TECHNO-ECONOMIC FEASIBILITY OF SUSTAINABLE OFF-GRID ELECTRICITY FOR SELECTED RESIDENTIAL ESTATES IN IKOYI, LAGOS, NIGERIA

***[1]Bakare, O. H., [1]Ogundari, I. O., [1]Adejuwon, O. O., [2]Ajiboye, O. K and [3]Salu, B. O.**

DOI10.51459/jostir.2026.2.1.0303

[1]African Institute for Science Policy and Innovation, Obafemi Awolowo University, Ile-Ife, Nigeria.

[2]Department of Science Laboratory, University of Medical Sciences, Ondo.

Correspondence
ayandimeji16@gmail.com

History
Received: 30-07-2025
Accepted: 27-01-2026
Published: April, 2026

https://www.futa.edu.ng

JOSTIR JOURNAL OF SCIENCE, TECHNOLOGY AND INNOVATION RESEARCH
https://jostir.futa.edu.ng

ABSTRACT

This study examined both the technological and economic feasibility of the design of an off-grid, photovoltaic (PV)-powered digital energy infrastructure in strategic residential estates in Ikoyi, Lagos state, Southwestern Nigeria. This research was intended to develop a strategic model in developing sustainable and economical power options. Site-based data on the techno-economic facets were gathered by site-visit, survey and literature review. Additionally, an engineering foresight analysis was utilized to evaluate potential energy projects and carbon dioxide emission reduction. According to the results, the housing estate uses 27.7MW of energy overall. The required energy consumption gave rise to the design of a 28MW PV system. Additionally, the PV system will cost $525,552 to build and $57,545 to operate each year. With an annual energy usage of 10,108,288 kWh and a total life cycle cost (LCC) of $0.16/kWh, the electricity generated $1,617,326 in income. The PV system will eliminate 2,708,733kg of CO_2 from the atmosphere in addition to providing constant electricity supply.

The Study found that the PV system stand-alone alternative electric power initiative for Housing Estates in Ikoyi Lagos State was technically feasible and economically viable.

Keywords: Sustainable, Off-grid, Photovoltaic, Life cycle cost, Residential estate, Ikoyi, Electricity

1. | Introduction

Modern society and the global economy heavily rely on energy to provide essential services such as transportation, healthcare, entertainment, food production, and telecommunications. Electricity, a carrier of energy, forms the backbone of civilization, with its steady availability and supply enabling the growth and development of societies worldwide. However, only 30% of the world's electricity was generated in 2021 from renewable energy sources; the remaining 70% came from non-renewable sources (Rahman *et al.*, 2022). Although this is unequal, investment in renewable energy across the globe has continued to rise over the past years, especially the development of off-grid photovoltaic energy systems that guarantee unrestrained supply of electricity. Conventional sources of energy - commonly known as fossil fuels - coal, petroleum oil and natural gas have been taken advantage of to generate electricity in power stations over centuries. The unfortunate fact is that use of these fossil fuels leads to the emission of carbon and other greenhouse gasses that trigger the degradation of the environment. It is projected that the world will need more energy by 56 per cent by

2040 and the energy demands will continue to rise on an average yearly rate. Governments and businesses must use alternative energy sources to solve the urgent problems and pave the way for a more sustainable and clean future in light of the growing concern over global warming and sustainable development. The Federal and State governments have been encountering low success in investments in electric power supply in Nigeria and thus the country is experiencing large power supply shortages. Electricity infrastructure is mainly supplied in the country using thermal plants which have seven thermal and three hydro generation plants. Its generation, transmission and distribution total installed capacities are 12.5 GW, 5.3 GW and 7.2 GW respectively. However, estimates of the actual amounts of power produced, transferred, and distributed are 3.9 GW, 3.6 GW, and 3.1 GW. Of this, 2,143 MW is provided by means of renewables, and hydropower is 2,111 MW (RENA, 2019). Access to electricity is not available to approximately 40% of the population (Olanipekun and Adelakun, 2020) even though the total hydropower potential in Nigeria is about 14,120 MW, which can produce more than 50,800 GWh of electricity per year (IHA, 2018). Nigeria's electricity supply is hampered by a number of variables, including organizational and governmental policies, financial issues, equipment theft, and rapid population increase. According to Ogundari *et al.* (2017), Omolade *et al.* (2019), and Ogundari *et al.* (2021), the residential sector uses 59.6% of the nation's electricity, while the commercial and industrial sectors use 30.4% and 10%, respectively. Nigeria continues to struggle with unpredictable electricity supplies, just like other developing nations The percentage of the population having a means of getting electricity has declined by more than 10.6%, and the country is among the least developed in the world in respect to per capita access and consumption of electricity over the past ten years (UNDP, 2017). The IEA (2019) predicts that renewable energy is on the rise due to declining costs of technology, and it is quickly changing the energy situation in unserved and neglected areas. The use of renewable energy technologies is highly influenced by government policies and priorities in a country where the market is not competitive as it is the case in Nigeria. These objectives and policies have enabled the creation of regulatory frameworks and non-regulatory support of the renewable energy. The Federal Government of Nigeria introduced the National Renewable Energy Master Plan (NREMP) in 2005 and revised it in 2012. However, the NREMP failed to materialize despite the goal of diversifying the energy portfolio and eventually shifting the country to a dependence on fossil fuels (Olanrele, 2023). Despite the development of such policies, renewable energy still contributes very little to Nigeria's national electrical system; in 2019, only 25% of the country's energy came from renewable sources, with solar energy making up a negligible portion of the total. One green energy source is solar power. As opposed to other sources of energy, solar energy is renewable and in abundance, which makes it an appealing substitute of grid electricity to be used at homes. This significance is amplified by the fact that the sun generates a lot of energy in one hour which equals the amount consumed by the world in a year. In one year, the volume of solar energy that gets to the Earth is about 178,000 terawatts, and this is approximately 15,000 times more the daily energy consumption of the planet (Agbo *et al.,* 2021). In April 2024, the Nigerian Electricity Regulatory Commission (NERC) declared a massive rise in electricity charges, increasing the rate to 225 Naira per kilowatt-hour (kWh) (up to 66). This extraordinary 340 percent increase raised a lot of popular protests by the organized labor and the National Assembly members. To contain the escalating instability, NERC has promptly categorized customers into five groups; Band A, B, C, D and E, according to the number of hours each is supplied with electric power per day, with the various tariffs. Customers in the Band A category are provided with one day power supply (20 to 24 hours a day) whereas customers in the Band B category have 16 to 20 hours. Conversely

