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Effect of Ambient Temperature and Solar Irradiance on Photovoltaic Modules' Performance

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A B S T R A C T

The impact of solar radiation and ambient temperature on solar PV energy yield and its corresponding economic implication was investigated. The electrical load assessment was done by physical inspection through periodic visits to study location. Five different scenarios were investigated for two locations - Ogun and Bayelsa States: Case I considers the PV performance based on the locations' historical solar radiation and temperature data, Case II considers 30 % increase in the solar radiation data while the ambient temperature data remains fixed, Case III focuses on when solar radiation data is decreased by 30 % while the ambient temperature data remains constant, Case IV considers the solar radiation data remains constant while the temperature values are increased by 30 %, and Case V examined the same solar radiation values with temperature data values being decreased by 30 %. The HOMER pro was used as the implementation tool, Electrical energy yield, Unmet electric load, Net present cost, Levelized cost, and Operating cost for Cases I, II, III, IV, and V in Ota, Ogun State were as follows: 28,659 kWh/y, 4.71kWh/y, $13,537, $0.166, 271.43kWh/y; 37,260 kWh/y, 1.63kWh/y, $12,417, $0.152, 290.43kWh/y; 20,058kWh/y, 3.22kWh/y, $15,663, $0.192, 293.14kWh/y; 28,659kWh/y, 4.71kWh/y, $13,537, $0.166, 271.43kWh/y; and 28,659kWh/y, 4.61kWh/y, $13,437, $0.156, 261.43kWh/y, respectively while similar trend was observed for Otuasega in Bayelsa State. The results of the analysis showed that the optimal performance of the PV module occurred at a higher solar radiation and a lower ambient temperature.

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NOMENCLATURE

SDG	Sustainable development goals	GHG	Greenhouse gases
HOMER	Hybrid optimization of multiple electric renewables	IEA	International energy agency
RESs	Renewable energy resources	PVm	Photovoltaic modules
NPC	Net present cost	EEY	Electrical energy yield
LCOE	Levilized cost of energy	CP	Capacity factor

INTRODUCTION

One of the critical needs of man for sustainable socio-economic development is access to an uninterrupted electrical energy supply (1), unfortunately, many of the sub-Saharan African countries are currently battling with an erratic supply of energy from their national grid which indeed has become a monster that seems insurmountable (2). It is not gainsaying that the erratic supply of energy has contributed in no small measure to the incidence of lingering poverty that has crippled the growth and development of many industries (local or foreign) and commercial centers in many developing countries around the globe (3, 4). This irregularity of

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energy supply from the national grid is so bad that owners of companies, commercial businesses, and residential buildings among others cannot no longer predict when supply from the national grid will be made available for their utilization (5, 6). This has not only limited the companies' productivity but also contributed immensely to the reduced level of comfort that residential building owners intend to enjoy by connecting to the national grid. It worth mentioning that instability in supply from the national grid is one of the compelling factors among others that necessitate green energy diversification which has been counted as one of seventeen sustainable development goals (SDG) advocated by the United Nations (UN) with a view of achieving the proposed global world transformation by 2030 (7).

Furthermore, SDG 7 advocates for the transition of the world energy system into an affordable clean, or green energy system. The transition of world energy into clean or green energy sources is believed to have some untapped mammoth potential that can enhance and at the same time revolutionize the world energy need by limiting the heavy dependence on fossil-fuel sources which indeed has contributed in no small measure to the release of greenhouse gases (GHG) such as oxides of nitrogen (nitrous oxide), carbon dioxide (CO_2), carbon monoxide (CO), and water vapor (8). This energy diversification is engineered to meet the minimum yardstick set by the International Energy Agency (IEA) for rating whether a household in the urban and rural community is energy-secured. For instance, a rural household is expected to have access to 250 kWh per year as the minimum threshold while the household in urban centers is expected to have access to a minimum threshold of 500 kWh per year (9).

However, the report published by IEA in 2020 revealed that about 77% of the global population in sub-Saharan African countries are living with no access to electricity not to mention having access to the stipulated minimum threshold of energy per year (9). Therefore, the transition to the utilization of clean energy resources is indeed a good panacea for tackling the global energy crisis, minimizing carbon emissions, and depletion of the ozone layer crises (10). Green energy sources are cleaner, devoid of noise, sustainable, environment-friendly, highly scalable, and relatively abundant in supply (1, 6). IEA viewed green energy sources as the least expensive channel for improving man's access to uninterrupted energy supply across the globe since their sources include solar energy, hydro energy, wind energy, bioenergy, tidal energy, geothermal energy, and hydrogen energy among others (11). The aforementioned renewable energy sources (RESs) originate from the three principal sources which include the light produced by the sun, the heat generated within the earth's crust, and the moon and sun's gravitational attraction (12).

