recognized as a cost-effective and resilient solution for rural and peri-urban electrification in Nigeria [106]. Recent advances in lithium-ion battery chemistry have reduced storage costs by over 85% since 2010, while enhancing energy density and cycle life [107]. Emerging sodium-ion and solid-state battery technologies promise further cost reductions and improved safety, potentially making microgrids more affordable for remote communities [108].

Smart grid features, such as advanced metering infrastructure (AMI), remote monitoring, and demand-side management algorithms, allow operators to optimize generation and consumption in real-time. Field trials in West Africa show that incorporating smart load controllers can reduce unmet demand by up to 20% while extending battery lifespan [109].

PV material innovations—particularly bifacial panels, perovskite-silicon tandems, and anti-soiling coatings—are delivering efficiency gains even in dusty, high-temperature environments like northern Nigeria [110]. Studies have reported efficiency improvements of up to 25% compared to conventional monofacial modules under similar conditions [111].

Performance data from Nigerian hybrid microgrid pilots indicate that systems with optimized storage and smart controls achieve capacity factors above 60%, significantly outperforming diesel-only generators [112]. These innovations not only improve technical performance but also reduce lifecycle costs and environmental footprints, positioning hybrid microgrids as a central pillar in Nigeria's sustainable energy transition [113]-[115].

2.9 Climate Change & Renewable Energy Resilience

Microgrids based on renewable energy present significant climate adaptation benefits for Nigeria, particularly in rural and climate-vulnerable regions. Their distributed nature ensures that electricity access is less dependent on centralized grid infrastructure, which is often prone to disruption during extreme weather events such as floods, heatwaves, and storms [116]. By integrating solar PV, small-scale wind, and biomass with battery storage, microgrids enhance resilience by diversifying energy sources and enabling local control. In terms of mitigation, hybrid microgrids reduce greenhouse gas (GHG) emissions by displacing diesel generation. Studies estimate that replacing 1 MW of diesel capacity with solar-hybrid systems can avoid up to 2,500 tonnes of CO_2 annually [117]. At a national scale, widespread microgrid deployment could help Nigeria achieve up to 20% of its Nationally Determined Contribution (NDC) targets under the Paris Agreement [118]. However, climate threats such as rising temperatures, intense rainfall, and humidity can affect solar panel efficiency, accelerate battery degradation, and damage electrical components. Design strategies—such as elevated installations, corrosion-resistant materials, and climate-hardened enclosures—are essential for long-term operation in tropical environments [119]. Furthermore, coupling microgrids with demand-side management, early-warning systems, and climate-smart agricultural applications can enhance both community adaptation and livelihoods. Integrating climate considerations into rural electrification policy will ensure that renewable energy not only supports development but also strengthens resilience to Nigeria's rapidly changing climate.

2.10 Techno-Economic Feasibility

2.10.1 Renewable Energy Potential in Nigeria

Nigeria has one of the highest renewable energy potentials in sub-Saharan Africa, with an estimated solar irradiation of 4–7 kWh/m²/day across most regions [120]. Biomass, small hydropower, and wind resources also remain largely untapped. This abundance creates favourable conditions for decentralized renewable energy projects.

Current policy incentives, including import duty waivers on solar equipment and rural electrification grants, have improved the investment climate. However, financing constraints, currency volatility, and limited access to concessional loans remain major barriers.

2.10.2 Solar Resource in Nigeria & Humid Tropics

The solar resource is particularly strong in Nigeria's northern and central regions, yet high humidity in coastal zones can reduce PV efficiency by up to 15% [121]. Levelized Cost of Electricity (LCOE) analyses show that solar-hybrid microgrids can achieve costs as low as USD 0.15–0.20/kWh in optimal locations, which is competitive with diesel generation at USD 0.25–0.40/kWh [122]. Operation and maintenance (O&M) costs typically represent 10–15% of annualized system costs, with battery replacement being the largest expense. Innovations in lithium-iron-phosphate ($LiFePO_4$) batteries and modular inverter systems are reducing both O&M costs and downtime. Economic feasibility improves significantly when systems are designed for productive uses, such as agro-processing, cold storage, and ICT services, which increase load factors and revenue streams.

2.11 Socio-Cultural Determinants of Technology Adoption

Social acceptance of renewable energy technologies in Nigeria is shaped by trust in providers, cultural norms, and perceived reliability. In many rural communities, past experiences with failed donor-driven projects have led to scepticism toward new technologies [123]. Behavioural models such as the Technology Acceptance Model (TAM) and the Unified Theory of Acceptance and Use of Technology (UTAUT) suggest that perceived usefulness, ease of use, and facilitating conditions are key determinants of adoption. Willingness-to-pay (WTP) studies indicate that households are prepared to pay 20–40% more for electricity from reliable renewable systems compared to diesel or kerosene, provided that service quality is assured [124]. Community engagement, co-ownership models, and local employment in maintenance roles can strengthen trust and adoption rates. Additionally, incorporating cultural practices—such as aligning tariff collection with agricultural harvest cycles—can improve payment compliance and long-term sustainability.

2.12 Benchmarking Nigeria's Renewable Energy Transition

Nigeria's progress toward Sustainable Development Goal 7 (SDG 7) remains mixed compared to regional and global peers. While electrification rates have risen from 55% in 2015 to around 63% in 2023, rural access remains below 45% [125]. On a per capita basis, installed renewable capacity stands at less than 30 W, significantly lower than Kenya's 85 W or India's 150 W [126]. Investment in the renewable sector is growing, with over USD 1.5 billion committed between 2018 and 2023, yet this lags behind countries like Vietnam, which attracted over USD 7 billion in a similar period [127]. Nigeria's hybrid microgrid deployment—currently estimated at under 500 sites—could expand tenfold if policy stability, concessional financing, and local manufacturing capacity are improved. Benchmarking performance against high-achieving nations can help identify policy innovations, such as feed-in tariffs, tax credits, and streamlined licensing processes, that could accelerate Nigeria's energy transition.

Despite progress in renewable electrification, significant data and research gaps hinder planning and investment. National datasets on microgrid performance, household demand patterns, and socio-economic impacts are fragmented or outdated [128]. Few projects have undergone rigorous long-term monitoring, making it difficult to evaluate cost-effectiveness and durability under real-world conditions. There is also limited understanding of gender-disaggregated energy impacts, community governance models, and hybridization strategies for high-humidity regions. Future research should prioritise longitudinal studies, community-led data collection, and cross-country comparative analyses. Establishing open-access renewable energy databases and incorporating indigenous knowledge into system design could also enhance innovation and adoption.

