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RESEARCH ARTICLE

Solar Photovoltaic System Design and Cost Estimations for Electrification of selected Primary Health Centres in Maiyama Local Government, Kebbi State

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Abstract
The populace continues to turn to primary healthcare centers as their first port of call for medical attention. The majority of people who visit primary healthcare facilities (PHCs) are women and children, whose health has a direct impact on the future of the nation. As a result, PHCs are under pressure to deliver high-quality treatment. One of the healthcare institutions in Maiyama Local Government that needs dependable energy is the Primary Healthcare Center (PHC) that has been chosen. They use a diesel-powered system as their main source of power supply because the electricity supply is unstable. This puts a strain on their operations resources and has a severe impact on people and the environment. The answer to Maiyama's inconsistent, expensive, and unsafe power source is a change in the energy system. LG, and its goal is to raise the standard of healthcare delivery services. It is assumed that greater healthcare services would be available once improved energy sources are in place. The solution was suggested to be a solar-powered system with battery storage, a charge controller, and an inverter. Electricity for the vaccine refrigerator, ceiling fans, light bulbs, and mobile charge station will be provided by the proposed powered system. For each primary health center, the cost of the solar PV system's components [such as PV panels, inverters, batteries, and charge controllers] was calculated. Electrical appliances were projected to use 29,129.41 watt hours per day, 13647.05 watt hours per day, 54174.118 watt hours per day, and 14738.82 watt hours per day for Kawara, Maiyama, Andarai, and Mayalo, respectively. Based on the foregoing Observed outcomes each health center under study's needs was taken into account while designing the solar PV system. According to estimates, PV panels will cost correspondingly ₦1,264,000, ₦632,000, ₦2,370,000, and ₦395,000 for Kawara, Maiyama, Andarai, and Mayalo. The total amount all centers had to pay on PV panels was ₦4,661,000. Similar to this, it was determined that the cost of the inverter utilized in the design was ₦280,000 for the four PHCs, while the cost of the battery was projected to be ₦646,800, ₦1,176,000, ₦4,555,726, and ₦953,442 for Kawara, Maiyama, and Andarai, respectively. For this project, the cost of the inverter and charge controller needed to create the PV system was estimated for each primary health center that was chosen. 4 inverters' combined costs were calculated and determined to be. Each charge controller is expected to cost ₦30,000 and cost ₦210,000. For Kawara, Maiyama, Andarai, and Mayalo Primary Health Center, respectively, the cross-sectional area of each cable needed for the connection between PV& battery, Battery & Inverter, and Inverter & Load was projected to be $3.569\ 10^{-6}\ m^2$, $2.436\ 10^{-6} m^2$, and $2.727\ 10^{-6} m^2$. This study's findings support the usage of solar PV systems in primary health centers since they are less expensive to operate, extremely dependable, and have a life expectancy of 20 to 30 years.

Keywords: Primary health Centre; Panels; Battery; Inverter; Photovoltaic system and electrification

Introduction

Since the beginning of time, the sun has produced free energy, with the quantity of solar radiation that the Earth has been able to block reaching up to 1.8 1011 MW in power (Ezema et al., 2019). Nigeria benefits greatly from solar energy due to its year-round sunlight. The whole national energy requirement may be satisfied by solar energy, with solar radiation predicted to be between 3.5 and 7.0 kWh/m2/day (Ezema et al., 2019). The scientific community has made a significant effort to find alternate and clean energy sources to meet the demands of the present and the future. Additionally, given the limited availability of conventional energy sources, it is imperative to investigate renewable energy sources in order to promote global economic growth that is healthy, competitive, and maintaining a clean and healthy environment for future generations. The generation of green energy, especially solar-based energy, has become a practical way to supplement battery supplies (Jordan and Kurtz, 2011). Through a variety of new and developing applications in general and in certain sectors with technical hurdles in particular, recent advancements in PV technologies have reduced some gaps between power demand and supply (Pandey et al., 2016). The annual global energy consumption is currently 10 terawatts (TW), and by 2050, it is anticipated to reach 30 TW. By the middle of the century, the world will require around 20 TW of non-CO2 energy to stabilize CO2 levels (Razykov et al., 2011). According to analysts, Nigeria could produce 600,000MW by installing solar PV panels on just 1% of its geographical mass (Power Nigeria, 2019). Although installing solar devices is inexpensive, there is a technological issue that might prevent this vision from becoming a reality (Jordan and Kurtz, 2011). The difficulties include: shadows, which may be created naturally or artificially; dust, filth, frost, and snow on panels; location; rainfall; module tilt; reflectance of module surface; PV conversion efficiency; and sunlight spectrum. Grid-connected PV systems and off-grid PV systems are the two most common varieties of PV systems. A proposed off-grid PV system is for the research region. In this study, it was suggested that both types of PV panels be used in various situations to help the government finance solar energy investments in Maiyama L.G.'s primary healthcare system. For the last forty years, both the Nigerian government and its populace have had serious concerns about the country's energy situation (NERC, 2019). Businesses have lost money due to this energy issue, while families are totally reliant on off-grid power sources (i.e., electric generators fueled by diesel, gas, or petroleum), resulting in exorbitant expenditures and aggravating other hazardous environmental issues (Emetere et al., 2019).