The common ancestor for a large number of these renewable energy resources is the energy received from the sun, no wonder it is referred to as the principal contributor to renewable energy resources (13). For instance, the sun produces the heat that determines the kind of weather leading to the formation of low and high-pressure areas within the atmosphere that produce the wind which is being harvested as wind energy. In a similar perspective, heat from the sun causes ocean water to vaporize into the atmosphere which is eventually returned to the land as rainfall thereby creating rivers whose energy is being harnessed to drive hydropower turbines (14, 15). Also, the process of photosynthesis occurred with the aid of energy received from the sun thereby leading to the creation of biomass energy resources.

Of all the sources, accessibility to solar energy is not limited to any geographical location although variability exists in the amount of solar irradiance available in different regions across the globe, unlike other forms of renewable energy resources whose performance is extremely location-dependent (16, 17). This advantage of not being too tied down to a particular location is perhaps the reason for the widespread adoption and utilization of photovoltaic cells for clean energy generation either for standalone applications or grid-tied applications (18). A photovoltaic cell is a semiconductor-based device that has the capability of capturing solar energy and converting it directly into electricity which can be utilized for several applications such as the lighting of residential areas, space and water heating, power solar cars, solar calculators, and remote sensing application (19). The amount of solar energy reaching the earth's surface is sufficient to support energy transition to photovoltaic-energy generation across the globe. It has been estimated that the amount of solar radiation reaching the earth's surface for just three days corresponds to the energy stored in all fossil energy sources put together and from another perspective, the amount of solar radiation that strikes the surface of the earth is approximately 8000 times greater than the average rate of primary energy use worldwide (19).

The performance of PV modules is critical in the design (choice of the right product), optimization (forecast of energy yield), and maintenance of PV systems for a particular application. Several factors affect the performance of PV modules and such factors include the tilt angle, mounting height, shading effect, type of module material, and environmental conditions such as ambient temperature and solar irradiance of the location. A good number of these factors such as tilt angle, mounting height, and module material among others can be controlled by the deliberate effort of man while factors such as solar irradiance and ambient temperature are location-dependent. The key factors that influence the behavior of PVs cells are the environmental factors such as ambient temperature and the solar irradiance condition which is the core objective of this present research. Quite a number of researchers have some studies in this regard, for instance, Salamah et al. (20) evaluated the effect of dust as well as cleaning approaches on PV performance subjected to different climatic regions, of interest in the work are dust life cycle, electrical properties, cleaning approach, and optical characteristics which were extensively reviewed. One of the significant contributions of the work centers on determination of PV characteristics curves under partial, full, and soft shadows has been defined. Dhimish and Tyrrell (21) presented performance ratio, power loss, and hotspot analysis occasioned by inducing degradation on photovoltaic modules. They showed that temperature and relative humidity are the chief cause of power loss in photovoltaic modules. The results of the analysis presented showed that hotspot was observed at a temperature between 25^0C to 45^0C which caused approximately 25% PV module power loss. It was also reported that approximately 60% of the observed photovoltaic modules were found to fail the reliability test based on the IEC61215 standard and that 71.16% was found to be the photovoltaic cell performance ratio. In another study presented by Barbon et al. (22) a generic algorithm for optimizing the performance of roof-mounted solar photovoltaic modules placed on irregular rooftop shapes was proposed. With the generic algorithm proposed, it was observed that enjoyed increased exposure to more solar irradiance which consequently caused more energy to be harvested. Also, with the generic algorithm proposed, the number of solar photovoltaic panels required in the design can easily be obtained in addition to obtaining the right tilt angle and dimension of mounting the module.