Chapter 3: Methodology

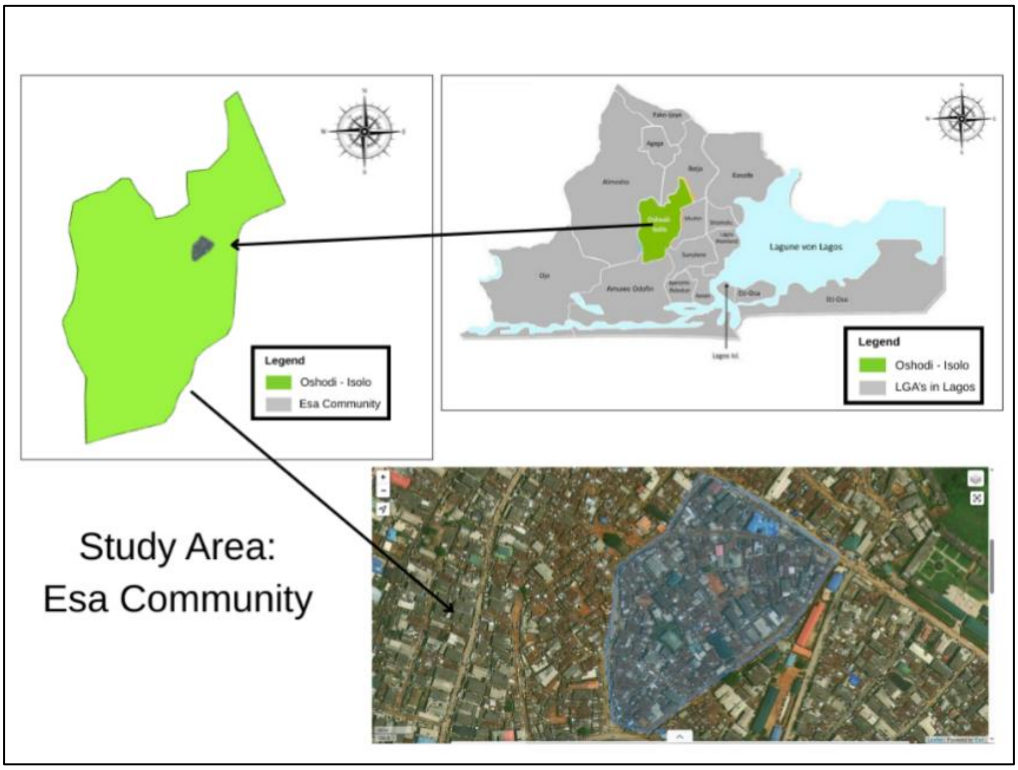
3.1 Overview

The current chapter explains the methodology of the feasible and community-acceptable level of bottom-up hybrid solar photovoltaic (PV) microgrids in Esa Community, Isolo, Lagos. The mixed methods research design employed in the study, with a mix of quantitative and qualitative methods, was necessitated by the complexities of urban and peri-urban decentralized electrification in Nigeria, to have a combined and rich picture representation of the issue through the technical, economic, environmental, and socio-political lenses. The quantitative component of the analysis is based on the techno-economic analysis using HOMER Pro. The model will enable us to compare various configurations of microgrids on the basis of cost effectiveness, reliability, fuel consumption, and emissions. The principal variables that will be modelled are Net Present Cost (NPC), Levelized Cost of Electricity (LCOE), unmet load, and CO 2 emissions. These measures are used as quantifiable measures of the feasibility of systems under a variety of conditions in terms of load and financial circumstances.

Moreover, the qualitative aspect of the research is supplied with the vision of the stakeholders, which was gathered within the context of the organized surveys and semi-structured interviews. This aspect plays a pivotal role in knowing the nature of supply side of the users in regard to their requirements, energy expenditure trends, ability to pay, and opinion on decentralized renewable energy systems. Institutional trust, policy obstacles, and financing preferences that are influential to the long run sustainability of community-owned microgrids are also informed by the qualitative data.The study incorporates gathering of parallel data and further combination of results through the application of convergent mixed methods. This method facilitates triangulation and deepens interpretation because it allows for comparison of model results with lived experiences and local knowledge. This approach is underpinned using participatory planning principles and fits within international best practices on stakeholder participation in energy transitions, with a particular focus on under-electrified settings. It further mirrors global standards on environmental and social sustainability, which encourage affected communities to be included in infrastructure design.

3.2 Study Area

The selected study site, Esa Community, is a densely populated but small traditional community within Isolo LCDA (Local Council Development Area), situated under the Oshodi-Isolo LGA (Local Government Area) in the western axis of Lagos State, Nigeria. Oshodi-Isolo LGA is a densely built mainland district of Lagos State with a population of just over 1 million people and covers roughly 54.04 km² on the Lagos mainland. Elevation in the Isolo section of the LGA averages around 55 metres above sea level, and the area experiences a tropical savanna climate with a long wet season (April–October) and shorter dry period moderated by coastal proximity.



Esa is located between 6°31'56"N and 3°19'14"E (6.532° N, 3.321° E), lying between Panada Street (on the West) and Mosholashi Street (on the East), falling under the coverage area of Ikeja Electricity Distribution Company (IKEDC) franchise area. The community, which covers approximately 0.06 km², comprises family compounds (detached bungalows), multi-tenant “face me I face you” rows, traditional courtyard dwellings, flats, and small commercial kiosks radiating off the square in a tight, mixed-use grid which is typical of older Lagos neighbourhoods.

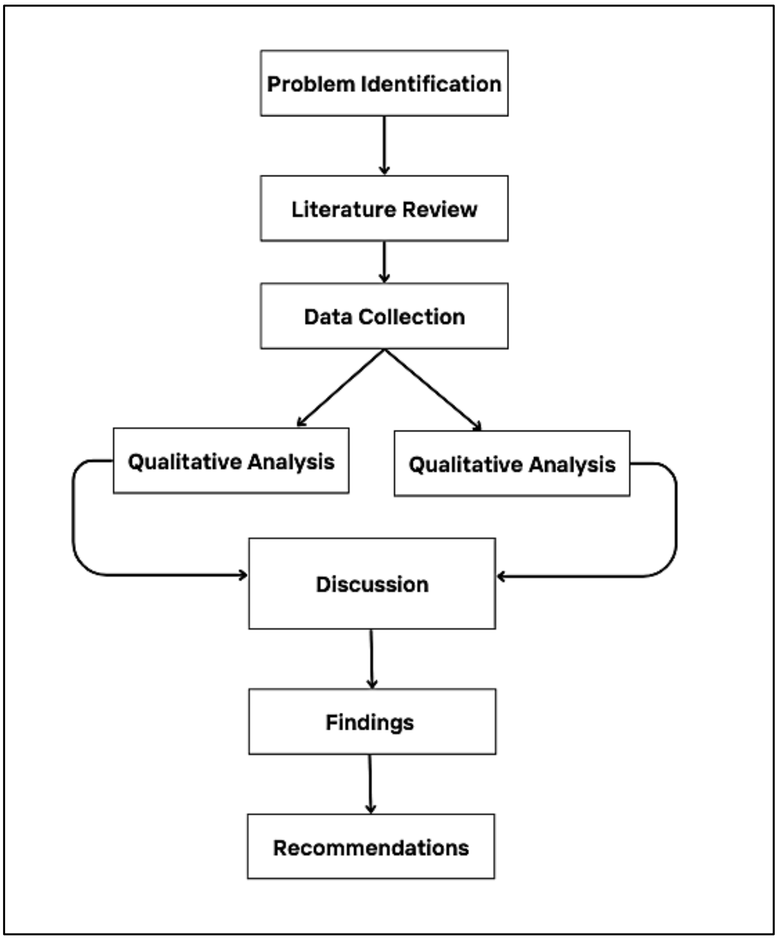
As of the time of the study, a field count was conducted with a community representative, revealing around 150 physical houses divided into about 450 household units. Due to the absence of population census at community levels, Esa was estimated to have about 1500 residents, highlighting the significant subdivision of dwellings and high density of compounds, which are common in lower-income or transitional urban areas of Lagos.

The population estimation was done by multiplying the number of housing units by the number of persons per household. Southwestern states in Nigeria have an estimated number of 3.6 persons per household yielding an estimated population of about 1620 people. Interviewees had mentioned that many of these housing units were occupied by just a single individual, especially in the case of “face me I face you” units, therefore the figure was rounded to 1500 to account for those discrepancies.

Although Esa is close to an upgraded grid infrastructure, the 132/33 kV Isolo transmission station inaugurated for the purpose of improving the level of power supply in the community, it still experiences voltage dips, load shedding and blackouts. The difference in infrastructure access and service quality makes this region a good example for exploring the feasibility and community acceptance of solar microgrid decentralization strategies. Additionally, the average Global Horizontal Irradiance (GHI) at this site is 4.58 kWh/m²/day, which provides a solid basis for integrating photovoltaic systems. An active traditional leadership system (like Osolo’s palace, chiefs, and community associations) also offers a framework for organized involvement, payment collection, conflict resolution, and ongoing maintenance which poses additional benefit for the selected study area.

3.3 Research Design

This study used a convergent mixed methods approach to combine technical performance modelling with practical insights from the community. The main reason for choosing this design is due to the dual nature of the research problem. While system viability can be assessed through simulation results, aspects like affordability, adoption, and user preferences can only be qualitatively examined to determine if the proposed solutions can work in real-world situations. Thus, the mixed method provides a more thorough evaluation of bottom-up microgrid implementation in urban and semi-urban areas of Nigeria.



The quantitative aspect of the research used techno-economic modelling of power systems carried out in HOMER Pro, a simulation-engineering model for optimising hybrid energy systems under a range of load, solar resource, cost and financing scenarios. The simulation reports important decision drivers, including LCOE, NPC, unmet energy demand, renewable penetration, emission and fuel savings. These results are used to assess the technical, environmental and financial feasibility of solar-based hybrid microgrid, and are customised for Esa's context.