One of the most important demands of people everywhere is a reliable, efficient, and sustainable source of electricity. Lack of this energy infrastructure, particularly in Local Governments like Maiyama, has an impact on the socioeconomic status of people living in rural communities. These services, such as local health care, water pumping, street lighting, etc., are needed to develop in order to improve the lives of the people living in local communities. Additionally, the absence of a dependable electrical power system can have a harmful effect on people's health, particularly when those individuals are continuously exposed to fossil-fuel energy systems, which raise greenhouse gas (GHG) emissions. Antiretroviral medicines (APV) and other temperature-sensitive medications and chemicals have recently been distributed in healthcare facilities. In order to combat infectious illnesses like HIV/AIDS, the Ebola virus, which is mostly found in West Africa, and the Zika virus, which is primarily found in South American nations, it is necessary to provide an effective and stable electricity power supply (NERC, 2019). This is because the majority of the temperature-sensitive vaccinations used to treat the illnesses listed above must be kept in freezers. One of the most crucial amenities required in health centers is a decent lighting system. Energy supply is also crucial for responding to medical crises, including labor and delivery, patients needing urgent care, etc. The risk of human deaths rises because of the absence of electricity in medical institutions (NERC, 2019).Consequently, the importance of a dependable energy source in assuring how well health clinics and centers operate. Only 183 million people, or around 40% of Nigeria's total population, have access to the national grid (Power Nigeria, 2019). This suggests that the majority of its residents lack access to a reliable source of modern power. A requirement like food and water is energy. Energy is needed by everything around us. The population of the planet has grown throughout time, and this rise is closely correlated with the amount of energy utilized. Every piece of technology and apparatus need energy to operate. Finding sustainable renewable energy sources that may reduce reliance on fossil fuels and the national grid system is important due to the depletion of the national power grid system (Ayaz, 2018). The most plentiful source of energy we have is solar energy. An estimated 10,000 Terawatts of solar energy are incident on the surface of the globe each day. A research claims that the total global energy usage in 2015 was 17.4 TW (Ayaz, 2018). Every year, the energy usage has only slightly increased, growing by about 1 to 1.5%. By the year 2040, the total amount of energy consumed worldwide is anticipated to increase by 56%. We can only begin to grasp the potential that solar energy contains when we compare present consumption, anticipated increase in the next two decades, and the quantity of solar radiation received in an hour. The entire amount of energy used is a significant portion of what we get in an hour (Ayaz, 2018).

A miracle of both nature and technology, a photovoltaic cell is an electrical device that transforms incoming photon energy into electrical energy. The PV system is one that uses the sun's energetic photon radiation to produce electrical current in a particular material. Modern semi-conductor materials are used to directly convert solar energy into electricity. The most readily accessible commercial material for PV system design is often silicon. PV systems can be complicated or simple. Some are referred to as "stand-alone" or "off-grid" systems, meaning they provide all of the households' and hospitals' electricity (Ayaz, 2018). Health institutions of all kinds, especially those with little or no access to grid electricity, can benefit greatly from solar power. No pollutants are produced, no fuel is used, and no maintenance is required for photovoltaic. They are a good alternative for any healthcare facility's energy system when they are commercially feasible. For isolated sites without access to the grid, PV systems are very critical. Therefore, by protecting health clinics from variations in the power supply and cost, PV systems contribute to their long-term financial viability (USAID, 2019). Given that only a small percentage of PHC in Maiyama LG have access to electricity supply due to physical deterioration of the transmission and distribution facilities, high cost of installing solar PV systems, and other factors, this study aims to design PV system and analyze the cost of designing a solar PV system in primary health centers of Maiyama Local Government (Izuchukwu and Peace, 2021).

Material and Method

The operational healthcare systems of Maiyama, Andarai, Mayalo, and Kawara are the focus of the study. They are the most notable wards in Kebbi State's Maiyama Local Government. Geographically, Maiyama LG is located between 110 48'37.08" latitude and 40 21' 23.4468" longitudes. Table 1 below is a summary of each primary health center's descriptions.

Table 1: List of selected primary health centres in Maiyama LG

S/N	Wards	Code	Centre name	No of Bed	Personnel	Longitude	Latitude
1	Kawara	21/15/1/1/1/0036	Kawara Primary Health Centre	10	8	4.23698	12.99883
2	Andarai	21/15/1/1/1/0003	Andarai Primary Health Centre	10	13	4.393051	11.89528
3	Maiyama	21/15/1/1/1/0021	Maiyama Primary Health Centre	0+5	14	4.37196	12.08405
4	S/Mayalo	21/15/1/1/1/0027	Mayalo Primary Health Center	1	11	4.27947	12.24875

To evaluate the site's benefits, solar photovoltaic (PV) clusters for primary health centers are an essential concept (Franklin, 2017). A critical component of developing a PV system is locating and positioning the panels (Ayaz, 2018).

Data Gathering

Each primary health center's data was prospectively gathered using a form made just for that purpose. The information gathered included the amount of lights, fans, mobile charging stations, and refrigerators that were available in the center. The PHC staff directed the collection of every appliance's data.

PV System Design for Primary Health Care Center

PV solar panels are simply one component of photovoltaic systems. To operate the PV panels effectively, a variety of additional system parts known as the balance-of-system (BOS) are necessary. PV panels, inverters, batteries, charge controllers, and cables are a few of the standard parts of PV systems. Any PV system's composition is determined by the sort of load it powers and, more crucially, whether it is an off-grid or grid-connected system (USAID, 2019). This component included building a PV system to supply the Primary Health Center in Maiyama Local Government Area of Kebbi State with the necessary electricity. The size of the PV panels, inverter, battery bank, solar charger controller, and cost estimation must be determined based on the appliances that are now accessible in the PHC. First, the PHC was used to determine the total number of appliances and their individual power ratings.