Bands C, D and E have an electricity supply of 12-16 hours, 8-12 hours and 4-8 hours, respectively. Due to these developments, there has been a rising demand to find alternative sources of electricity that do not go through the national grid to overcome the challenges caused by the new tariffs including high cost, insufficiency, instability (the national grid has collapsed more than ten times this year) as well as economic hardship that has been worsened by the previous abolition of the petroleum subsidy. This has led to the utilization of generators that are powered by diesel or petrol as the alternative source of energy. Nonetheless, these alternative sources are not sustainable and cause pollution of the environment due to CO_2 emissions. It has been found out that solar energy with photovoltaic (PV) technologies can produce cleaner electricity and be more environmentally sustainable than any alternative (Mitrašinović, 2021; Hasan *et al.,* 2023). Therefore, the objectives of this study are to ascertain the amount of electricity consumed in residential estates, assess the techno-economic characteristics of photovoltaic (PV) systems as options for off-grid electric power supply, determine whether deploying PV systems for off-grid electricity supply is feasible, and investigate the environmental benefits of PV systems.

2. | Literature Review

A comparison has been made between the projected active lifespan and cost-effectiveness of various commercial power generation technologies and current solar electricity solutions. As shown in Table 1, it is evident that renewable energy options are better suited for a sustainable future and contribute positively to the global economy (Romano *et al.,* 2017).

Table 1 | Juxtaposing Different Electrical Power Generation Technologies

S/N	Power Generation Option	Installation Cost per MW ($)	Expected active life (years)	Load Factor (%)	Impact to Environment
1	Thermal	3-6	50-80	>70	High
2	Hydropower	3-6	100	>85	Low
3	Natural Gas	0.72-2.0	80-95	>95	Medium
4	Nuclear	5.0	50-70	>98	High
5	Solar	3.8-4.5	25-30	>25	Least
6	Wind based	2.2-6.2	25-30	>38	Low
7	Biomass	4.5-8.0	20-25	>75	Low
8	Geothermal	4.5-6.0	30-50	>80	Medium

Source | Sawin *et al.* (2015)

The sustainability of solar PV electricity both in terms of cost in the long run and a friendly environmental impact has led to the adoption of sunlight for electricity generation, often defined as the utilization of Solar energy. Photovoltaics (PVs), which use solar energy in the form of photons striking surfaces to cause electrons to flow (photo-electric effect), can directly use this energy. Concentrating solar power is an indirect technique that uses solar energy to raise the temperature of water or enclosed spaces (solar collectors) in order to produce electricity (Islam *et al.,* 2018).

2.1 | Solar Radiation

Solar energy has a potential solution to the challenges of energy, environmental degradation and sustainability, which is serious global threat. Combustion of fossil fuels has continuously resulted in the adverse environmental effects and has been a major threat to the future of energy among mankind. The concept of solar energy has received much attention with renewable energy (RE) becoming increasingly popular (Maka and Alabid, 2022). Solar energy is renewable and is in contrast to other resources. Therefore, it is becoming a potential substitute to conventional grid power as a source of residential and commercial power. Photovoltaic (PV) technology is used to convert solar radiation into electricity by overcoming the photovoltaic effect of solar cells. With a series of solar PV cells, the possibility of creating a large amount of electricity is possible by connecting the cells in series or parallel mode. Despite the relatively high starting cost of PV systems, solar energy is widely recognized as a viable energy source in many parts of the world. The quantity of solar energy that is reflected to the earth surface by the sun is known as solar irradiance, and the average energy density of the solar energy is 1000 W/m^2 (Oji *et al.,* 2012). Solar panels when under full sunlight are to be expected to produce between 140 and 160 W per square meter, which is equivalent to 14 and 16% efficiency (Oji *et al.,* 2012). Full sun hours refer to the duration of time, e.g., five hours, when the sun is irradiated by the sun with an irradiance of about 1000 W/m^2. The complete energy taken by the sun is called insolation. The quantity of solar energy available and amount of the full sun hours vary with different areas as solar electricity generation depends on the geographical location. In Nigeria, the sunlight gets 3000 hours annually. The country however has poor energy results. Approximately, 97,000 rural neighborhoods have no electricity, and the main reason is related to the lack of proper infrastructure (Agbo *et al.,* 2021). The energy supply is highly unpredictable, despite having traditional sources of energy.

2.2 | Energy Circumstances in Nigeria

Due to its widespread availability, solar energy is the most attractive and efficient method of generating electricity when compared to other renewable sources in developing nations like Nigeria, where people heavily rely on fossil fuels. In contrast to wind energy and hydropower, which require enormous regions of open spaces and water masses, respectively, solar energy could be used with much less space (Okoro and Madueme, 2006). Because of its adaptability, solar energy may be used in a variety of Nigerian fields, including engineering, agriculture, medicine, power generation, and recreation. Nigeria has two main seasons: wet and dry. It is situated between 8^0E and 10^0N. Such seasonal changes have a great effect on the use of various renewable energy sources. As an example, the efficiency of hydropower stations is affected by the changes in the water availability. Furthermore, the lack of natural gas in different wells of Niger Delta also constitutes a challenge to thermal power plants and makes people turn to petrol and diesel generators as more convenient ones (Charles and Meisens, 2014). Nigeria has been aware of the renewable energy (RE) as an important source of complementing electrical power generation since the early 2000s. Although this alternative source of energy is implemented at a small scale in the local economies, it has not been implemented on a larger scale in the national grid (Ma'Sud *et al.,* 2015). The changing oil prices, the presence of unnatural climatic variations (including global warming) and the ever-increasing demand of electricity are some of the factors that have necessitated the Nigerian government to step up in embracing photovoltaic (PV) technology. As of today, solar PV is presently deployed in certain areas of Nigeria with the main purpose of providing secondary power or serving as a backup during the times of various supply or outages (Njok *et al.,* 2020). These applications are telecom masts, street lights, parks among others. Although Nigeria has a massive amount of fossil fuel, it is necessary to focus on the creation of the balanced energy mix involving renewable energy sources. This would be a strategic change as the country would be able to make a steady stream of foreign exchange by exporting these renewable materials with the world showing a decreasing demand with fossil fuels. The use of crude oil alone poses a threat to the reduction of the overall GDP of Nigeria (Sambo, 2005). In order to overcome this difficulty, it is necessary to strengthen the supporting work of research, development, and demonstration projects in the current research institutions as well as involve the prospective partners of different spheres. One of the viable remedies is to train local craftsmen on how to design, construct, operate and maintain the solar energy systems as well to provide soft loans to facilitate production and adoption. As a developing country with a large population, Nigeria has been blessed with an abundant amount of sunlight, and therefore there is a large population of its people who are not connected to the electricity supply which creates a great potential in the development of solar energy market. With the increase in the applications of solar energy, numerous photovoltaic (PV) cell technologies have come into existence. In 2008, the photovoltaic industry garnered a consolidated revenue of 37 billion across the world with the fastest growth being witnessed in the grid application industry (Onuk *et al.,* 2011). In 2012, Nigeria was extensively depending on fossil fuels as a source of electricity with 79 percent of its power generation depending on this energy. The thermal power generation in the country was approximately two-thirds of the natural gas and oil. Such a dependency on fossil fuels ranked Nigeria as the 46th most significant producer of carbon dioxide (CO_2) in the world, with a CO_2 generation of an estimated 73.69 metric tons of CO_2 into the air in 2011 (Charles and Meisen, 2014).