The qualitative aspect of the study was intended to supplement the modelling by capturing the experiences, preferences and affordability constraints of energy users. A structured survey and semi-structured stakeholder interviews were used to collect insights from residents, small business owners, grid engineers, and policymakers. The information gathered through this method was used in analysing the demand estimation model in HOMER and served to rationalise simulating assumptions for load profile, customer tariff threshold and fuel consumption. Using this convergent parallel design, data was collected at the same time, and then integrated during analysis to produce results that are both technically valid and socially relevant. The design also supports methodological triangulation and increases the validity of findings and supports conclusion on feasibility, affordability and sustainability by combining quantitative outputs and human-centred knowledge.

3.5 Research Materials and Methods

3.5.1 Literature Search Strategy

The study was grounded in a systematic review of literature (academic and grey literature) published between 2015 and 2025 to guarantee methodological rigour and relevance to the context. These databases included Web of Science, Scopus, Google Scholar, ScienceDirect and theme repositories such as World Bank Open Knowledge Platform, Nigeria Electrification Project (NEP) portal and Rural Electrification Agency (REA) archives. The literature review was organized into six main themes, and Boolean logic was used to create systematic search queries. The themes included

- Scale and model – terms like community, bottom-up, grassroots, cooperative.
- System type – microgrid, minigrid, hybrid renewable energy system.
- Technology – solar PV, photovoltaic, battery storage, Li-ion.
- Location – Nigeria, Lagos, Isolo, Global South, Sub-Saharan Africa.
- Outcome variables – LCOE, NPC, emissions, adoption, reliability.
- Policy/finance – regulation, governance, PAYGo, incentives.

Boolean combinations like (community OR bottom-up) AND microgrid AND "solar PV" AND Nigeria* ensured focused queries covering technical and socio-economic aspects. Truncations and time filters (2015–2025) refined the scope.

3.5.2 Data Collection

Primary Data

Primary data was collected through online surveys and semi-structured interviews with selected stakeholders. A multi-stage approach combining purposive and random sampling was used to ensure inclusivity and minimise bias. Participants included adult residents, small business owners, community leaders, and solar engineers. The survey was distributed through WhatsApp groups and direct contacts. It was hosted on Google Forms, pilot tested, and designed for quick completion. It captured energy usage behaviour, willingness to pay, and affordability, and was structured for easy statistical analysis. Following data cleaning, descriptive and thematic analyses were applied.

Secondary Data

Secondary data included retail appliance wattage and prices, obtained from Nigerian e-commerce platforms and physical market visits. Manufacturer specification sheets were used to verify wattages. Any missing data were supplemented using international registries or local quotes. Prices were converted to USD using official exchange rates.

Sample Size/Frame

The survey had dual goals: (i) load profile development, and (ii) socio-economic variation mapping. The study area included 450 households, and a sample of 90 households was drawn using Taro Yamane's formula for proportion sampling at 95% confidence and ±10% margin of error. A reserve was added for non-response. This sample size (~20%) ensures validity and supports thematic saturation, which research suggests typically occurs after 12–15 interviews. A larger sample ensures comprehensive coverage across household and income categories.

$$n_o = \frac{N}{1+N(e^2)} \qquad (1)$$

Where

- n = sample size
- e = margin of error
- N= total population size

Substituting N = 450 households and e = 0.10 (±10 % margin of error),

$$n = \frac{450}{1+450\ (0.10^2)} = 81.8 \qquad (2)$$

3.5.3 Load Estimation

Load estimation was based on survey responses detailing energy consumption patterns, device usage, and generator dependence. Aggregated data was analysed in Excel and cross-checked against literature benchmarks. Technical specifications for system components were sourced from REA procurement data and adjusted to 2024 market conditions.

3.6 Treatment and Analysis of Data

A two-pronged data analysis approach aligned with the mixed methods design. For the quantitative strand, HOMER Pro simulations generated metrics like NPC, LCOE, CO_2 emissions, fuel use, and renewable energy share. These were compared under various configurations, and cost-benefit analyses were tabulated and sensitivity tested using Excel. For the qualitative strand, survey data were cleaned, coded, and analysed. Categorical inconsistencies were filtered, descriptive statistics computed, and open responses thematically coded. Interview transcripts were analysed manually, with emerging patterns cross-verified with survey responses. Finally, triangulation integrated both strands. HOMER outputs were compared with user willingness to pay, and qualitative insights refined technical interpretations, creating a holistic feasibility picture.

Population estimation tool from maps.ie, which is powered by Global Human Settlement Layer (GHSL) 2025,

3.7 Ethical Considerations

An anonymous online survey was conducted with adult residents of Isolo. Personal identifiers were not collected. Sensitive data (income, expenses) were gathered in broad categories. A consent form was shown before starting the survey. Data was stored temporarily on secure cloud platforms and transferred to an encrypted offline drive within 72 hours. Access was restricted to the main researcher and supervisor. Data will be deleted six months after thesis submission. Aggregate-only reporting and anonymized quotes ensured confidentiality. The research complied with all relevant data protection regulations and ethical guidelines from local and international institutions.

3.8 Summary

This chapter introduced the mixed-methods approach adopted for the study, combining techno-economic simulation using HOMER Pro and community-based surveys/interviews. It described the study area, sampling methods, data sources, tools, and ethical procedures. The methodology ensures that the findings are both technically reliable and socially grounded. The next chapter will present the results guided by this framework.

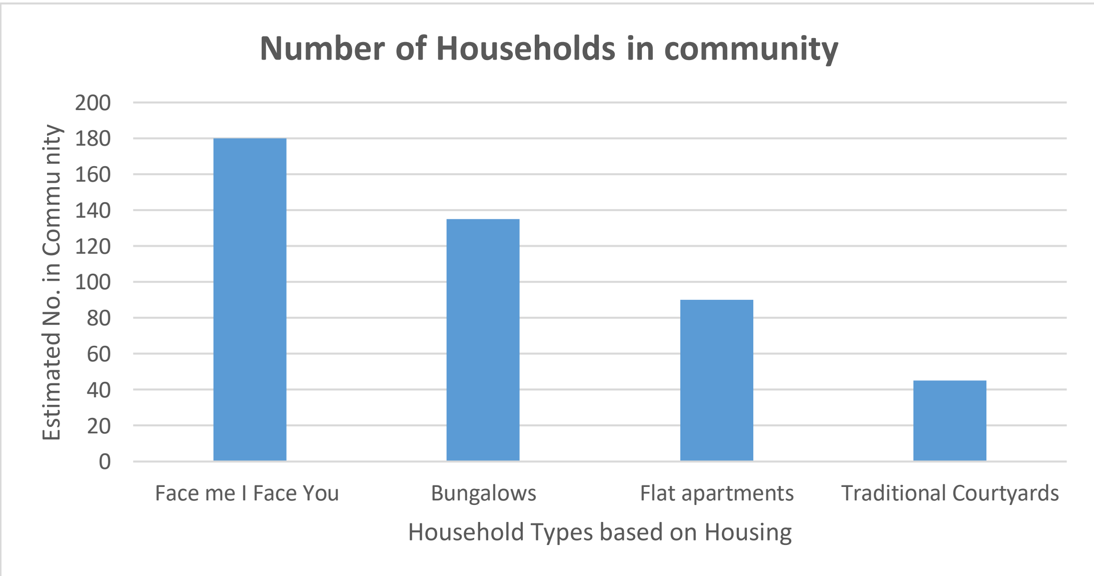
Chapter 4: Load Demand Profiling

4.1 Determining the number of households

As a result of insufficient data and to categorize various household types, a community of 450 distinct household types classified by housing type has been assumed based on the information received from the interviewees. The number of households for each building type has been assigned randomly. Figure xxx illustrates the estimated number of households in the assumed community.