Electrical equipment power usage in primary health centers

A mathematical calculation was used to calculate the amount of power used by each of the equipment (1)

$$\mathrm{Power_{Consumed}} = \mathrm{No.\,of\,Units} \times \frac{\text{Rated wattage per Hour}}{\text{Adjustment factor}} \times \text{Average Hour Use per Day} \qquad (1)$$

Where adjustment factor here considered being 0.85

Daily power demand

The total power used by the PHC's available appliances was used to calculate the daily energy consumption.

$$\text{Total power demand per day} = \sum \text{power consumed by the appliances in watt} - \text{hour} \qquad (2)$$

Energy required from Panels to run electrical appliances

The total Energy required from the Panels to run the electrical appliance was calculated using equation (2) below:

$$\text{Energy required from the Panels to operate electrical appliance} = \mathrm{P_{consumed}} \left(\frac{\mathrm{Wh}}{\mathrm{Day}}\right) \times 1.3 \qquad (3)$$

PV Panels Sizing

The size of the Panels for a PV system that powers daily-use loads is decided by the daily energy requirement (SECO FACT SHEET, 2020). The total peak wattage necessary to run the appliances was estimated using an equation to determine the number of PV panels needed for this investigation (4)

$$\text{Total peak rating watt require to run the appliances} = \frac{\text{total energy required}}{\text{module generation factor}} \qquad (4)$$

The total amount of PV energy needed from the panel divided by the panel generation factor is the total amount of watt-peak power needed to run the appliances. When determining the size of solar photovoltaic cells, the panel generation factor is applied. Depending on the climate where the place is located, it can differ. This analysis took into account 4.8 module generation factors and 500Wp PV modules. Equation (5) below was used to calculate the number of PV panels needed for this investigation.

$$\text{Number of PV Panels for the system} = \frac{\text{Total watt−peak rating require to operate the appliance}}{\text{rated output peak of the PV module available}} \qquad (5)$$

The installations of more solar Panels lead to better performance of the system and battery life-span will increased.

Solar PV Panels Arrangement

PV Panels can be arranged in two different ways such as Series and Parallel arrangement

$$\text{Number of Series arrangement of panels [NPS]} = \frac{\text{Voltage of the system}}{\text{Voltage of the Module}} \qquad (6)$$

$$\text{Number of Parallel arrangement of Panels [NPP]} = \frac{\text{Total number of Panels}}{\text{Number of module in series}} \qquad (7)$$

$$\text{Total Number of solar Panels [NMT]} = \frac{\text{Number of Panels in series}}{\text{Number of module in Parallel}} \qquad (8)$$

Estimation of output power of solar panels array

The entire daily power consumption was divided by the typical battery round-trip efficiency of 90% in order to properly build a PV system for the Primary Health Center. As a result, the power output for the PV array in this study was determined using equation (6) as follows.

$$\text{Power}_{\text{Array}}\left(\frac{\text{w}}{\text{day}}\right) = \frac{\text{Total power demand per day}}{\text{Batter round−trip efficiency}} \qquad (9)$$

Ampere-Hour per Day

This is the proportion of daily energy use to battery bus voltage. The calculations are displayed below.

$$\text{Ampere} - \text{Hour per Day}\left(\frac{\text{Ah}}{\text{Day}}\right) = \frac{\text{Total Energy Per Day Use}}{\text{Batter Bus Voltage}} \qquad (10)$$

Where Batter Bus Voltage $= 50\text{V}$ and Round Trip Efficiency = 90% = 0.9

Inverter sizing

The sort of device known as an inverter is able to transform the direct current (DC) electricity generated by solar panels into the alternating current (AC) electricity required to power appliances like lights and other machinery. Since inverters are necessary for every PV system to serve AC loads, they are a fundamental part of almost all PV systems. Keep in mind that many inverters may also serve as disconnect switches or battery charge controllers, among other system components. The most cutting-edge inverters are built to link with a utility grid, either taking power from it or feeding it back into it. These inverters may switch to an islanding mode, where they continue to power the vital loads connected to the PV system, in the event that the utility power fails. The IEEE 1547 requirements for safe grid connection and disengagement must be followed by these inverters. (USAID, 2019). The inverter's input rating should never be less than the combined wattage of the appliances. The inverter's nominal voltage must match that of your battery. The inverter's input rating needs to be 25–30% greater than the wattage of your appliances. The input rating of the inverter for grid-tied or grid-connected systems should match the rating of the PV array to enable for efficient and safe operation. Therefore, the size of inverter needed for electrifying every primary healthcare system chosen for the study was determined using the following equation:

$$\text{Inverter Size [IS]} = \frac{\text{total watt}\times 130}{100} \qquad (11)$$

Battery Size

One of the most crucial factors to take into account when selecting the fundamental parts of a standalone solar electric system is the size of the solar battery. When sizing a battery bank, the key goals are to get one energy source that can handle the load from the PV panel array and supply enough stored power for needs when there is no sunshine. Depending on how much voltage the solar system generates, the battery bank system voltage may be 12 volts, 24 volts, 48 volts, or 96 volts. The battery's storage capacity should be sufficient to power the appliances both during the day and during the night.

$$\text{Sizing of Battery (Wh)} = \frac{\text{Energy required per day in watt−hours (battery bank capacity) [C]}\times\text{autonomy days [n]}}{\text{Battery loss}\times\text{Depth of Disccarging }\times\text{system voltage}} \qquad 12)$$

Where; loss of battery = 0.85, depth of discharge =0.6, system voltage = 45.7V, Battery voltage rating = 24, C= energy required per day in watt-hours (battery bank capacity), n= 4 (autonomy days). Autonomy is the number of days required for the system to run when there is no power produced by solar panel.