2.3 | Rate of Radiation in Nigeria

The sun releases energy at a rate of around 3.8 x 1023 kW/s, and Nigeria receives an average of 4.85 × 10 12kW/h of energy every day. An average of six hours of sunshine each day may provide this energy, which is equal to the daily production of 1.082 million tons of oil (Shaaban and Petinrin, 2014; Bala, 2014). Estimated in standard units of energy, this is almost 4,000 times Nigeria's current daily production of crude oil and 13,000 times its daily production of natural gas (Shaaban and Petinrin, 2014). In cases were used as a free, renewable energy source, this clean energy can greatly benefit several sectors of the Nigerian economy (Adelekan, 2012). With an area of roughly 924 km^2 and an average irradiation of 5.535 kWh/m^2, Nigeria is expected to generate 1,831.06 kWh of solar energy annually. According to Madabo (2010), the insulation of solar energy is more than 117,000 times greater than the quantity of electricity generated in 1998 and almost 27 times greater than the nation's traditional power sources in terms of energy units. Approximately, 3.7 per cent of the country would be required to be exploited in order to tap solar energy equivalent to the traditional reserves of energy. Based on the estimation by Bala EJ (Bala and Pam, 2012), 1 percent of the total land area of Nigeria would be capable of producing approximately 333, 480 MW of electricity with an approximate capacity factor of 26 in case 1 percent of the area is fitted with solar technology whose efficiency is 5 percent. Such possible capacity of electricity production would be adequate to serve the needs of the country up to 2050. Photovoltaic (solar-to-electric) conversion Photovoltaic conversion is a method of producing electricity by converting sunlight into electricity (Gredler, 2011). This is achieved by converting direct sunlight to electricity by the use of Photovoltaic (PV) cells, which are made of special materials referred to as semiconductors. These semiconductors are used to conduct the electricity by the photoelectric effect which is the process whereby the sunlight activates the semiconductor material leading to the production of electrical energy. A complete solar electric system is a combination of PV solar panels, inverters, charge controllers and solar batteries. This design allows uninterrupted flow of power as pointed out in the research article by Osueke and Ezugwu (2011). A photosensitive switch may be used in order to smartly turn the solar inverter on or off to improve the efficiency and lifespan of the system. The PV panel is the most crucial and vital part of a solar electric system. As discussed above, these PV panels consist of semiconductors and work on the principle of photoelectric effect which generates energy proportional to the incident energy of the sun. When the solar cells are kept in series, their voltage will be greater, and each cell will produce about half a volt. Nevertheless, under load, even 12-volt solar panels are capable of producing around 14-18V, and thus, they can power a 12-volt battery as observed in the research conducted by Njok *et al.* (2020).) The solar electric system depends on the photovoltaic (PV) panel as its foundation. These panels are made of semiconductors and work on the principle of photoelectric effect and the amount of energy generated relies on the amount of sunlight the panels get. Individual cells of solar cells are to be put in series to get a more useful voltage since a typical solar cell can only generate a few half-volts. As an example, under a load, 12-volt solar panels can produce 14 to 18 volts, and thus they will be able to charge a 12-volt battery (Njok *et al.,* 2020).

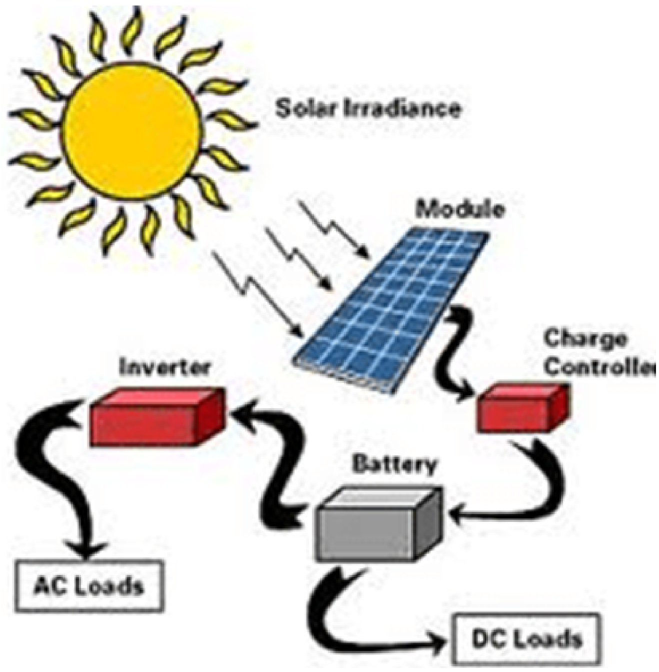

Figure 1 | Component of Solar-to-Electricity System

Source | Kumar and Vijana (2016)

The intensity of a photovoltaic (PV) panel may depend on a variety of factors, such as the DC rating of the panel, the slope of the panel, and the geographical location or the solar irradiation pattern of the place where the panel is installed (Al Sharif and Kim, 2016). An average panel with 1 kW rating costs around 1000 dollars (Al Sharif and Kim, 2016). The amount of sunlight on a solar panel is directly proportional to the amount of power that the panel can generate. A solar panel is however never normally used to directly supply electrical equipment. The changes in the intensity of the sunlight lead to the panels producing different voltage output, and hence the inconsistency is not appropriate in the majority of electrical equipment. To address these fluctuations and ensure a consistent power supply, a battery bank is employed to store energy, allowing for power consumption when solar energy is inadequate, whether during the day or at night. Most batteries used in solar photovoltaic systems are either 6 volts or 12 volts and can be connected to a battery bank like solar PV systems.