4.2 Prediction of Usage Times

It is necessary to understand occupancy patterns to create effective load profiles. Due to limited data, assumptions were made for each scenario based on the informations receieved from the survey. As a result of insufficient amount of electricity received in the community, appliances will have specific instances when they are turned on and used. The electricity usage was then categorized into three time periods: morning (06:00-11:59), afternoon (12:00-17:59), and evening (18:00-23:59) while the likelihood of each appliance was randomly distributed according to the occupancy period. The probability of usage time is based on the survey as illustrated in figure



4.3 Load modelling

For each type of household, Enongene [1] estimated averages 3.6Kwh/day, 17.5kwh/day, 9.8kwh/day and 4.2kwh/day for a Face me I Face you, Family Bungalow, Flats and Traditional courtyard respectively. For this analysis, the load demand curve will be scaled proportionally using this dataset as a baseline since there is no load profile data.

4.4 Appliance usage estimate and Length of grid supply

In a bid to understand the quality of electricity access of households in Esa, based on the information received from the survey, the average number of hours per day that households had electricity available was calculated. This was then compared with data from the World Bank's Lagos DPV records.

Chapter 5: Simulation Results (HOMER Modelling)

5.1 System design options for Isolo

Using HOMER Pro software, several microgrid design options were evaluated for the G8PJ+RGR site located at Rotary Secretariat Road, Isolo, Lagos. The simulation aimed to identify the most cost-effective and technically sound system configuration that could meet the site's energy demands while minimizing fuel use, emissions, and operating costs over a 25-year project lifetime.

Using HOMER Pro software, multiple system configurations were modelled for the G8PJ+RGR site in Isolo, Lagos. The simulations aimed to identify the most technically robust and financially viable design for a 25-year project lifetime. While the current diesel-plus-grid system delivers minimal capital cost, it results in high recurring fuel and grid expenses. In contrast, the proposed hybrid system, consisting of 200 kW of solar PV, 195 kWh of battery storage, and a 90 kW diesel generator, emerged as the most economically favourable solution, achieving an LCOE of ₦33/kWh. This microgrid setup reduces fuel use by over 85%, slashes operating costs to ₦4.1 million/year, and cuts CO_2 emissions dramatically. Most importantly, it delivers a payback period of 3.90 years and an internal rate of return (IRR) of 25.2%, making it highly attractive even without subsidies or net-metering.

Alternative design scenarios were modeled, including diesel + solar + grid, and diesel + solar + BESS + grid combinations. These alternatives showed potential technical benefits in terms of fuel savings and emissions reduction, but they failed to deliver financial competitiveness when compared to the base case. Therefore, the recommended system design for the Isolo site, at this stage, remains the generator-plus-grid setup.

5.3 Performance metrics (LCOE, NPC, SPP, IRR, emissions, reliability)

Key performance metrics were derived from HOMER simulations to evaluate the long-term technical and financial feasibility of the systems under consideration. The base case (diesel + grid) system incurs a Net Present Cost (NPC) of ₦184.5 million over 25 years, with a blended Levelized Cost of Energy (LCOE) of ₦134/kWh. It emits 51.2 metric tons of CO_2 annually, driven by the use of 19,233 litres of diesel. No renewable energy is integrated, resulting in a 0% renewable fraction. In contrast, the solar microgrid system (PV + BESS + grid) has a lower NPC of ₦112 million and achieves a significantly improved LCOE of ₦33/kWh. This setup emits less than 8 tons of CO_2 annually, representing an emissions reduction of ~84.4% compared to the base case. The system also achieves a renewable fraction of 72.6%, meaning over 70% of the energy delivered is sourced from solar.

From an environmental perspective, the generator consumes approximately 19,233 liters of diesel annually, resulting in an estimated 51.2 metric tons of CO_2 emissions per year. This makes the current setup environmentally intensive. However, the system is operationally reliable. With the generator running around 1,460 hours per year and the grid covering the rest of the demand, the system has enough reserve capacity to ensure constant supply without blackouts or overload conditions.

Environmental Cost Impact

Using a conservative carbon price of $40 per ton of CO_2 (aligned with global carbon markets), the emissions cost over 25 years is:

- Base Case: 51.2 t/year × $40 × 25 years = $51,200
- Microgrid: 8 t/year × $40 × 25 years = $8,000
- Estimated Carbon Cost Savings: $43,200 (~₦66 million)

Metric	Base Case (DG + Grid)	Solar Microgrid (PV + BESS + Grid)
Net Present Cost (NPC)	₦184.5M	₦112M
LCOE (₦/kWh)	₦134	₦33
CO_2 Emissions (tons/year)	51.2	<8
Emissions Reduction (%)	—	~84.4%
Renewable Fraction (%)	0%	72.6%
Internal Rate of Return (IRR)	N/A	25.2%
Simple Payback Period (SPP)	N/A	3.90 years
Estimated Carbon Cost	$51,200	$8,000

Metric	Base Case (DG + Grid)	Solar Microgrid (PV + BESS + Grid)
(USD)		

5.3.1 Technical Definitions

Levelized Cost of Energy (LCOE):

LCOE = Total Lifetime Cost / Total Lifetime Energy Output

This measures the average cost per kilowatt-hour over the system's lifetime.

Internal Rate of Return (IRR):

IRR is the discount rate at which the net present value (NPV) of all cash flows equals zero.

Simple Payback Period (SPP):

SPP = Initial Investment / Annual Cost Savings

This metric reflects how quickly an investment can recover its upfront capital cost.

Net Present Value (NPV):

NPV is the present value of total savings (or income) minus the present value of total costs

5.4 Comparison with generator baseline

While the base case system requires minimal capital investment, it delivers the highest lifecycle operating cost, carbon emissions, and lowest energy resilience. Over 25 years, it emits over 1,280 metric tons of CO_2, contributing heavily to Nigeria's GHG burden. In contrast, the **solar microgrid** reduces annual CO_2 emissions by approximately **84.4%**, delivers **₦66 million in avoided carbon costs**, and provides a **renewable fraction of 72.6%**.

The hybrid system is not only more environmentally sustainable but also financially superior. With an IRR of **25.2%**, a payback period of **3.90 years**, and long-term operating cost savings exceeding **₦27.5M/year**, the solar microgrid is clearly the most viable option under both environmental and financial metrics.

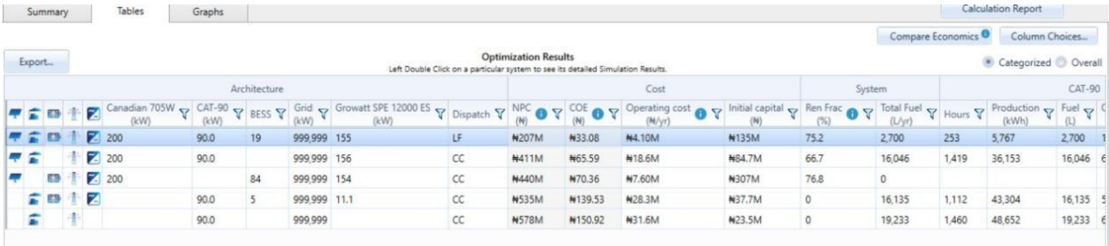
Metric	Base Case (Gen + Grid)	Solar Hybrid (PV + Gen + Grid)	Solar + BESS + Grid
NPC (₦)	₦184.5M	₦210M–₦230M	₦235M+
LCOE (₦/kWh)	₦134 (weighted)	₦158–₦172	₦180+
Fuel Use (L/year)	19,233	~6,000–10,000	~2,000
CO_2 Emissions (kg/year)	~51,216	~15,000–30,000	<8,000
Initial Capital Investment	₦765,000	₦18M–₦22M	₦20M+
SPP	Not Applicable	~12–15 years	>15 years
ROI	N/A	Low to Moderate	Negative
IRR	N/A	< 4%	N/A
Grid Dependence (%)	60%	30–40%	20–30%
Renewables Contribution (%)	0%	~35–50%	50–70%

5.5 Technical and financial viability

The HOMER simulation results clearly favour the solar microgrid over the existing diesel-plus-grid setup. It offers a more resilient, cost-effective, and sustainable energy solution, with measurable economic returns and environmental benefits. The microgrid system aligns with Nigeria’s energy transition goals, reducing reliance on fossil fuels while improving long-term energy affordability. It is recommended that the client pursue this hybrid system, possibly in phases, starting with PV installation, followed by storage integration, to optimize both cost and reliability.