Al-Damooka et al. (23) investigated the photovoltaic module performance under severe climatic conditions using Iraq as a case study. The work revealed that at both inclined and horizontal positions the module-free conventional current was observed to be weaker than at the vertical position. It was also reported that the rate of heat transmission was observed to be at about 1.3m height and at any height above this, a rise in module temperature becomes significant regardless of the tilt angle. Also, the work reported lower convective heat transfer at the bottom of the PV module in the horizontal direction. Furthermore, both performance and reliability analysis of PV modules in the long-term using tropical environmental conditions was investigated by Atsu et al. (24). The presented results showed that the rate of photovoltaic module degradation depends on weather conditions which significantly impact the PV performance. The works further summarized techniques that can be employed for analyzing PV performance including visual inspection, I-V characteristic curve techniques, partial shadow condition, and infrared (IR) thermography. Similarly, the magnetic binding force between the photovoltaic cell module and the dust particles was investigated by Ajewole et al. (25).

The effect of dust particles on PV arrays ranges from diminished reliability, soiling of PV modules, and degradation of solar cells in the long term. The adhesive force examined by the author of this work includes capillary force, Van der Waal force of attraction, and gravitational force of attraction. The authors pointed out that capillary force dominated the binding force between the dust particles and PV module surfaces most especially under relatively high humidity while under dry conditions Van der Waal force is supreme to other types of binding forces. Also, Ajewole et al (25) conducted an experimental investigation on the impact of fin-cooling photovoltaic modules with a view to increasing the energy yield. They revealed that as cell temperature rises, cell degradations occur which has a significant negative effect on the expected energy yield of the module. Also, the attached fin was fabricated from aluminum and copper; it was concluded that employing aluminum fins at the back of the solar panel array can potentially reduce the cell temperature by 7.4°C which in turn implies an increase in energy yield of about 2.72% (26). The study also established that a temperature of about 85^0C is suitable for maximum PV module operation.

The impact of highly efficient modular cells and their consequences on lowering the levelized energy cost was presented by Wang et al. (27). In this regard, the bifacial module was investigated in terms of energy yield and the cost of producing such yield. Growth in energy forecast of bifacial solar panel modules in economic value was projected to be around 40% come 2025. Also, Chantana et al. (28) employed a multiple regression approach to analyze the performance of solar photovoltaic modules in different regions of the world. The performance of the said approach was benched using the energy predictor strategy. The outcome of the analysis showed that the multiple regression technique is deficient in predicting the energy yield of solar photovoltaic modules. Several authors have investigated the possibilities of power generation using solar photovoltaic solar modules and some have hybridized it with other renewable energy sources and measured the performance using metrics such as electrical energy production, economics, and sensitivity analysis. However, the effect of varying the solar irradiance and environmental ambient temperature has received little or no attention hence, this research analyses the effect of environmental temperature and solar irradiance conditions on photovoltaic module performance in Ogun and Bayelsa State, Nigeria.

MATERIAL AND METHODS

The problem addressed in this research is the analysis of the impact of prevailing environmental conditions - solar irradiance and ambient temperature- on the solar photovoltaic array energy yield and its corresponding economic implication. The clinic of Bells University of Technology, Ota, Ogun State was used as the case study; the electrical load assessment was done by physical inspection during periodic visits to the study location. The duration of the utilization of these pieces of electrical equipment was also monitored for one week. The duration of usage and wattage ratings of each piece of equipment were used to model the load profile that served as the basis of the analysis. The prevailing environmental conditions that is the solar irradiance and the ambient temperature were obtained from the NASA website. The average solar irradiance and ambient temperature were used to benchmark the solar photovoltaic performance at the value of irradiance above and below this average value. The hybrid optimization of multiple electric renewables (HOMER) was used as the implementation tool. The metrics of interest in this analysis include the electrical energy yield, capacity shortage, capacity factor of the PVs, unmet load, excess electricity generated, lifetime throughput, econometric metric (Net Present Cost, Levelized Cost of Energy, and operational cost), and state of charge of the battery.

Description of the case study

The location used for this case study is situated on the Longitude 6.6859° N and Latitude 3.1711° E. The clinic is a block of two buildings, the first block contains the administrative offices, the Doctor's offices, and laboratories for conducting all kinds of tests. The second block has two wings one wing for males and the other wing for female students. The nurses’ offices are situated close to the patient wards for close monitoring and treatment of students and members of staff.

Assessment of electrical loads and modeling of load profile

The starting point of any power system analysis is the load assessments, with appropriate load assessments appropriate strategies can be adopted to mitigate identified challenges. The load to be assessed in this case is the appliances that consume electrical energy. These pieces of appliances are meant to be powered with photovoltaic solar arrays. The quantity of loads to be served determines the size and the number of panels to be used alongside the inverter size. The identified electrical consuming appliances and the duration of usage of each of the electrical appliances in the study location are detailed in Table 1.