2.4 | Computational Technique for Photovoltaics

Gaining an understanding of various solar PV-related characteristics is crucial to estimating solar PV output capacity. The solar array's output energy, *E*, is computed using equation (1);

$$E = C_{PV} \times F_{PV} \times PSH \qquad (1)$$

Where C_{PV} is the capacity of the PV array, and PSH is the peak solar hour, F_{PV} is the PV derating factor. 'This derating factor reflects the impact of temperature, dust, wire losses, and other factors that can affect the solar array's output energy' (Al Sharif & Kim, 2016); Al-Ghezi *et al.,* 2022).

The percentage of incident solar irradiance (power) that is transformed into electrical energy is shown by the solar array's performance ratio, or PR. This percentage can be computed using equation (2);

Performance ratio of Solar PVs:

$$PR = \frac{(Pmea/Pmax)}{(Emea/100)} \qquad (2)$$

Where Emea is the measured incident solar irradiance (power) on the PV array, Pmea and Pmax are the measured and maximum power respectively from the PV array (Ogbulezie *et al.,* 2020).

2.5 | Ikoyi Lagos

Located on Lagos Island, Ikoyi is one of the wealthiest areas of Lagos, Nigeria. It is situated in the northeastern region of Obalende, bordering the Lagos Lagoon and taking up the eastern half of Lagos Island. Ikoyi is regarded as one of the wealthiest communities in the Eti-Osa Local Government Area (Onajomo, 2022). Ikoyi is a prestigious neighborhood that has changed to be characterized by a combination of domestical residential houses and businesses. Ikoyi was initially a residential district of the expatriates as stipulated by the British Colonial Government, but I guess the Ikoyi charm was probably because of its closeness to the sea. With time the neighborhood has evolved and now is one of the best places where any big corporation can locate its headquarters. Nowadays Ikoyi is a neighborhood of the Nigerian elite including diplomats, top managers of the business world and high-rank officials.

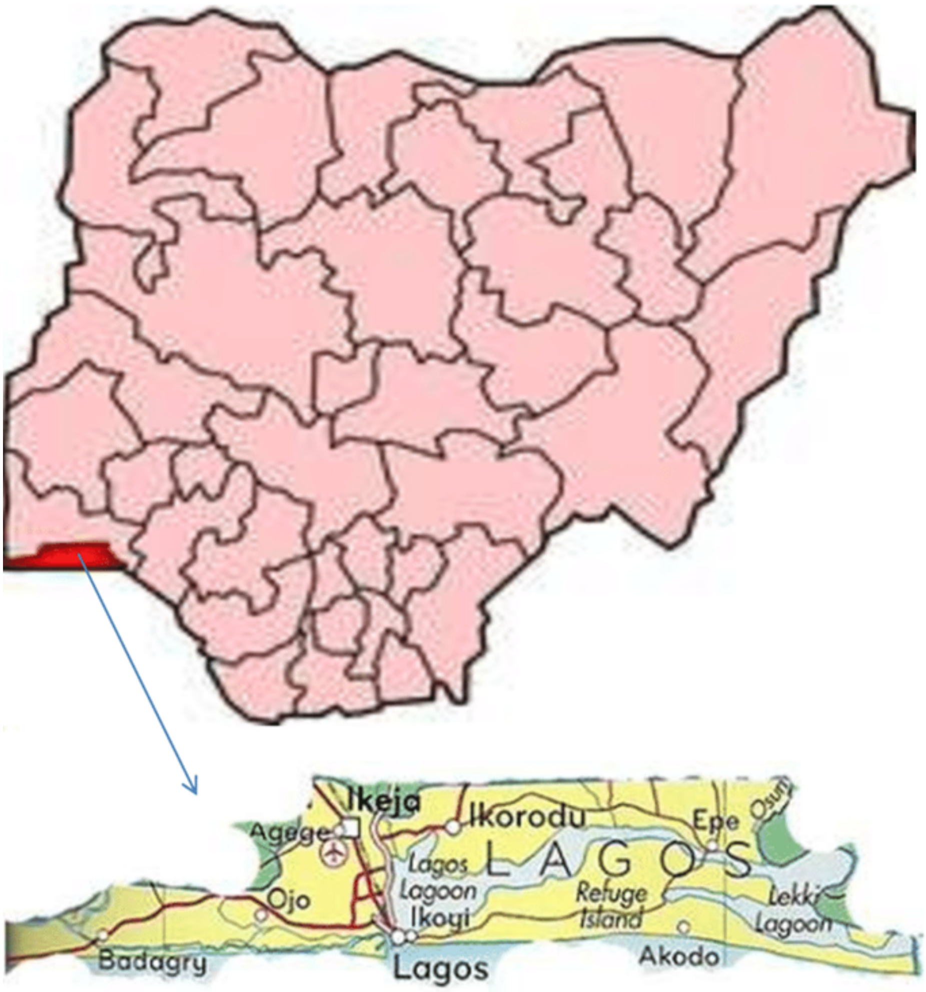

Figure 2 | Map of Nigeria Showing Lagos State and Ikoyi

Source | Adeyeye *et al.* (2015)

Ikoyi is home to some of Nigeria's most opulent neighbourhoods and is thought to have the priciest real estate in all of Africa, with a brand-new one-bedroom flat costing about N120 million (about US $1 million). Such residential provision is at vertical apartment complexes due to shortage of available land. Prices of luxury three-bedroom apartments in Ikoyi cost between $45 and 80,000 (N5.2 million to N9.3 million) per annum. Only five years prior rent was between 10,000 and 30 000 per year (N1.16 million to N3.5 million). The value of an acre (six standard plots) of land in prime locations such as Banana Island, Parkview Estate, and Osborne Road is now ranging between N400,000,000 and

N450,000,000, whereas it used to be between N50, 000,000 and N150, 000,000 five years ago. Ikoyi contains more modern neighbourhoods of Banana Island, Parkview Estate and Dolphin Estate. Eko Electricity Distribution Company (EKEDC) mainly serves the region and most of the customers in Band A have a projection of 20 to 24 hours of electricity supply. Although it is believed that the people living at the Ikoyi area are rich, they constantly encounter issues of irregular power supply. It is not the capacity to pay the new tariff; the question is how reliable is electricity. Consequently, many residents have turned to alternative power sources, primarily diesel- or petrol-powered generators.