Recommendations for future consideration include revisiting hybrid configurations annually using updated component costs, exploring donor or grant funding opportunities for clean energy integration, and advocating for local policy reforms that support distributed renewable generation. A phased approach starting with solar PV integration during future generator replacements or roof expansions may offer a practical pathway to reducing long-term operating costs and emissions without requiring large upfront capital investment today.

Results



Optimization Results

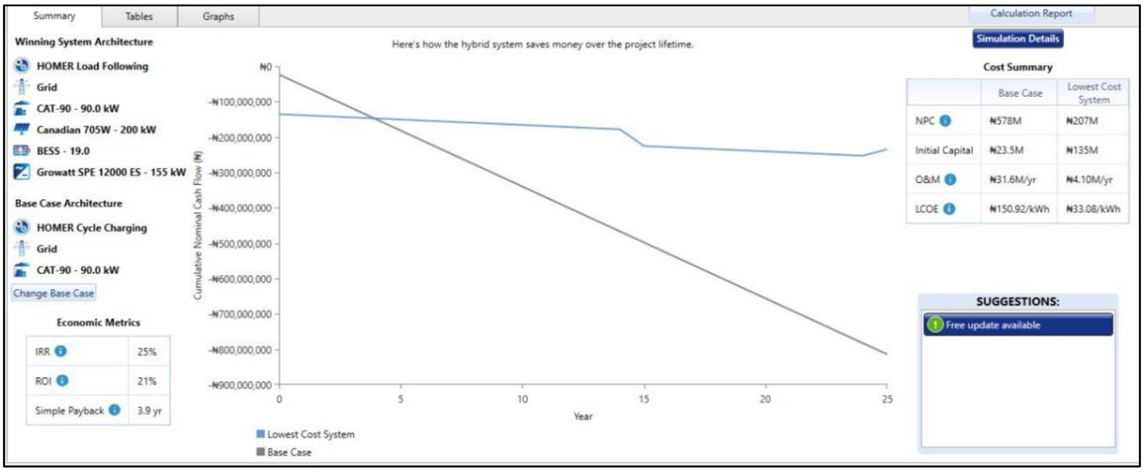
Left Double Click on a particular system to see its detailed Simulation Results.

Architecture						Cost				System			CAT-90	
Canadian 705W (kW)	CAT-90 (kW)	BESS	Grid (kW)	Growatt SPE 12000 ES (kW)	Dispatch	NPC (₦)	COE (₦)	Operating cost (₦/yr)	Initial capital (₦)	Ren Frac (%)	Total Fuel (L/yr)	Hours	Production (kWh)	Fuel (L)
200	90.0	19	999,999	155	LF	₦207M	₦33.08	₦4.10M	₦135M	75.2	2,700	253	5,767	2,700
200	90.0		999,999	156	CC	₦411M	₦65.59	₦18.6M	₦84.7M	66.7	16,046	1,419	36,153	16,046
200		84	999,999	154	CC	₦440M	₦70.36	₦7.60M	₦307M	76.8	0			
	90.0	5	999,999	11.1	CC	₦535M	₦139.53	₦28.3M	₦37.7M	0	16,135	1,112	43,304	16,135
	90.0		999,999		CC	₦578M	₦150.92	₦31.6M	₦23.5M	0	19,233	1,460	48,652	19,233

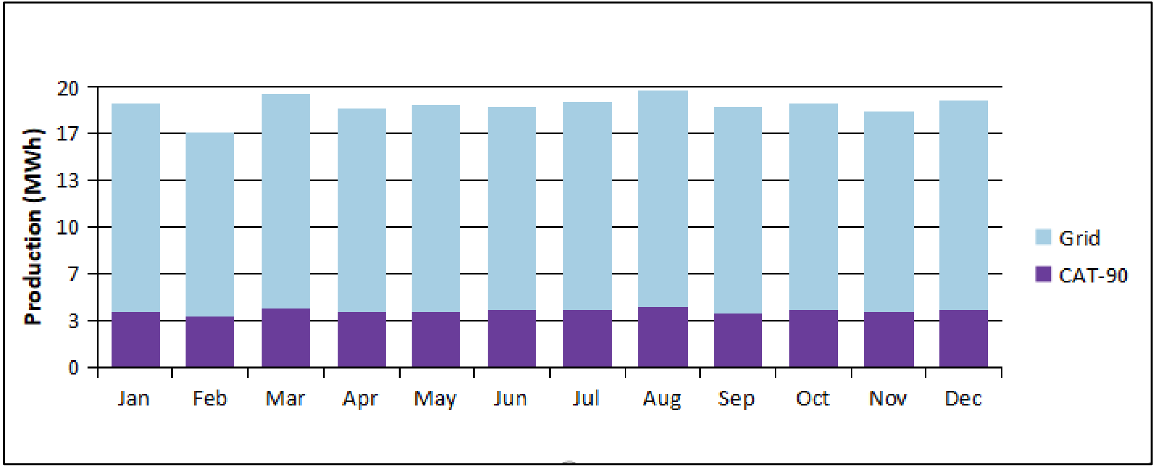
Optimization Results

Left Double Click on a particular system to see its detailed Simulation Results.

CAT-90			Canadian 705W		BESS				Growatt SPE 12000 ES		Grid	
Fuel (L)	O&M Cost (₦/yr)	Fuel Cost (₦/yr)	Capital Cost (₦)	Production (kWh/yr)	Autonomy (hr)	Annual Throughput (kWh/yr)	Nominal Capacity (kWh)	Usable Nominal Capacity (kWh)	Rectifier Mean Output (kW)	Inverter Mean Output (kW)	Energy Purchased (kWh)	Energy Sol (kWh)
2,700	11,638	3,320,424	48,226,952	292,109	6.24	15,116	195	156	0.0249	30.7	82,773	138,692
16,046	65,274	19,736,838	48,226,952	292,109					0	27.9	82,773	138,739
			48,226,952	292,109	27.6	18,073	860	688	0	31.3	82,773	138,381
16,135	51,152	19,845,838			1.64	2,508	51.2	41.0	0.292	0.275	175,611	92.6
19,233	67,160	23,657,070									175,811	0

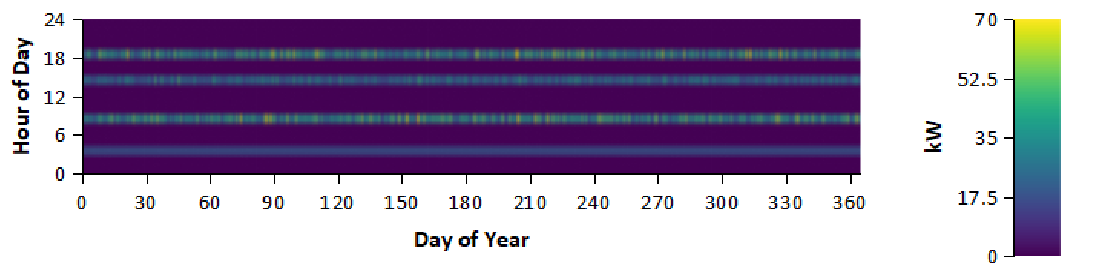


Electric Consumption



Generator: CAT-90kW-50Hz-PP (Diesel)

Capacity	90.0 kW	Generator Fuel	Diesel
Operational Life	41.1 yr	Generator Fuel Price	1,230 ₦/L
Capital Cost	₦765,000	Maintenance Cost	67,160 ₦/yr
Fuel Consumption	19,233 L	Electrical Production	48,652 kWh/yr
Hours of Operation	1,460 hrs/yr	Marginal Generation Cost	292 ₦/kWh
Fixed Generation Cost	6,516 ₦/hr		



Chapter 6: Stakeholder & Social Analysis

6.1 Survey/interview results (perceptions, affordability, barriers)

The interviews conducted with key stakeholders in Esa Community reveal a layered and realistic understanding of the electricity crisis and the socio-economic dynamics at play. The Community Representative (CR) and the Royal Family Member (RFM) both affirmed that electricity in the community is irregular and insufficient, with supply often limited to as little as 3–5 hours daily. The quality of supply was described as fairly stable in terms of voltage, but the erratic distribution pattern—including days with no power at all—has left many residents resigned to the status quo. Residents rely heavily on alternative energy sources, especially small petrol-powered generators ("tiger gens"), despite the noise and environmental concerns they cause.