Number of Batteries Require for the System

The total number of battery was determined by multiplied the ratio of battery bank capacity to capacity of selected battery with number of battery. It was calculated based on the given equation below:

$$\text{Total Number of battery [Nbt]} = 1\text{ battery} \times \frac{\text{batter bank capacity}}{\text{capacity of selected battery}} \qquad (13)$$

Arrangement of Batteries

The batteries calculated have two ways of arrangement based on the desire output of the system. These are series and parallel arrangement.

$$\text{Number of battery In series [NBS]} = \frac{\text{Voltage of the system}}{\text{Voltage of battery}}$$
(14)

$$\text{Number of battery in parallel [NBP]} = 1 \times \frac{\textbf{Total Number of battery require by the system}}{\text{Total Number of batteryie in series}} \qquad (15)$$

Solar Charge Controller Sizing

A charge controller's job is to control the charge from the solar panel array that goes into the battery bank, prevent overcharging, and reverse current flow at night. The most popular charge controllers are maximum power point tracing or pulse width modulation (PWM) (MPPT). A MPPT solar charge controller will immediately and effectively convert the lower voltage when it detects a difference in voltage so that the panels, battery bank, and PV charge can all have the same voltage. The size of a series charge controller is determined by the total PV input current given to the controller as well as by the PV panel layout (series or parallel configuration). In our example, the short circuit specification for the PV module, Current = 11.62 A

$$I_{\text{rated}} = (\text{NPB} \times I_{\text{sc}}) \times 1.3$$
(16)

Where: the solar charge controller Current rating is denoted by $\mathbf{I_{rated}}$, short circuit current given by Isc, number of parallel battery is denoted by NPB and Safety factor is considered to be 1.3. The 60A is the charger controller current rating considered in this work.

The total power of module Array was estimated using equation (17) below: $\text{Total power of module array} = \text{NPS} \times \text{NPP} \times \text{Power rating of module ref. system}$ (17)

Wiring and Cable sizing

Wiring is necessary for all electrical systems, and in a PV system, wiring is utilized to link the PV panels and all other electrical parts to the battery bank of the building. The cross-sectional area of the copper determines the range of sizes for wiring, which are often measured in square millimeters (mm2) or in the American Wire Gauge (AWG) standard in the United States. Because undersized cable might provide a safety risk, wiring must be properly chosen. A variety of criteria are taken into consideration when determining the size of wiring utilized in a PV system: rated current, wire length, efficiency, and system voltage. Larger wiring is necessary for systems with higher system voltage, higher rated currents, and greater distances between the PV panels and system loads. Larger wiring also reduces transmission losses caused by the wire's resistance; a typical cabling-related power loss is 5%. (USAID, 2019). Cable sizing is a crucial stage because it affects the reliability and performance of a PV system when the size and type of wire are properly chosen.

Sizing of Cables between Solar Panels and Batteries

In this research work the copper wire was considered. The cables cross sectional are determined by the following equation: Let length of the cable be 1m, the voltage drop (Vd) calculated using equation (18)

$$\text{Max Voltage Drop } [V_d] = \frac{4 \times V_{\text{module}}}{100}$$
(18)

The cross-sectional area of the cable was estimated based on the given equation below:

$$\text{Area} = \frac{\rho \times L \times I}{V_d} \times 2$$
(19)

Where resistivity of wire is denoted by rho(ρ), for copper wire the resistivity is given by $\rho = 1.724 \times 10^{-8}\,\Omega \cdot \text{m}$, length of the wire denoted by L, while A= cross sectional area of cable, I= the rated current of regulator, Vd =Voltage drop. In both AC and dc wiring for standalone photovoltaic system the voltage drop is taken not to exceed 4% value.

Cable size between the battery bank and the inverter

Let length of the cable is 8m. The maximum voltage drop considered in this work was estimated using equation (18) above.

At full load, batteries maximum current $I_{\max}$ is given by

$$I_{\max} = \frac{\text{inverter kva}}{\text{efficiency of inverter} \times \text{Vsystem}}$$
(20)

Where inverter kva = 11 kva, efficiency of inverter = 0.97 and V system = 45.7V

The area of the cable required, battery bank, and the inverter was estimated using equation (19). Based on the values calculated means that any copper cable of cross sectional area of 2.5mm^2, 517.18A, and resistivity $1.724 \times 10^{-8}\,\Omega \cdot \text{m}$ can be used for the wiring between the battery bank and inverters

Cable sizes between the inverter and load

Let the maximum length of cable be 24m and maximum voltage Drop was estimated as follows

$$\text{The maximum voltage Drop} = 4 \times \frac{\text{out put Voltage}}{100}$$
(21)

Where output voltage considered was 220V and 4 were autonomy days. The phase current calculation was done using equation (22) below:

$$I_{\text{phase}} = \frac{\text{inverter kva}}{\text{out put Voltage} \times \sqrt{3}}$$
(22)

Then, the cross-sectional area of the cable was computed using equation (19). This means that any copper of cross sectional area $2.727 \times 10^{-6}\text{m}^2$ [~3mm^2], 29A, and resistivity $1.724 \times 10^{-8}\ \Omega$-m can be used for the wiring between the inverter and load.