Mathematical modeling total energy consumed

The energy consumed by each of the appliances was computed using Equation [1] thus;

$$E_{con} = P \times T \quad [1]$$

where; E_{con}= Energy consumed in kWh, P= Appliance wattage rating (W), T= Duration of usage in hours.

The total energy consumed by all the electrical appliances within the clinic was estimated using Equation [2] which represents is the summation of energy consumed by the n^{th} number of electrical appliances;

$$E_T = \sum_{i=1}^{n} E_{con(i)} \quad [2]$$

Table 1. Electrical consuming appliances at the Bells University clinics

Items	Electrical equipment	Quantity	Rated capacity (W)	Total load (W)	Duration of usage (h)	Energy demand (Wh)
1	Refrigerator Vaccine	1	40	40	24	960
2	Refrigerator non-medical	1	125	125	11	1375
3	Centrifuge	1	70	70	4	280
4	Microscope	1	20	20	6.5	130
5	Blood chemical analyzer	1	45	45	7	315
6	Hematology analyzer	1	230	230	7	1610
7	CD4 Machine	1	200	200	5	1000
8	Television	4	15	60	24	1440
9	CFL bulbs	8	18	144	~24	3450
10	Ceiling fan	5	40	200	16	3200
11	Halogen lamp (security)	4	50	200	12	2400
12	Desktop Computer	1	65	65	14	910
13	Printer	1	200	200	1	200
						Total: 17270

where; $E_T =$ Total energy required to power all the appliances (kWh), $E_i =$ Energy consumed by individual appliances in kWh, $\sum_{i=1}^{n} E_{con(i)}$= summation of energy consumed by all the appliances.

The total daily energy demand of the clinic is 17.27 kWh as shown in Table 1, which is spread on 24-hour profile according to the usage of the appliances to obtain a working load profile. The daily hourly energy consumption profile of the clinic then serves as the input data to the HOMER load model as the basis of the simulation.

Solar irradiance and ambient temperature resources

Environmental resources such as solar irradiance and ambient temperature influence the performance of photovoltaic cells. This can be computed using mathematical equations proposed by Angstrom (29) thus;

$$H = H_o\left(a + b\left(\frac{s}{S_o}\right)\right) \quad [3]$$

where; $H =$ daily value of global radiation $(MJ/m^2\ day)$; $H_o =$ daily mean value of extraterrestrial radiation $(MJ/m^2\ day)$; $s =$ number of a bright sunshine hour; $S_o =$ daily average value of day length; a and b = empirical Angstrom constants.

The numerical value of the daily mean value of extraterrestrial radiation can be computed using the Equation [4] given by Sanusi et al. (30) thus;

$$H_o\left(\frac{24 \times 3600}{\pi}\right) I_{SC} E_0 [\cos\psi \cos\delta \sin\omega_s] + \frac{\pi\omega_s}{180}\sin\psi \quad [4]$$

$$I_{SC} = 1.367\ MJm^{-2}hour^{-1} \quad [4a]$$

$$E_0 = 1 + 0.033\ \cos\left(\frac{360n_d}{365}\right) \quad [4b]$$

where; $I_{SC} =$ Solar constant, $E_0 =$ Eccentricity correction, $\psi =$ Site latitude, $\delta =$ Solar declination, $\omega_s =$ mean sunset hour angle usually for month consideration, the I_{SC} and eccentricity correction (E_0) can equally be computed with equations $n_d =$ day number of the year/ Julian day (for instance, 1 Jan., $n_d = 1$ and 31st Dec., $n_d = 365$).

In recent times, the National Aeronautics and Space Administration (NASA) and independent organizations have made the job of evaluating solar irradiance and ambient temperature an easy task. The solar irradiance of a particular location can be assessed by inputting the location coordinate in the search engine of NASA. The average ambient temperature and average solar irradiance used in this analysis were obtained from the NASA website and were introduced into the HOMER model for this study.