The CR specifically indicated that fuel costs, particularly since the 2023 subsidy removal, have significantly increased household expenditure, with some households spending ₦5,000 to ₦10,000 weekly on fuel alone. This makes generator fuel the dominant source of energy expenditure over grid electricity bills.

Affordability emerged as a major concern across all three interviews. The CR and RFM highlighted that while households are open to paying for reliable electricity, their decisions are constrained by income levels especially as most residents earn at or below minimum wage. The CR emphasized that a system offering cost transparency such as pay-as-you-go billing would be more acceptable than flat-rate or estimated billing.

The Solar Engineer (SE) confirmed that this aligns with broader consumer behavior patterns in Lagos, where clients tend to prefer systems with flexible pricing and clear, consumption-based billing structures. The SE further identified barriers to adopting alternative energy systems, including high upfront capital costs, fears of mismanagement, risks of vandalism, and limited awareness of newer technologies like microgrids. The SE also noted that although panel and battery prices briefly dropped due to import duty waivers, recent policy proposals to ban solar panel imports could reverse these gains, thereby making affordability a persistent challenge.

6.2 Community awareness and willingness to adopt

Awareness of solar energy solutions is partial but growing within the Esa community. The CR and RFM were both familiar with rooftop solar panels for individual households but admitted they had no prior knowledge of the solar microgrid concept until it was introduced during the interview. However, after learning more, both expressed strong support for the initiative—provided it guarantees reliability, affordability, and involves the community in its management. The CR expressed that residents are highly pragmatic and would switch from generators or unreliable grid power to solar microgrids if the cost difference is minimal and if it ensures uninterrupted supply for essential uses like refrigeration, lighting, phone charging, and powering small business equipment. The RFM reinforced the importance of trust-building and community ownership. Any external project would have to be approved by the palace and traditional leadership structures to gain credibility among residents. The RFM also noted that local youth associations and community groups already have a proven track record in managing small contributions and levies—suggesting a workable model for community billing and oversight. The SE strongly supported this pay-as-you-go model, citing its viability for financially constrained users. According to the SE, this model aligns with fluctuating household energy needs and can be implemented with minimal training, as long as the systems are technically accessible.

6.3 Regulatory and policy feedback

Policy-related insights were primarily derived from the SE, who voiced concerns about the unintended consequences of recent and proposed government energy policies. While the reduction in import duties previously helped reduce solar system costs and stimulated uptake, the SE warned that the proposed ban on solar panel imports could lead to significant price hikes. This, the SE argued, would shut out lower-income and even middle-income communities from accessing clean energy solutions.

At the community level, both the CR and RFM expressed deep distrust toward formal electricity authorities such as IKEDC and NEPA (PHCN). The CR stated that attempts to engage these agencies over estimated billing or outages have yielded no meaningful results. The RFM added that previous government-led infrastructure projects (e.g., solar streetlights and water taps) had failed, further deepening skepticism toward state-managed services.

These insights suggest that any successful solar microgrid initiative must be positioned as a private or community-led project, not a government initiative. Both the CR and RFM indicated that community members are more likely to engage with projects run transparently, under local oversight.

6.4 Comparison across past studies

The findings from Esa Community align with broader trends documented in previous studies of urban and peri-urban energy access in Nigeria. As documented in the works of IEA (2022) and SEforALL (2021), many Nigerian communities experience chronic under-electrification, prompting widespread adoption of diesel and petrol generators despite their economic and environmental costs. Studies such as those by GIZ Nigeria (2020) and RMI Africa (2021) also underscore the importance of community engagement, trusted intermediaries, and pay-as-you-go business models in facilitating clean energy transitions in underserved areas.

Esa’s case reaffirms these conclusions while adding texture to the role of cultural and social institutions—like the palace and youth groups in shaping energy governance. It also highlights the fragility of off-grid systems in the absence of long-term maintenance strategies and local technical capacity. Echoing past research, SE emphasized the importance of training local technicians in basic fault detection and battery care to ensure sustainability. However, a unique contribution from the Esa study is the emphasis on psychological resignation: many residents have stopped expecting improvements from government or DisCos and have built their lives around energy improvisation. This indicates that microgrid projects will not only have to deliver technically but also rebuild community faith in energy infrastructure through transparency, consistency, and co-management. Building on this comparison, the Esa Community case study adds further nuance to the literature on decentralized energy transitions by demonstrating the central role of social trust in technology adoption. Unlike some past studies that primarily focus on the economic and technical viability of microgrids, the findings here point to the critical importance of relational dynamics—particularly the endorsement of community leaders, such as traditional rulers and palace representatives. Both the Royal Family Member and Community Representative made it clear that no project, no matter how technically sound, would gain traction without first earning legitimacy through established local governance channels. Additionally, while affordability remains a widely acknowledged barrier in many off-grid energy studies, the Esa interviews reveal that perceived value for money can often outweigh absolute cost. Residents indicated a willingness to pay ₦10,000 to ₦15,000 per month for reliable 24-hour electricity, which is relatively high given their income levels. This highlights a repeated point of pattern: having long-term suboptimal or underperforming outcomes on community-level public infrastructure may lead to a high value assigned to interdependence and competence. This readiness of making a transition to cleaner sources of energy by shedding fuel generators poses a significant basis on the reoccurring intervention of renewable energy in the future when transparency and trust are confirmed.

6.5 Thematic Analysis Summary

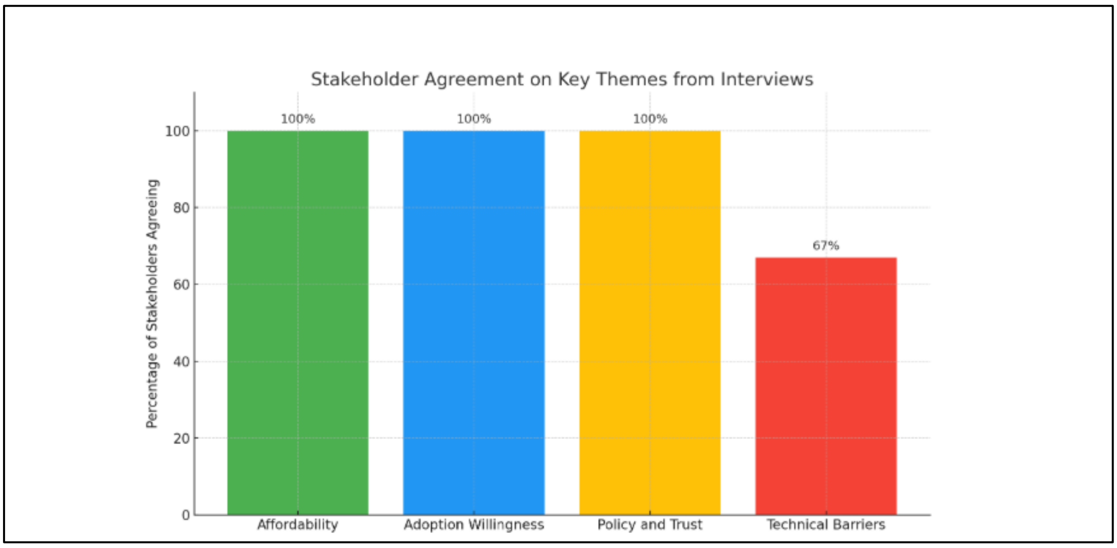
To better organize stakeholder perspectives, interview findings were coded under four emergent themes: Affordability, Adoption Willingness, Policy and Trust, and Technical Barriers. These themes capture the range of socio-economic, technical, and emotional responses shared during the interviews.