3. | Methodology

The study takes into account two privately owned home estates in the Ikoyi region. The 250 and 200 three-bedroom homes that make up the housing estate were constructed as a single construction. It is assumed that every housing unit has the same electrical load demand. The housing estates have been approved by the government and have been properly documented with the Lagos State Real Estate Regulatory Agency (LASRERA). The majority of the people living in the housing estates are members of the corporate working class, who typically have three children per family and are well educated (holding at least a Master's degree).

The highest potential demand for electric power is the basis for energy planning. Therefore, it is projected that the housing units in the estates will utilize electric appliances for the maximum amount of time each day—24 hours. This presumption is based on NERC's classification of the region as a band A energy user. Each apartment in the individually owned housing estates has the same basic electric appliances installed, along with matching decor. To verify the validity of identical housing designs and essential electric appliance installations, ten housing units in each estate were visited at random.

To achieve the first objective, an energy audit of the housing estates was conducted. This entails:

a. Conducting a thorough walkthrough of the building to identify major energy-consuming systems through an audit entailing appliance inventorying,

b. Detailed electric power load of appliances, wattage measurement, and

c. Appliance time of use measurement.

All of the dwelling units that were visited had 15W compact fluorescent bulbs (CFL) under the energy-efficient scenario. Data on Life Cycle Costs (LCC) for off-grid power systems over a 20-year period are gathered from primary and secondary sources in order to accomplish objective ii. Designing the stand-alone PV system for the estate's electrification was the initial phase. The predicted total energy usage per household is used to calculate the peak power of the PV generator design. The literature provides additional parameters for the computation. The dimensions of the battery, digital charge regulator, and inverter must then be ascertained. Electric power suppliers provide the related costs of the standalone PV system's components, which are then entered into the LCC formulas to calculate the LCC of the power choice. The energy supply systems' cost evaluation was calculated using the following formulae:

3.1 | LCC Analysis Capital Cost

Capital cost (cc): These are the one-time fixed cost of purchasing and installing the plant.

Non-recurring cost: This is a form of fixed cost used for the replacement of parts and may be referred to as Life Replacement Cost as shown in equation (3).

$$\text{LRC} = \sum \left[IC \times \left\{ 1 + \left(\frac{1+Ge}{1+Dr} \right)^{Ry} \right\} \right] \quad (3)$$

Where LRC is the non-recurring costs (Life Replacement Costs), IC is the cost of the item, Ge is the general escalation value and is 10.8% as of

2023 (Adefarati *et al.,* 2024), Dr is the Discount rate which is equivalent to the present lending rate and is 27.50% as at November 2024 (Ononuju *et al.,* 2024) and Ry is the item replacement year which is 10 years.

Recurring Cost: These are the regular costs that account for servicing costs.

$$LFC = AFC \times \left[\left(\frac{1+Fe}{Dr-Fe}\right) \times \left(1-\left(\frac{1+Fe}{1+Dr}\right)^{P}\right)\right] \quad (4)$$

Where LFC is the life cycle fuel cost, Fe is the fuel escalation and p is the life cycle of the PV system which is 25 years.

$$LMC = AMC \times \left[\left(\frac{1+Ge}{Dr-Ge}\right) \times \left(1-\left(\frac{1+Ge}{1+Dr}\right)^{P}\right)\right] \quad (5)$$

LMC is the life cycle maintenance cost, and AMC represents annual maintenance cost.

Life Cycle Costs are determined by the equation (6):

$$LCC = \frac{cc+LFC+LMC+LRC}{Period \times 365 \times kWh/day} \quad (6)$$

The costs for the housing estates using the PV system option were computed and the viability was determined.

4. | Results and Discussion

This section presents the calculations performed in the study. The experiment is founded on the 24-hour power supply according to the methodology. As it is known, power distribution companies have been known to charge its customers based on their highest maximum possible demand per 24-hour period. Power supply planning and billing in Nigeria is based on the 24-hour template of power supply and this is also the case with the study. The consumption of electricity in the housing estates can be analyzed and the following results are obtained. The overall power rating per unit housing is 8,262 W, which is equated to the 61,536 Wh/day or 61.536 kWh/day of energy consumption (Table 2). The later calculations showed that in the case of the Estate One which has 3-bedrooms apartments and 250 housing units, the total energy consumption is 15,384 kWh/day which is 5,615.16 MWh/year (Table 3). In the same way, the total energy consumption calculated in the case of Estate Two with 200 housing units is 12,307 kWh/day, which denotes 4,492.13 MWh/year (Table 4).

Table 2 | Electricity Consumption Per Housing Unit

S/N	Electrical Appliances	Quantity	Power Rating/ Unit (W)	Total Power Rating (W)	Daily Use (h)	Energy Consumption (Wh/day)
1	TV	2	220	440	8	3520
2	Freezer	1	350	350	24	8400
3	Fridge	1	220	220	24	5280
4	Fan	4	100	400	10	4000
5	AC	4	750	3000	8	24000
6	Washing machine	1	500	500	1	500
7	Bulb	20	15	300	12	3600
8	Iron	1	1000	1000	1	1000
9	Water heater	1	300	300	1	300
10	Sound system	1	100	100	8	800
11	Microwave	1	850	850	1	850
12	Electric pressure cooker	1	1000	1000	4	4000
13	Laptop	3	100	300	10	3000
14	Phone charger	6	7	42	8	336
15	Oven	1	2000	2000	0.6	1200
16	Toaster	1	750	750	1	750
	TOTAL		**8262**	**11552**		**61536**

Therefore, a comprehensive examination of the data from both estates yields a total energy demand consumption of 27,691 kWh/day and 10,108.288 MWh/year (Table 5).

Table 3 | Energy Consumption for Housing Estate One

	(Average 3-Bedroom Apartment)	
	Per Unit	**For the 250 Units**
Power Rating (kW)	8.262	2,065.5
Electricity consumption (kWh/day)	61.536	15,384
Electricity consumption (kWh/year)	22,460.64	5,615,160

Table 4 | Energy Consumption for Housing Estate Two

	(Average 3-bedroom apartment)	
	Per Household	**For the 200 Houses**
Power Rating (kW)	8.262	1,652.4
Electricity consumption (kWh/day)	61.536	12,307
Electricity consumption (kWh/year)	22,460.64	4,492,128

Table 5 | Electric Power Load and Energy Consumption for Each of the Selected

S/N	**Estate**	**Total Number of Housing Units**	**Total Power Load Demand (kW)**	**Total Energy Demand Per Day (kWh)**	**Total Energy Demand Per Year (kWh)**
1	Estate one	250	2,065.5	15,384	5,615,160
2	Estate two	200	1,652.4	12,307	4,492,128
	TOTAL	**450**	**3,717**	**27,691**	**10,108,288**

4.1 | Designing the Appropriate PV for the Housing Estate

There are 450 housing units in the two estates, with a combined total daily electricity consumption of 27,691 kWh. Therefore, to determine the total Wh/day needed from the PV modules:

Total Wh/day = total appliances Wh/day × 1.3; where 1.3 is the energy lost in the system.