The proposed investigation of the effect of solar radiation and the ambient temperature on the performance of solar photovoltaic cells is undertaken in terms of five scenarios such as cases I, II, III, IV and V. Case I deals with introducing the average solar radiation and ambient temperature data into the HOMER software to ascertain the response of the solar array to the two factors. This behaviour is what is referred to in this study as the baseline evaluation. However, cases II to V present the effect of increasing the solar radiation values for January to December by 30 % while the ambient temperature values for the months are kept constant. Case III considers decreasing the solar radiation values for the months by 30 % while the temperature values remain unchanged; In case IV the solar radiation values for the months remain unchanged while the ambient temperature values for the months are increased by 30 %, while in case V the solar radiation values for the months remain unchanged and the ambient temperature values for the months are decreased by 30 %.

Solar photovoltaic array model

The solar photovoltaic array output can be computed by Equation [5] based on the methodology indicated in the HOMER tool.

$$\text{Module } PV_{output} = \frac{((PV_m)\times(d_f)\times(S_l)\times(1+\alpha_p[(T_d + \frac{NOCT-20℃}{S_r}.S_l) - T_{c,STC}])}{S_{STC}} \quad [5]$$

where: Module PV_o= Output of the solar photovoltaic, PV_m= power rating of a single PV module, d_f= Derating factor, S_l = solar irradiance at BTS location, α_p = temperature coefficient of power, T_d= solar irradiance at standard test condition (STC), S_{STC}= nominal operating cell temperature, $NOCT$ = nominal operating cell temperature, S_r= reference solar irradiance of 0.8 kW/m^2, $T_{c,STC}$ = cell temperature at STC.

Equation [5] stands for the output of a single module. However, the output of an array of solar PV can be computed by Equation [6], where n is the total number of solar PV modules;

$$\text{Array}PV_{output} = \text{ Module } PV_{output} \times n \quad [6]$$

Modeling of battery bank capacity

Due to the stochastic nature of solar energy, the performance of solar photovoltaic cells tends to be unsatisfactory, especially during cloudy days. There is therefore the need to design a good backup system with an energy storage device such as a battery. The ampere-hour (AH) capacity of the battery depends on the depth of discharge, days of autonomy, efficiency of the battery, and nominal DC system voltage. These factors are modeled mathematically to obtain the Ampere Hour capacity of the battery with Equation [7].

$$BC_{\text{AH}} = \frac{E_{ADED} \times D_{Au}}{V_{DC} \times DoD \times \eta_B} \quad [7]$$

where; $BC_{\text{AH}} =$ the battery capacity in ampere-hours,

E_{ADED} = average daily energy demand in kWh/day, D_{Au} = days of autonomy, V_{DC} = nominal system voltage (DC), DoD = depth of discharge, η_B= battery efficiency.

Modeling of inverter size

The inverter system plays a major role in the energy system's design as it is required to convert the DC energy from the battery bank to AC output for AC load utilization. In the design of an inverter system, there is a need to compute the appropriate size which will not only accommodates the immediate loads but also the future loads (safe factor of say 25 %). It is pertinent to know that the nominal voltage of the inverter system and that of the battery bank must be the same; this is in addition to the fact that the inverter input rating should at all-time be more than the load. To accommodate the starting current of the inductive load, the inverter capacity has to be multiplied by a factor of 3 in addition to the inclusion of a safe factor (20 to 30 %). The total inverter size capacity can be computed using Equation [8]:

$$I_{Cs} = 1.25 \times [P_{res} + (3 \times (P_{ind})] \quad [8]$$

where; I_{Cs}= the inverter size, P_{res}= total resistive load, P_{ind} = total inductive loads.

To further deepen the scope of the paper, the PV performance analysis is then compared with using other energy resources such as diesel, natural gas and the grid to meet the load demand requirements of the clinics.

Generator sizing

The size of a power generating source in HOMER model is expected not to be less than 1.2 of the peak load (L_{peak}) of the user. However, in this study a factor of 1.5 of the peak load is applied to allow for possible increase in demand. Therefore, β is 1.5 in Equation [9] that is used to calculate the size of the generator.

$$G_{size} = \beta * L_{peak} \quad [9]$$

where G_{size} is the generator size.

The fuel consumption of a generator in the HOMER environment may be determined by Equation [10] (31).

$$F = F_o Y_{gen} + F_1 P_{gen} \quad [10]$$

where F, F_o, Y_{gen}, F_1 and P_{gen} are fuel consumption rate (L/hr), generator fuel curve intercept coefficient (L/hr/kW_{rated}), generator fuel curve slope (L/hr/W_{output}), rated capacity of the generator (kW), and output of the generator in the time step (kW).