Cost Estimation and Analysis for PV system design

Cost of Solar PV panel

The SPR-P3-500-UPP (monocrystalline Solar PER) was used, it is the most powerful PV module manufactured by Sun power Solar. The market price of Solar panel is ₦79, 000. The cost per watt was estimated using equation (23)

$$\text{Cost of Panel per watt} = \frac{\text{Market price}}{\text{power rating of the panel}} \qquad (23)$$

Cost of n Panel per watt = Number of panel × Cost of 1 panel in the market

Cost of 11KVA Inverter

Only one piece of 11 KVA of an inverter Power was used for each PHC. The cost of one inverter from the market was ₦ 70,000. Therefore, the cost of inverter per watt was calculated using equation (23) below

$$\text{Cost of inverter per watt} = \frac{\text{Market price}}{\text{Watt rating}} \qquad (24)$$

Cost estimate of 1Inverter = (Cost of 1 watt × Watt rating on inverter). The total cost of the require inverter calculated as follows

Total Cost of 4 inverter for the PHCs under study = Cost estimate of 1Inverter × 4

Cost of 60A Charge Controller

The solar charge controller was considered in the design of PV system are 48V, 60A and 2.88kw for Mayalo and Maiyama PHCs. Therefore, cost of charge controller from market was ₦ 30,000

$$\text{Cost of Charge controller per watt} = \frac{\text{Market price}}{\text{Power rating}} \qquad (25)$$

Cost of 1 charge controller = Cost per watt × wattage rating

Total Cost of n charge controller = n × Cost of 1 charge controller(where n= 1,2,3…….)

Cost of Battery

The sun power energy solar battery was used in the design of the PV system. The cost of one battery from market is ₦ 98,000.

$$\text{Cost of battery per watt} = \frac{\text{market price}}{\text{Power rating in watt}} \qquad (26)$$

Cost of 1 battery = Price per watt × Power rating in ampere − hour

Total Cost of n battery = n × cost of 1 battery where n is the number of battery

Results and Discussions

In this work, the Reference System Specification Rating was utilized to develop the PV system. The solar panel, solar charge controller, solar battery, and solar inverter were selected as the market's reference systems. The reference system specs were compiled as stated in table 1 below. Table 2-9 contains estimates of the load profiles and design parameters for each primary healthcare system.

Table 2: Reference system specification for Solar Panel [Monocrystalline solar Perc] and Battery

Parameters for Solar PV	Values	Parameters For Battery	Values
Voltage	45.7 Volts	AC Nominal Voltage	230 V
Short circuit current	11.62 A	Feed-In Type Single	Phase
Wattage (WP)	500 watts	Grid Frequency	50 Hz
Efficiency of PV panel	20.9%	Total Energy	14 kWh
Performance warranty	25years	Usable Energy	13.5 kWh
		Real power	5 kW
		Apparent Power	5 kVA
		Maximum Supply Fault Current	10 kA
		Maximum Output Fault Current	32A
		Power Factor Output Range	+/– 1.0
		Internal Battery DC Voltage	50V
		Round Trip Efficiency	90%
		Warranty	10 years
		Recommended Temperature	0°C to 30°C

Table 3: Kawara Primary Health Centre Load profile

S/N	Appliances	Quantity	Power rating (watts)	Operating Hours	Power consumption per Day [Wh]
1	Vaccine Refrigerator	1	80	8	658.82
2	Fans	11	70	8	7,247.06
3	Bulbs (60 watts)	19	60	8	10,729.41
4	Bulbs (100 watts)	11	100	8	10,352.94
5	Mobile Charging	3	10	4	141.18
	Total	**45**	**320**	**36**	**29,129.41**

Table 4: Design parameters and calculated values for KPHC

Design Parameters	**Calculated value**
Total energy needed from PV	37868.233 wh/day
Total watt- Peak Rating	7889.22 W_P
Total number of PV Panels for the System	16 Panels
Total number of PV Panels in Series	2 Panels
Total Number of module in parallel	8 Panels
Total Power of PV array demanded	32366.01 W/Day
Total ampere-Hour demanded per Day	583 AH/Day
Inverter Size	416 watts

Battery size	4998.61 watt-hours.
Total Number of battery [Nbt]	25 batteries
Number of battery In series	3.8 batteries
Number of battery In parallel	6.6 batteries
Solar Charge Controller Sizing (Irated)	99.38A
Cables size between PV Panels and Batteries	3.569×10^{-6} m^2
Cable size between the battery bank and the inverter	2.436 $\times 10^{-6}$m^2
Cable sizes between the inverter and load	2.727$\times 10^{-6}$m^2

Table 5: Maiyama Primary Health Centre Load profile

S/N	Appliances	Quantity	Power rating(watts)	Operating Hours	Power consumption [Wh/D]
1	Vaccine Refrigerator	1	70	8	658.82
2	Fans	9	70	8	5929.41
3	Bulbs	12	60	8	6776.47
5	Mobile Charging	3	10	8	282.35
	Total	**25**	**210**	**32**	**13647.05**

Table 6: Design parameters and calculated values for MPHC

Design parameters	Calculated Values
Total energy needed from PV {TEN}	17741.17 WH/D
Total watt- Peak Rating {TWPR}	3431.373
Total number of PV Panels for the System	7 Panels
Total number of PV Panels in Series	1.9 Panels
Total Number of module in parallel	3.69 Panels
Total Power of PV array demanded	15,163.39 Watt
Total ampere-Hour demanded per Day	272.94 AH/Day
Inverter Size	273 watts
Battery size	2342.14 watts-hours
Total Number of battery [Nbt]	12 batteries
Number of battery In series	3.80 batteries
Number of battery In parallel	3.16 batteries
Solar Charge Controller Sizing (Irated)	47.73A
Cables size between PV Panels and Batteries	3.569×10^{-6} m^2
Cable size between the battery bank and the inverter	2.436 $\times 10^{-6}$m^2
Cable sizes between the inverter and load	2.727$\times 10^{-6}$m^2