Total Wh/day = 27,691 × 1.3 = 35, 998.3 kWh/day

4.1.1 | Determining the Size of the PV Module

This requires the panel generating factor. The factor in Nigeria has been determined to be 3.65 (Onwuzuruike and Aminu, 2019). Therefore;

Total W_{peak} rating required for the PV module =

$$\frac{35{,}998.3}{3.65}$$

PV module W_{peak} = 9,862.55 kW

4.1.2 | Determining the number of PV panels required for the system

The number of PV panels needed for the system is determined by:

$$\text{Number of PV panels} = \frac{9{,}862{,}550}{550}$$

A total peak rating of 9,862 kW is required for the PV module. A polycrystalline-60 rectangular cells module type CS6-P-230-P with a peak power of

Pmpp = 550 W, a cross-sectional area of 1.61 m2, and a rating of 12 VDC is chosen to install electricity. The number of PV panels is 28,886.51, which is approximately 28,887 modules, assuming that the efficiency of the PV is 60%.

4.1.3 | Determining the Size of the Inverter

The total wattage of all appliances is 3,717 KW. For safety, the inverter's minimum size should be at least 25% bigger than the total appliance wattage.

Thus, minimum inverter size = 3717 + (3717 × 0.25) = 3717 + 929 = 4,646 KW

4.1.4 | Determining the Size of the Battery

Battery capacity (Ah) =

$$\frac{Total\ Wh\ per\ day \times Days\ of\ Autonomy}{DoD \times VB\ (nominal) \times Battery\ Efficiency}$$

Where, DoD = depth of discharge = 0.6,

Battery efficiency = 85%,

V_B Nominal = nominal battery voltage = 5000 V,

Days of Autonomy = 2 days.

Battery capacity (Ah) = $\frac{27,691,000 \times 2}{0.6 \times 5000\ V \times 0.85}$ = 21718Ah

The PV system's battery block will consist of twenty-two (22) parallel 5000 V/1000 Ah battery units, each with 2 days of autonomy.

4.1.5 | Determining the Size of the Solar Digital Charge Regulator

Size of Charge Regulator = [Wp + (Wp × 0.15)]

Size of Charge Regulator

= [9,862.55 + (9,862.55 × 0.1)]kW

= 10, 848.805 kW

The total power demand of the two estates is 3,717.9 kW, while the total energy consumption is 27,691 kWh/day. It is, therefore, advisable to make the design of the PV power generating rating to be for 28.0 MW.

4.2 | LCC for the PV System

The tariff class for the Ikoyi axis of Lagos State is Band A, which is billed at ₦ 209.50/kWh.

$$\text{Daily cost of electricity} = \text{Daily Electricity Demand}\left(\frac{\text{KWh}}{\text{day}}\right) \times \text{Electricity Tariff}\left(\frac{\text{x₦}}{\text{KWh}}\right) \quad 7$$

= 27,691 (kWh/day) X ₦209.5/kWh

= ₦5,801,264.5/day ($3,867.51)

Annual Cost = 304 days/year × Daily Cost of Electricity Demand (x₦ /day) 8

= ₦ 1,763,584,000 ($ 1,175,723.04)

$$\text{LEC} = \text{AEC} \times \left(\frac{1+Ee}{1+Dr}\right) \times 1 - \left(\frac{1+Ee}{Dr-Fe}\right)^N \quad 9$$

E_e =19% (0.19) D_r =27.5% (0.275) (CBN, 2024)

N (Period) = 20 years, Daily Demand (kWh/day) = 27,691kWh/day

Using the above equation; LEC = $54,460,043.2

$$\text{LCC (\$ / kWh)} = \frac{\text{LEC}}{Period \times 304 days \times kWh / day} \quad 10$$

$$\text{LCC (\$ / kWh)} = \frac{\$54,460,043.2}{168,361,280 kWh}$$

LCC($/KWh) = $0.323/kWh (₦484.50/kWh)

Life Cycle Cost for Grid Supply = $0.323/kWh (₦484.50/kWh)

Table 6 | Cost of the PV System

Item	Component	Quantity	Unit Price ($)	Life Time (Years)	Total Price ($)
1	PV module (CS6P-230-P)	28887 W	1.2/W	25	34,664
2	Inverter 50KVA/360V	93	3,200	10	297,600
3	Battery 2v 1000Ah	22	150	10	3,300
4	Switches and circuit breaker	1	105	5	105
5	Installation Materials				100
6	Digital Charge Controller	311	285	10	88,635
7	Installation Cost				350
8	Total System Cost				**424,754**

Table 7 | Techno-Economic Assessment of the Off-grid PV System

Item	Description	Amount ($)
1	***Capital Cost***	
	Cost of Land	NIL
	Cost of building	50,000
	Cost of PV system	424,754
	Cash in hand	50,798.68
	Total investment	***525,552.68***
2	***Operations Cost***	
	Depreciation (29.7% of TOC)	17091.14
	Operations & Maintenance (41% of TOC)	23,593.83
	Other costs (insurance, taxes) (20% of TOC)	11,509.19
	Total Operating Costs (Annual)	***57,545.93***
3	***Revenue (Equals cost of conventional tariff)***	
	The electricity tariff for band A customers is $0.16. The yearly energy demand is 10,108,288 kWh	1,617,326.08

NB: The photovoltaic panels of the system was purposively mounted on the rooftops of the buildings in the estate to eliminate the cost of securing land, which is relatively scarce in the study area.

4.3 | Environmental Benefits of the PV Systems

The environmental advantages of the residential complex's PV alternative power supply are examined in this section.

Households and businesses in Nigeria frequently employ diesel generators as a backup power source during blackouts. Carbon dioxide (CO2), a recognized greenhouse gas, is released by diesel fuel. By using the PV system, the CO2 that would have been produced if diesel fuel had been used as the alternative power source is eliminated (Ogundari *et al.,* 2017).