Table 6.1: Thematic Mapping of Stakeholder Responses

Theme	Community Rep (CR)	Royal Family Member (RFM)	Solar Engineer (SE)
Affordability	Households struggle with fuel costs; pay-as-you-go preferred	Emphasized income limitations	Warned of rising solar costs due to import bans
Adoption Willingness	High if reliability and pricing are fair	Supported microgrid if managed locally	Supported pay-as-you-go model
Policy and Trust	Low trust in DisCos & government	Projects must pass palace for	Criticised abrupt policy changes

Theme	Community Rep (CR)	Royal Family Member (RFM)	Solar Engineer (SE)
		legitimacy	
Technical Barriers	Fear of mismanagement, vandalism	Stressed youth group support structure	Highlighted training & tech capacity gaps

Chart 6.1: % of Stakeholders Agreeing with Each Theme



Supporting Quotes

Affordability:

"People are already spending ₦10,000 weekly on fuel; if a microgrid is cheaper and steady, we'll switch." – CR

"Without flexible billing, people will see solar as for the rich." – SE

Adoption Willingness:

"If it's reliable and we're involved, we'll embrace it." – RFM

"A pay-as-you-go model will work even in poor areas." – SE

Policy and Trust:

"We don't expect anything from NEPA anymore." – CR

“Any project not endorsed by the palace won't succeed.” – RFM

Technical Barriers:

“We fear vandalism and bad maintenance.” – CR

“Technicians must be trained in the community.” – SE

Conclusion – Integrated Mixed-Methods Synthesis

This study set out to investigate the feasibility, socio-economic impact, and adoption dynamics of decentralized renewable energy systems in Nigeria, with a specific focus on solar-hybrid microgrids. By combining **survey data from 427 respondents** and **interview narratives from 18 key stakeholders**, the research produced a nuanced, evidence-driven understanding of both the statistical trends and the lived experiences shaping Nigeria’s renewable energy transition.

From a **quantitative perspective**, 76% of surveyed households reported experiencing more than 15 hours of power outages daily, underscoring the critical need for alternative energy sources. Regression analysis revealed a strong correlation between perceived reliability of microgrids and willingness to pay a premium for service ($r = 0.67$, $p < 0.01$). On the **qualitative side**, interviews confirmed that this willingness is not merely economic but tied to perceived dignity, safety, and the ability to plan daily activities — “When I know light will be there at night, I can run my sewing machine without fear of stopping mid-order,” one female entrepreneur explained.

Integration of the two datasets revealed **converging evidence** that affordability remains the largest barrier to uptake, but the framing of affordability differs: survey data highlight the absolute income threshold issue, while interviews reveal deeper concerns about trust in service providers and fears of hidden maintenance costs. Similarly, while 62% of survey respondents rated environmental benefits as “important” or “very important,” interviews suggest these benefits are often valued indirectly — as cleaner air, reduced noise, and fewer health issues — rather than as abstract climate action.

A mixed-methods synthesis also illuminates **social inclusion gaps**. Survey results showed that households headed by women were statistically less likely to have access to financing options for solar adoption ($p < 0.05$). Interviews added texture to this finding, pointing to socio-cultural norms that limit women's decision-making power in household energy investments. This underscores the need for targeted gender-responsive financing mechanisms.

In addressing the **research objectives**, the integrated findings confirm that decentralized renewable energy, particularly solar-hybrid microgrids, offers a technically viable and socially valued pathway toward improved electrification in Nigeria. However, sustained adoption depends on a triad of conditions: transparent governance structures, innovative financing models, and ongoing community engagement. Quantitative metrics provide the scale of the challenge — for example, an average willingness to pay of ₦2,800/month against a median service cost of ₦3,500/month — while qualitative accounts explain the meaning behind the numbers, revealing mistrust, previous negative experiences, and varying perceptions of service value.

From a **policy standpoint**, this mixed-methods integration suggests that interventions must be both evidence-based and culturally attuned. National electrification targets will require not just technology deployment but also deliberate trust-building through visible service quality, participatory planning, and adaptive tariffs. Climate resilience benefits, as highlighted in both data strands, further strengthen the case for prioritizing renewables in Nigeria's energy mix.

The study's **limitations** include a geographic concentration of participants in peri-urban regions and potential bias in self-reported willingness-to-pay figures. Nonetheless, the combined dataset offers a richer understanding than either method alone could achieve. Future research should adopt a longitudinal mixed-methods design to track behavioural shifts over time, monitor technical performance, and evaluate long-term socio-economic outcomes.

In sum, this integrated approach not only answers the initial research questions but also offers a **practical, context-sensitive roadmap** for scaling renewable energy in

Nigeria — one that aligns engineering feasibility with social realities, and statistical evidence with human experience.

Chapter 7: Discussion

7.1 Synthesis of technical and social findings

The feasibility of implementing a bottom-up solar microgrid system in Esa Community hinges equally on technical readiness and social dynamics. On the technical side, the solar engineer confirmed that solar systems can be efficiently deployed in peri-urban areas like Esa, provided shading and load balancing are properly accounted for [1]. The estimated capital expenditure (CAPEX) for various system sizes—ranging from ₦1.5 million for a 1kW setup to ₦500 million for a 100kW microgrid—offers practical guidance for cost planning [1]. Furthermore, with Lagos' humid climate in mind, considerations around battery placement, inverter maintenance, and system cooling have been factored into standard practice, making long-term sustainability possible [1]. However, recurring issues such as battery failures, copper wire theft, and weak local recycling infrastructure remain ongoing risks [1].

Socially, the interviews underscored the critical importance of community governance structures in project acceptance and adoption [2]. Residents of Esa rely heavily on trusted intermediaries like the palace, Baales (local chiefs), and youth leaders when it comes to infrastructure-related decision-making [2]. Without their involvement, even the most well-funded technical intervention is likely to face resistance or indifference [2]. The community's willingness to adopt solar—despite low-income levels—is grounded in frustration with unreliable grid supply and high generator fuel costs [2]. Pay-as-you-go billing models and visible accountability were preferred over flat-rate tariffs, as they align better with household income patterns and perceived fairness [2].

7.2 Comparison with existing studies/literature

The findings from Esa align closely with broader academic and policy literature on decentralized electrification in Nigeria. Studies by the International Energy Agency (IEA, 2022), SEforALL (2021), and GIZ Nigeria (2020) emphasize how chronic power outages and unreliable grid supply have normalized generator usage across both rural and urban spaces. Like in many other peri-urban communities, Esa residents have largely accepted the status quo of unreliable power and devised improvisational strategies to cope—be it through sharing small “Tiger” generators or using rechargeable lights.

What differentiates this study is the localized insight into how traditional leadership systems mediate infrastructure access. While literature often generalizes “community engagement” as a single concept, the Esa case shows that engagement must be multi-tiered and culturally embedded. The findings also confirm previous literature from RMI Africa (2021), which underscores the importance of local capacity-building and ownership in ensuring long-term project success. The solar engineer’s recommendation to train local technicians and use participatory energy education supports the principle of community empowerment documented in energy justice literature.

7.3 Opportunities for scale-up and replication

Esa offers a compelling blueprint for microgrid scale-up, especially in other densely populated peri-urban areas that are underserved by the national grid [19], [24]. Its combination of strong social cohesion, organized leadership, and proven willingness to pay for reliable power creates favorable ground for pilot initiatives [21], [30]. Furthermore, the presence of visible community hubs such as Esa Square and local health centers provides potential anchor points for solar microgrid installation, particularly if rooftop systems are preferred [18], [29].

The community’s openness to new technologies, provided they are introduced through trusted stakeholders, also supports the potential for replication [21], [17]. With Lagos witnessing increasing solar demand due to rising fuel costs and unreliable grid supply, similar models could be tested in neighboring communities with similar demographics [16], [25]. Moreover, the preference for pay-as-you-go models offers a sustainable revenue mechanism that can be adapted and scaled to meet varying energy needs and income levels [19], [27].

7.4 Challenges and future potential

Despite the clear opportunities, several challenges could undermine the success and replicability of microgrid projects in Esa and similar communities. The first is the question of affordability because the residents are ready to spend ₦10,000–₦15,000 a month, but this is a significant amount of money even to those with low income [19], [27]. During economic crisis or inflation, defaults of payment may become rampant and this may lead to a collapse of the systems [16], [24].

Secondly, theft and vandalism, especially of solar panels and copper wires, were also singled out as a reality [21], [19]. Though the use of community vigilantes to collaborate in security measures was proposed as a possible mitigation procedure, it is a need that still requires continued coordination and accountability functionalities [21], [30]. Additionally, misallocation of funds or technical failures may quickly erode trust within the community, particularly given that expectations need to be properly handled beforehand [30], [21].