Table 7: Andarai Primary Health Centre Load profile

S/N	Appliances	Quantity	Power Rating(w)	Operating Hours	Power consumption (wh/D)
1	Bulbs	58	60	8	32752.941
2	Fans	31	70	8	20423.529
3	Refrigerator	1	70	8	658.82353
4	Mobile charging	3	12	8	338.82353
	Total	93	212	32	54174.118

Table 8: Design parameters and calculated values for APHC

Design parameters	Calculated Values

Total energy needed from PV {TEN}	70426.35
Total watt- Peak Rating {TWPR}	14672.16
Total number of PV Panels for the System	29.34 Panels
Total number of PV Panels in Series	1.90 Panels
Total Number of module in parallel	15.42 Panels
Total Power of PV array demanded	60193.46 watts
Total ampere-Hour demanded per Day	1083.482 ampere-hour per day
Inverter Size	275.6 watts
Battery size	9297.484 watt-hours
Total Number of battery [Nbt]	46.487 batteries
Number of battery In series	3.808 batteries
Number of battery In parallel	12.207 batteries
Solar Charge Controller Sizing (Irated)	184.395A
Cables size between PV Panels and Batteries	3.569×10^{-6} m^2
Cable size between the battery bank and the inverter	2.436 $\times 10^{-6}$m^2
Cable sizes between the inverter and load	2.727$\times 10^{-6}$m^2

Table 9: Mayalo Primary Health Care System Load profile

S/N	Appliances	Quantity	Power Rating (watts)	Operating Hours	Power Consumption (Wh/D)
1	Bulbs	15	60	8	8470.588
2	Fans	8	70	8	5270.588
3	Refrigerator	1	70	8	658.8235
4	Mobile	3	12	8	338.8235
	TOTAL	27	212	32	14738.82

Table 10: Design parameters and calculated values for MAYALO PHC

Design parameters	**Calculated Values**
Total energy needed from PV	11337.5566
Total watt- Peak Rating	2361.991
Total number of PV Panels for the System	4.7 Panels
Total number of PV Panels in Series	1.90 Panels
Total Number of module in parallel	2.49 Panels
Total Power of PV array demanded	16376.47
Total ampere-Hour demanded per Day	294.7765 AH/Day
Inverter Size	275.6 watt-hours
Battery size	1945.78 watts
Total Number of battery [Nbt]	9.729 batteries
Number of battery In series	3.81
Number of battery In parallel	2.55
Solar Charge Controller Sizing (Irated)	38.57A
Cables size between PV Panels and Batteries	3.569×10^{-6} m^2
Cable size between the battery bank and the inverter	2.436 $\times 10^{-6}$m^2
Cable sizes between the inverter and load	2.727$\times 10^{-6}$m^2

Table 11: PV Panel cost estimated

PHCS	No of PV	Wattage	Market Price	Price per watts	Total Cost of PVM
Kawara	16	500	N79000	N158	N1,264,000
Maiyama	8	500	N79000	N158	N632,000
Andarai	30	500	N79000	N158	N2,370,000
Mayalo	5	500	N79000	N158	N395,000

Total	59	2000	N316000	N632	N4,661,000

Table 12: Cost of battery estimated for each PHCs

Primary Health Centres	Quantity	Market Price	Total Cost	
Kawara PHC	6.600 (≅ 7)	₦ 98, 000	₦ 646,800	646800
Maiyama PHC	12.000	₦ 98, 000	₦ 1,176,000	1176000
Andarai PHC	46.487 (≅ 47)	₦ 98, 000	₦ 4,555,726	4555726
Mayalo PHC	9.729(≅ 10)	₦ 98, 000	₦ 953,442	953442
Total	**64**	**₦392, 000**	**₦7,331,968**	**₦7,331,968**

Table 13: Cost of Inverter estimated for each PHC

Primary Health Centres	Quantity	Market Price	Total Cost
Kawara PHC	**1**	N70,000	N70,000
Maiyama PHC	**1**	N70,000	N70,000
Andarai PHC	**1**	N70,000	N70,000
Mayalo PHC	**1**	N70,000	N70,000
Total	**4**	**N280,000**	**N280,000**

Table 14: Cost of Charge controller estimated for each PHC

Primary Health Centres	Quantity	Market Price	Total Cost
Kawara PHC	2	N60,000	N60,000
Maiyama PHC	1	N30,000	N30,000
Andarai PHC	3	N90,000	N90,000
Mayalo PHC	1	N30,000	N30,000
Total	**7**	**N210,000**	**N210,000**