Guaranteed power supply per project

The PV system would guarantee the daily supply of 27,691kWh of electricity.

Thus,

Annual power supply in the estate = (27,691×365) kWh = 10, 107,215 kWh

Electric power supply from a diesel generator alternative power option

One litre of diesel can produce 10kWh of energy (Oviroh and Jen, 2018)

Daily electricity consumption in the residential complex is 27,691kWh.

Thus, 27,691kWh would require = $\frac{27{,}691\times 1}{10}$

S = 2,769.1 litres of diesel per day.

A litre of diesel emits 2.68kg of carbon dioxide (CO_2).

Thus,

1 litre of diesel consumption = 2.68kg of CO_2

2,769.1litres of diesel consumption

= (2.68×2,769.1) kg of CO_2

= 7,421.118kg of CO_2

The daily consumption of electricity would require;

2,769.1litres of diesel for electric power generation, and generate 7,421.118kg (7.42 metric tonnes) of CO_2.

In a year, diesel requirements would be (2,769.1 × 365) litres of diesel or 1,010,721.5 liters. This amount of diesel would emit (1,010,721.5×2.68) kg of CO_2; i.e. this amount of diesel would emit 2,708,733.62kg (2,708.73 metric tonnes) of CO_2

Thus,

The deployment of the PV system for alternative electric power supply in the housing estates would eliminate the use of 1,010,721.5 liters of diesel and remove 2,708,733.62kg (2,708.73 metric tonnes) of CO_2 emissions from the atmosphere, thereby improving the air quality.

5 | Conclusion

This study examined the techno-economic feasibility of an off-grid alternative power supply option, specifically PV system developments, for selected housing estates in Ikoyi, Lagos, Nigeria, aiming to mitigate the erratic nature of the power supply in the area and alleviate the heavy financial burden resulting from the recent tariff hike. This action was taken in compliance with the combined electric power programs for the area. A strategic engineering foresight analysis was utilized to evaluate the potential energy projects and carbon dioxide emission reduction.

The investigation found that each housing unit in the estate has a power rating of 8,262W, corresponding to an energy consumption of 61.536 kWh/day. A total of 27,691kWh/day and 10,108.288MWh/year is the energy consumption in the estate. A 28MW PV system was therefore designed for the 450 housing units in the estate. This power facility would cost an estimated $525,552 million, with a total yearly operating cost of $57,545, and have a yearly revenue of $1,617,326. The PV system will provide a guaranteed constant supply of electricity in the estate. It will also take away the use of 1,010721 litres of diesel that will be used in the estate to provide the needed electricity by the generating sets. The PV systems will equally take away 2,708,733kg of CO_2 from the atmosphere that would have been produced by the use of diesel generating sets. This removal of CO_2 from the atmosphere will improve the air quality in the estate.

The investigation found that the PV system stand-alone alternative electric power initiative for Housing

Estates in Ikoyi, Lagos State was technically feasible, and being more environmentally and economically viable relative to the alternate diesel-powered electricity generation systems, was suitable for residential electricity deployment in the study area.

Reference

Adefarati, T., Bansal, R.C., Naidoo, R., Onaolapo, K.A., Bettayeb, M., Olulope, P.K. and Sobowale, A.A., 2024. Design and techno-economic assessment of a standalone photovoltaic-diesel-battery hybrid energy system for electrification of rural areas: A step towards sustainable development. *Renewable Energy*, *227*, p.120556.

Adeyeye, S.A., Oyewole, O.B., Obadina, A.O. and Omemu, A.M., 2015. Influence of smoking method on quality of traditional smoked Bonga shad (Ethmalosa frimbriata) fish from Lagos State, Nigeria. *African Journal of Food Science*, *9*(4), pp.200-207.

Agbo, E.P., Edet, C.O., Magu, T.O., Njok, A.O., Ekpo, C.M. and Louis, H., 2021. Solar energy: A panacea for the electricity generation crisis in Nigeria. *Heliyon*, *7*(5).

Al-Ghezi, M.K., Ahmed, R.T. and Chaichan, M.T., 2022. The Influence of Temperature and Irradiance on Performance of the photovoltaic panel in the Middle of Iraq. *International Journal of Renewable Energy Development*, *11*(2), p.501.

Alsharif, M.H. and Kim, J., 2016. Optimal solar power system for remote telecommunication base stations: A case study based on the characteristics of South Korea's solar radiation exposure. *Sustainability*, *8*(9), p.942.

Koksal, M.A., Rowlands, I.H. and Parker, P., 2015. Energy, cost, and emission end-use profiles of homes: An Ontario (Canada) case study. *Applied Energy*, *142*, pp.303-316.

Babatunde, M.A. and Shuaibu, M.I., 2009, August. The demand for residential electricity in Nigeria: A bound testing approach. In *Proceedings of 2nd International Workshop on Empirical Methods in Energy Economics.*

Bala, E.J., 2014, March. Nigeria's power sector reform: what next after privatization. In *Power Electr. World Africa Conf.*

Bala, E.J. and Pam, G.Y., 2012. Energy sources and sustainable development of the north. In *A paper presented at Conference on "The North and Strategies for Sustainable Development," organised by Arewa House, Kaduna, Nigeria* (pp. 5-6).

CBN (2017). Statistical Bulletin. Available at: https://www.cbn.gov.ng/out/2018/sd/2017%20statistical%20bulletin_explanatory%20notes_final.pdf. Accessed on: 11/06/2024.

Charles, A. and Meisen, P., 2014. How is 100% renewable energy possible for Nigeria. *Global Energy Network Institute (GENI), California*.

DODO, U.A., ASHIGWUIKE, E.C. and ERONU, E.M., 2021. Renewable energy readiness in Nigeria: a review focusing on power generation. *UNIABUJA Journal of Engineering and Technology (UJET)*, *1*(1).

Hasan, M. M., Hossain, S., Mofijur, M., Kabir, Z., Badruddin, I. A., Yunus Khan, T. M., & Jassim, E. (2023). Harnessing solar power: a review of photovoltaic innovations, solar thermal systems, and the dawn of energy storage solutions. *Energies*, *16*(18), 6456.

IEA (2020). World Energy Outlook. Available at: https://www.iea.org/reports/world-energy-outlook-2020. Accessed on: 11/06/2024.

IHA (2018). Africa Hydropower Regional Profile. Available at: https://www.hydropower.org/region-profiles/africa. Accessed on: 26/06/2024.