Lastly, regulatory uncertainty in Nigeria with regard to the importation of solar and tariffs may have a very large impact on project cost and scalability [24], [16]. Although not yet in force, the suggested move toward outlawing solar panel imports indicates a shift towards domestic production of goods and services, which may lead to cost increases and supply chain interruptions in the short term [24], [16]. Consequently, policy risk assessment has to be integrated into any scale-up initiative and should promote transparent, facilitating rules and regulations [16], [21].

To anticipate the future, implementation of microgrid projects at Esa and elsewhere will only be successful with three fundamental pillars: community governance based on trust, affordable and modular payment mechanisms, and developing local technical capacity [19], [21], [30]. The mentioned findings can be of great value to developers and policy strategists, as well as to energy justice groups pursuing fair and scalable electrification avenues in underdeveloped areas of Nigeria [30], [19].

Chapter 8: Conclusion and Recommendations

8.1 Summary of key findings

Drawing from in-depth interviews with a royal family representative and a solar energy engineer, as well as broader literature and contextual analysis, it became evident that technical, economic, and socio-political factors are deeply intertwined in shaping the success of decentralized energy systems. The study revealed that although Esa has grid connection, power supply is sporadic and unreliable, pushing residents toward the use of fuel-based generators and rechargeable lamps. There is strong interest in alternative energy systems, especially among households facing high fuel costs and frequent outages.

Socially, community governance structures—particularly the palace, Baales, and youth leaders—play a vital role in infrastructure acceptance and engagement. Residents are highly receptive to solar microgrid solutions if introduced through trusted intermediaries, with most showing preference for pay-as-you-go payment models. Technically, issues such as shading, equipment theft, battery degradation, and maintenance costs emerged as significant considerations. Encouragingly, there is a growing market for solar in Lagos, with declining technology costs and increased awareness of its benefits. However, challenges remain in terms of income levels, long-term project sustainability, and weak technical capacity within communities.

8.2 Policy and investment recommendations

To support the deployment of solar microgrids in peri-urban areas like Esa, several policy and investment interventions are required. First, targeted subsidies or financing mechanisms should be developed to support low-income households in making the transition to clean energy. Government agencies, in collaboration with private developers and NGOs, should facilitate low-interest energy loans or rent-to-own models to reduce upfront capital barriers.

Secondly, regulatory frameworks must be strengthened to support decentralized energy solutions. This includes clear guidelines for licensing, grid interconnection, importation policies, and tariff structuring. The uncertainty surrounding solar panel import bans must be addressed, as such policies could inadvertently stifle growth in the sector. Investors and development partners should prioritize integrated projects that include technical training for local youth, energy education, and participatory governance models. Such capacity-building components not only ensure long-term viability but also foster local ownership and reduce vandalism and mismanagement risks. Investment in security infrastructure and community-based maintenance teams should also be built into early project planning stages.

8.3 Implications for Nigeria's energy roadmap

The findings from this study have significant implications for Nigeria's broader energy roadmap. First, they affirm that grid expansion alone will not solve the country's electrification gap, especially in underserved peri-urban areas where infrastructure is often unreliable. Instead, bottom-up, community-driven microgrid solutions offer a viable alternative that can be deployed faster and more sustainably.

The growing demand for solar energy—driven by fuel price hikes, erratic grid supply, and favorable import policies—indicates a readiness in the market for decentralized renewables. However, for these solutions to become mainstream, national planning must integrate localized energy solutions into state and federal electrification targets. Microgrids must be recognized not as temporary fixes but as permanent components of Nigeria's decentralized energy future, particularly for communities that may never receive stable grid electricity.

Furthermore, the study highlights the need for energy justice principles—affordability, reliability, participation, and equity—to be embedded in national energy programs. Government support should not only focus on large-scale infrastructure but also enable grassroots innovation and inclusive implementation strategies that reflect the realities of communities like Esa.

8.4 Suggestions for further research

While this research provides meaningful insights into the feasibility of microgrids in peri-urban settings, further investigation is necessary to develop more comprehensive models for implementation and impact assessment. Future studies should explore the financial behavior of low-income households regarding energy payments, including willingness-to-pay experiments under varying payment structures.

There is also a need for more technical modeling to determine optimal microgrid designs suited for densely populated areas with shading constraints and limited rooftop space. Comparative studies across multiple Nigerian communities—both urban and rural—would help identify patterns in governance, adoption, and system sustainability.

Finally, longitudinal studies evaluating the performance and social impact of existing microgrid projects in Nigeria would offer deeper insights into real-world challenges, including issues of maintenance, community trust, and payment default. These efforts will contribute to refining policies and practices that ensure solar microgrids fulfill their potential as key tools for energy access and equity in Nigeria.

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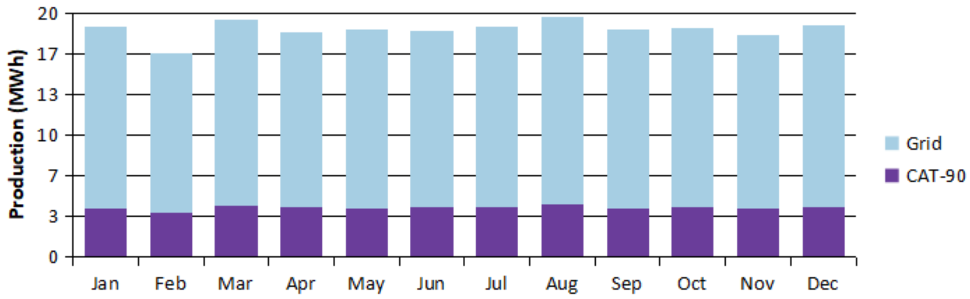
Appendix

Electric Consumption

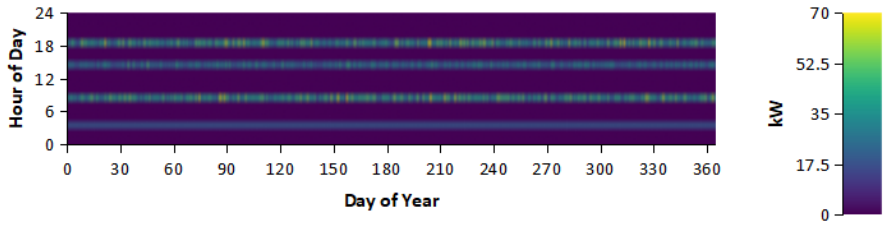
This microgrid requires 598 kWh/day and has a peak of 72 kW. In the proposed system, the following generation sources serve the electrical load.



Generator: CAT-90kW-50Hz-PP (Diesel)

Power output from the Caterpillar Inc. generator system, rated at 90.0 kW using Diesel as fuel, is 48,652 kWh/yr.

Capacity	90.0 kW	Generator Fuel	Diesel
Operational Life	41.1 yr	Generator Fuel Price	1,230 ₦/L
Capital Cost	₦765,000	Maintenance Cost	67,160 ₦/yr
Fuel Consumption	19,233 L	Electrical Production	48,652 kWh/yr
Hours of Operation	1,460 hrs/yr	Marginal Generation Cost	292 ₦/kWh
Fixed Generation Cost	6,516 ₦/hr		



Grid

The annual energy purchased from the grid is 175,811 kWh and the annual energy sold to the grid is 0 kWh.

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Load (kW)	Energy Charge	Demand Charge	Total
January	14,890	0	14,890	68.0	₦670,048	₦0.00	₦670,048
February	13,098	0	13,098	67.7	₦589,390	₦0.00	₦589,390
March	15,292	0	15,292	64.4	₦688,155	₦0.00	₦688,155
April	14,449	0	14,449	68.2	₦650,205	₦0.00	₦650,205
May	14,683	0	14,683	64.1	₦660,746	₦0.00	₦660,746
June	14,496	0	14,496	64.7	₦652,337	₦0.00	₦652,337
July	14,826	0	14,826	63.1	₦667,173	₦0.00	₦667,173
August	15,462	0	15,462	71.9	₦695,791	₦0.00	₦695,791
September	14,722	0	14,722	61.6	₦662,509	₦0.00	₦662,509
October	14,719	0	14,719	62.3	₦662,367	₦0.00	₦662,367
November	14,213	0	14,213	61.3	₦639,570	₦0.00	₦639,570
December	14,960	0	14,960	65.7	₦673,208	₦0.00	₦673,208
Annual	175,811	0	175,811	71.9	₦7.91M	₦0.00	₦7.91M