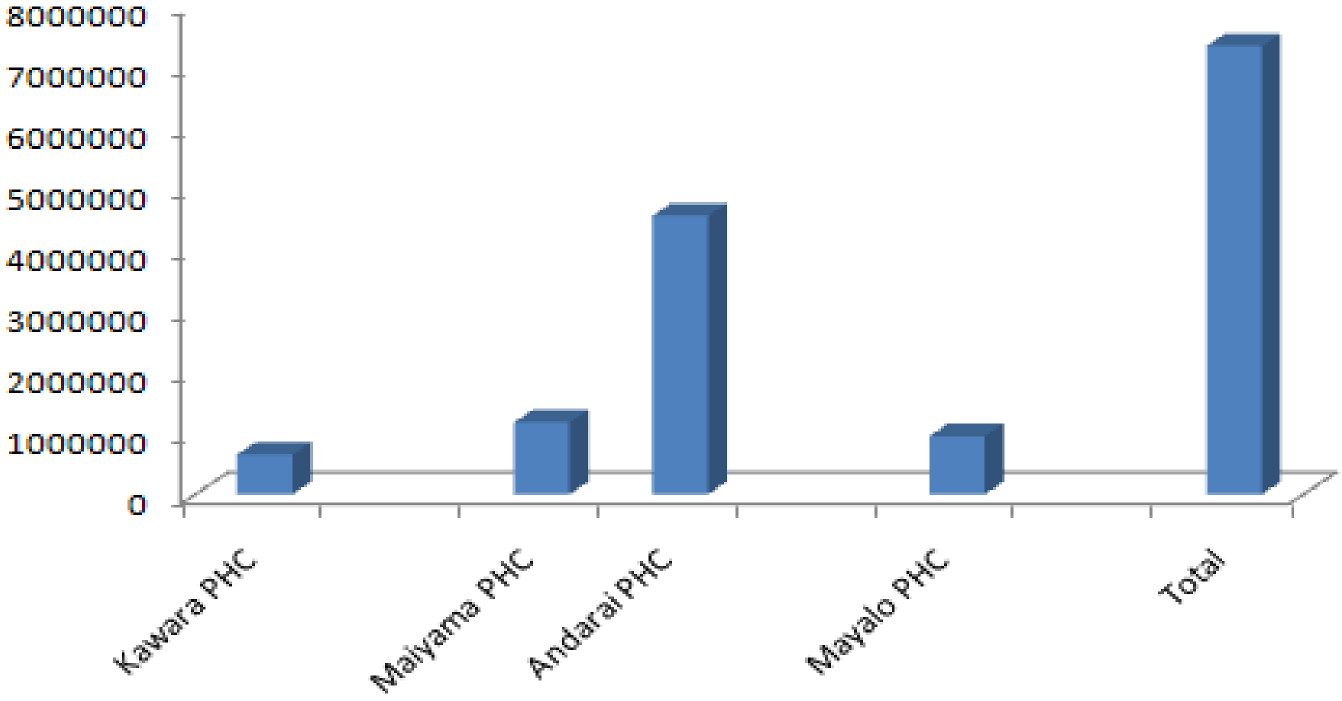

Figure 1: Comparison of battery cost estimated for the four Primary Health Centres

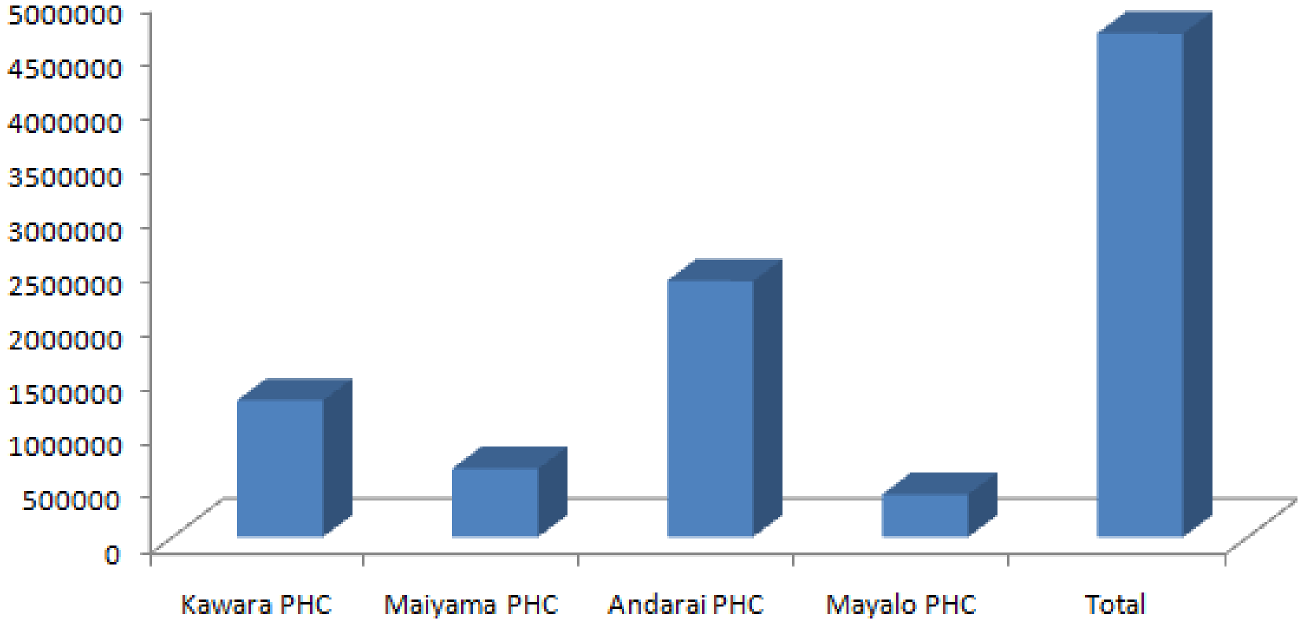

Figure 2: Comparison of total cost analyzed among the four selected PHC

Discussion

Solar energy is viewed as the most promising source of clean, renewable energy and a remedy for the consequences of greenhouse gas emissions in order to address the issue of the use of fossil fuels (Samaila et al., 2021). The main conclusion of this study is that the efficient operation of Primary Health Care Centers depends on the design and cost estimation for access to reliable energy. Through off-grid solar PV, this may be quickly delivered to PHCs. As a result, it is important to give PHC energy demands first priority in order to promote the delivery of 24-hour services in Nigeria, where the electricity system is still underdeveloped and overburdened. The report advises that all PHCs be designed, built, and renovated using typical off-grid renewable energy sources such solar power for lighting, heating, and cooling.