Islam, M. T., Huda, N., Abdullah, A. B., & Saidur, R. (2018). A comprehensive review of state-of-the-art concentrating solar power (CSP) technologies: Current status and research trends. *Renewable and Sustainable Energy Reviews*, *91*, 987-1018.

Kumar, S.S. and Vijayan, S.N., 2016. Solar tracking system using a refrigerant as working medium for solar energy conversion. *Int. J. Mech. Aerospace, Ind. Mechatron. Manuf. Eng*, *10*(8), pp.1610-1615.

Maka, A.O. and Alabid, J.M., 2022. Solar energy technology and its roles in sustainable development. *Clean Energy*, *6*(3), pp.476-483.

Mas'ud, A.A., Wirba, A.V., Muhammad-Sukki, F., Mas'ud, I.A., Munir, A.B. and Yunus, N.M., 2015. An assessment of renewable energy readiness in Africa: Case study of Nigeria and Cameroon. *Renewable and Sustainable Energy Reviews*, *51*, pp.775-784.

Mitrašinović, A. M. (2021). Photovoltaics advancements for transition from renewable to clean energy. *Energy*, *237*, 121510.

Nadabo, S. L. (2010). *Renewable Energy as a Solution to Nigerian Crisis*. Final Research Thesis at the University of Applied Sciences (Unpublished M.Sc. Thesis).

Njok, A.O., Iloke, J.I., Panjwani, M.K. and Hussain, M.F., 2020. The impact of coloured filters on the performance of polycrystalline photovoltaic panel in an uncontrolled environment. *International Journal of Electrical and Computer Engineering*, *10*(4), p.4436.

Njok, A.O., Ogbulezie, J.C., Panjwani, M.K. and Larik, R.M., 2020. Investigation of monthly variations in the efficiencies of photovoltaics due to sunrise and sunset times. *Indonesian Journal of Electrical Engineering and Computer Science*, *18*(1), pp.310-317.

Ogbulezie, J.C., Njok, A.O., Panjwani, M.K. and Panjwani, S.K., 2020. The impact of high temperature and irradiance source on the efficiency of polycrystalline photovoltaic panel in a controlled environment. *International Journal of Electrical and Computer Engineering*, *10*(4), p.3942.

Ogundari, I.O., Akinwale, Y.O., Adepoju, A.O., Atoyebi, M.K. and Akarakiri, J.B., 2017. Suburban housing development and off-grid electric power supply assessment for north-central Nigeria. *International Journal of Sustainable energy planning and Management*, *12*, pp.47-63.

Ogundari, I., Ayoola, P. and Bakare, O., 2021. Techno-economic assessment of municipal natural gas-powered (Off-Grid) alternative electric power supply in Lagos State, Nigeria. *Ife Journal of Technology*, *28*(1), pp.28-36.

Oji, J.O., Idusuyi, N., Aliu, T.O., Petinrin, M.O., Odejobi, O.A. and Adetunji, A.R., 2012. Utilization of solar energy for power generation in Nigeria. *International Journal of Energy Engineering*, *2*(2), pp.54-59.

Okoro, O.I. and Madueme, T.C., 2006. Solar energy: a necessary investment in a developing economy. *International Journal of Sustainable Energy*, *25*(01), pp.23-31.

Olanipekun, B. A., & Adelakun, N. O. (2020). Assessment of renewable energy in Nigeria: challenges and benefits. *International Journal* *of Engineering Trends and Technology (IJETT)–Volume*, *68*.

Omolade, A., Nwosa, P. and Amassoma, D., 2019. Structure and nature of alternative sources of electricity supply to households in Nigeria. *Problems and Perspectives in Management*, *17*(2), p.147.

Onajomo, T.S., 2022. Geospatial assessment of land use/cover, rainfall, and flood incidents in Eti–Osa, Lagos, Nigeria. *South African Journal of Geomatics*, *11*(2), pp.202-217.

Ononuju, F.N., Nwosu, J.I. and Ukaegbu, V.U., 2024. Economic evaluation of mineral deposit: A bottom-up approach. *Scientia Africana*, *23*(2), pp.341-350.

Onuk, O.E., Akuru, U.B., Animalu, A.O.E., Unachukwu, G.O. and Oparaku, O.U., 2011. Utility interactive solar PV energy demonstration project at the University of Nigeria, Nsukka. *African Journal of Physics*, *4*, pp.104-111.

Osueke, C.O. and Ezugwu, C.A.K., 2011. Study of Nigeria's energy resources and its composition. *Int. J. Sci. Res. Eng*, *2*, p.12.

Rahman, A., Aziz, T. and Deeba, S.R., 2021. A time of use tariff scheme for demand side management of residential energy consumers in Bangladesh. *Energy Reports*, *7*, pp.3189-3198.

Rahman, A., Farrok, O. and Haque, M.M., 2022. Environmental impact of renewable energy source based electrical power plants: Solar, wind, hydroelectric, biomass, geothermal, tidal, ocean, and osmotic. *Renewable and sustainable energy reviews*, *161*, p.112279.

RENA (Editor) (2019). The Nigerian Energy Sector "An Overview with a Special Emphasis on Renewable Energy. Energy Efficiency and Rural Electrification 2nd Edition.

Romano, A.A., Scandurra, G., Carfora, A. and Fodor, M., 2017. Renewable investments: The impact of green policies in developing and developed countries. *Renewable and Sustainable Energy Reviews*, *68*, pp.738-747.

Sambo, A.S., 2005. Renewable energy for rural development: the Nigerian perspective. *ISESCO Science and Technology Vision*, *1*(2005), pp.12-22.

Sawin, J. L., Sverrisson, F., & Wilson Rickerson. (2015). *Renewables 2015 Global Status Repor*t. Available at: http://www.ren21.net/wpcontent/uploads/2015/07/GSR2015_KeyFindings_lowres.pdf. Accessed on: 05/28/2024.

Shaaban, M. and Petinrin, J.O., 2014. Renewable energy potentials in Nigeria: Meeting rural energy needs. *Renewable and sustainable energy reviews*, *29*, pp.72-84.

Sulaiman, S.A., Hussain, H.H., Leh, N.S.H.N. and Razali, M.S., 2011. Effects of dust on the performance of PV panels. *World Academy of Science, Engineering and Technology,* 58(2011), pp.588-593.

Onwuzuruike, J.A. and Aminu, M.A., 2019. Experimental determination of panel generation factor for Apo area of Federal Capital Territory in Nigeria. *J. Sci. Res. Reports*, 24(3), pp.1-5.