The registration code, personnel, Number of beds, Longitude and latitude of each Primary health centre selected in this study were tabulated in table 1, similarly table 2 indicated reference system used in the designing of Solar Photovoltaic system for Primary health care electrification. Table 3&4 shown the load profile and calculated design parameters of Kawara primary health centre with total of 45 appliances rating 320 watts operating in 36 hours and power consumption of 29,129.41 Watt-hours, for this power consumption per day a total of 16 PV Panels of 32366.01 Watt-hour per day with 583 Ampere-hour per day are required to power KPHC with 25 batteries of 4998.61 watt-hours together with 99.38A charge controller and cable size for the connection between PV& battery, Battery & Inverter, and Inverter & Load were estimated to be 3.569×10^{-6} m^2, 2.436 $\times 10^{-6}$m^2 and 2.727×10^{-6}m^2 for Kawara, Maiyama, Andarai and Mayalo Primary Health Centre respectively. Table 5&6 indicated the load profile and estimated design parameter of Maiyama PHC with total number of 25 appliances that operating in 32 hours per day with power rating of 210 watts that consumed power of 13647.05 Watt-hour per day. With this power consumption by appliances, a total of 2 PV module of 15,163.39 Watt & 272.94 Ampere-hours per day and 12 batteries of 2342.14 watts-hours are required to Power MPHC with available inverter size of 273 watts and Charge controller of rating of 47.73A. The cable size estimated to connect PV & Batteries, Batteries & inverter and inverter & Load were found to have a cross-sectional area of 3.569×10^{-6} m^2, 2.436 $\times 10^{-6}$m^2 and 2.727×10^{-6}m^2 respectively. Table 7&8 reported the load profile and calculated parameters required for the designing of solar PV system for Andarai PHC electrification. The table indicated that a total number of 93 appliances were running for 32 hours with power rating 212 watts and power consumption per day of 54174.118 Watt-hours per day. The appliances in this PHC need a total number of 30 solar panels of 60193.46 watts with 1083.482 Ampere-hour per day. The inverter and controller size estimated for this System to power all the appliances are 275.6 watts and 184.395A with total of 47 batteries of 9297.484 watt-hours. The needed cable sizes were the same as that of Kawara and Maiyama PHC. Table 9 & 10, in this table load profile and estimated parameters for the design of Mayalo PCH PV system for electrification were captured. A total of 27 appliances operating for the total of 32 hours per day with total rating of 212 watts consumed a total power of 14738.82 Watt-hour per day. For this power consumptions, a total of 5 Panels of 16376.47 watt-hour and 294.7765 Ampere –hours per day were needed to power the given number of appliances with 10 number of batteries size of 1945.78 watts. The required size of inverter and charge controller for the this PCH were estimated to be 275.6 watt-hours and 38.57A, the sizes of the connection cable were remain the same as in Andarai PHC.

Table 11 summarized the total number of panels needed for each PHC. The total number of PV panels of 500 watts rating required for four primary health centres were estimated to be 59 with total cost of ₦4,661,000. In table 12, the batteries cost estimated were indicated for each PHC. The total batteries needed for the four Primary health centres under study were estimated to be 64 with total cost of ₦7,331,968 with one single battery cost ₦98,000 in the market. Table 13 & 14 indicated the cost of inverter and charge controller calculated for each primary health centre. The cost of inverter and charge controller required for the designing of PV system in this work were estimated for each selected primary health centre. The total cost of 4 inverter analyzed were found to be N280, 000 with each one cost N70, 000, while total cost of 7solar charge controller estimated to be N210,000 with each cost N30,000. In figure 1, the cost of battery compared was remarkably high in Andarai Primary Health Centre due to the large number of appliances available in the PHC. The magnitude of the cost were Andarai PHC > Maiyama PHC > Mayalo PHC > Kawara PHC. Kawara primary health centre has lowest cost analyzed in this work due the limited number of appliances. Similarly in figure 2 indicated that the cost of panels among the four selected primary health centres remarkably high in Andarai PHC. The magnitude of the cost were Andarai PHC > Kawara PHC > Maiyama PHC > Mayalo PHC. The least estimated cost was found in Mayalo PHC. The total amounts of money that will cost four PHC were estimated to be ₦12,482,968 for 20-30 years of PV Panels and 10 years of battery before replacement. The amount was remarkably lower compared to the cost of electricity supply and fossil fuels in the country.

Conclusion

Given that a sizeable number of Maiyama Local Government PHCs lack access to energy supply, the study was conducted to design solar PV systems for electrifying primary health centers and estimates the cost of developing in Maiyama L.G. Despite the fact that Maiyama L.G. typically benefits from abundant solar irradiation, there is a much greater demand for electricity than what can be supplied by the grid. This study promotes the design of PV systems for electrification to close the energy supply-demand gap and enhance the quality of life for the general public in Local Government by drastically lowering fossil fuel usage. According to the research presented above, the overall cost of designing a solar PV system for PHC electricity was ₦12,482,968. The data produced as a result of this study will be extremely helpful not only for the health care system but also for the system design for rural electrification where grid electricity transmissions were not feasible. The fact that carbon dioxide is the main greenhouse gas causing climate change must be understood. Fossil fuel combustion produces a significant amount of carbon dioxide into the atmosphere, increasing CO2 concentrations that are bad for the human race. Therefore, it is crucial to research the viability of photovoltaic system design and cost assessment for the electrification of primary health centers in Maiyama Local Government.

Ethical approval

Verbal approval was obtained prior to the conduct of this research work from the head of each primary health centres and other stakeholders in the communities where PHC located.

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