The same generator is used for analyzing the application of diesel and natural gas resources to power the clinic.

Grid analysis

The hourly load profile of the clinic is also presented to the grid model in HOMER environment to determine the cost of the electricity purchased throughout the year for the two locations: Ogun and Bayelsa States. The total cost of electricity consumed in the year is the sum of the costs of electricity purchased from the grid from January to December. The energy cost can be calculated by Equation [11]. The environmental impact of the energy consumed can be determined by Equation [12] in terms of the carbon dioxide emissions.

$$E_{cost} = \sum_{i=1}^{12} E_i \quad [11]$$

where; E_{cost}, i and E_i represents the total cost, the month and energy cost for the month, respectively.

$$Emissions = \alpha * E_T \quad [12]$$

where; α and E_T represent the emissions factor (kg CO_2 /kWh) and the total energy purchased from the grid in the year.

Performance metrics

To evaluate the performance of monocrystalline solar panel the following metrics were used, the electrical energy produced, the Net Present Cost (NPC), Unmet Energy, Cost of Energy (COE), Levelized Cost of Energy (LCOE), Mean day Energy Output, Capacity Shortage, Lifetime Throughput, Capacity factor of PV and Excess Electricity Generation.

RESULTS AND DISCUSSION

Load profile of the study location

Data presented in Table 2 are the load demand evaluation metrics for the Bells University clinic, the clinic load factor is approximately 34% which is comparatively low. The load factor indicates the actual quantity of energy (kWh) delivered on a system for a given period, the load factor is expected to be closer to 100 % if not 100 %, a low load factor implies that the unit average cost of the energy will be higher but at high load factor, the unit average cost of energy is comparatively reduced. Also, the average load demand per day is about 17.27 kWh/day while peak load demand is approximately 2.12 kW. The peak of the load profile is originally 1.22 kW as shown in Figure 1 but because of the consideration for the day-to-day random variability of 10 % and time step of 20 % in the load model, the peak load was raised to 2.12 kW as presented in Table 2. Therefore, this study is based on a daily demand of 17.27 kWh as shown in Table 1 and a peak load of 2.12 kW as presented in Table 2.

The daily, and monthly load profile of the study location based on the duration of usage of the clinic-connected loads is shown in Figures 1 and 2, respectively. The daily load curve gives an impression of load spread for twenty-four hours, observation of the daily load profile revealed that between 0 hours to 6 a.m., there are

Table 2. Load demand evaluation metric for Bells University clinic

Metric Evaluation of Clinic Load Demand	Baseline	Scaled
Average Load Demand (kWh/day)	17.27	17.27
Average Load (kW)	0.72	0.72
Peak Load (kW)	2.12	2.12
Clinic Load Factor	0.34	0.34
Type of Load	AC	

constant loads that run for twenty hours which implies that the energy supply to the clinic must not be interrupted in any way if active activity will be maintained. It is also imperative to know that the base load of the clinic is approximately 0.5 kW, which implies that at any time of the day, constant energy of roughly 0.6 kW must be made available to the clinic. In a similar vein, the clinic's peak energy demand is between the hours of 7 a.m. to 4 p.m, this shows that morning to evening hours in the clinic are extremely busy hours as more of the electrical appliances are connected to the supply. Also, during these hours, medical tests are being conducted and clinic pieces of equipment are massively put into use. It is imperative to know that the peak load of the Bells University clinic is about 1.22 kW. Also, during the evening session between 16 to 24 hours, the clinic connected loads were observed to drop significantly from 1.4 kW to 1.0 kW, 0.8 kW, and 0.9kW respectively. This shows that some pieces of equipment are put on hold as the staff in the morning session hand over to the staff in the evening session and at about 19 hours of the day, the load demand rises, at this time the security lights and some other equipment are put into use. It is pertinent to know that the daily load pattern translates into the monthly load consumption pattern which is subsequently reflected in the seasonal energy demand pattern.

Harvesting of environmental solar irradiance and ambient temperature

With the coordinates of Bells University, Ota, Ogun State, Nigeria input into the HOMER software, the NASA solar irradiance and the ambient temperature of Bells University clinic were obtained. The solar radiation and the ambient temperature of Otuasega (Long. 4.9353° N, Lat. 6.4184° E) in Bayelsa State were also obtained. The

Figure 1. Hourly load curve of Bells University clinic

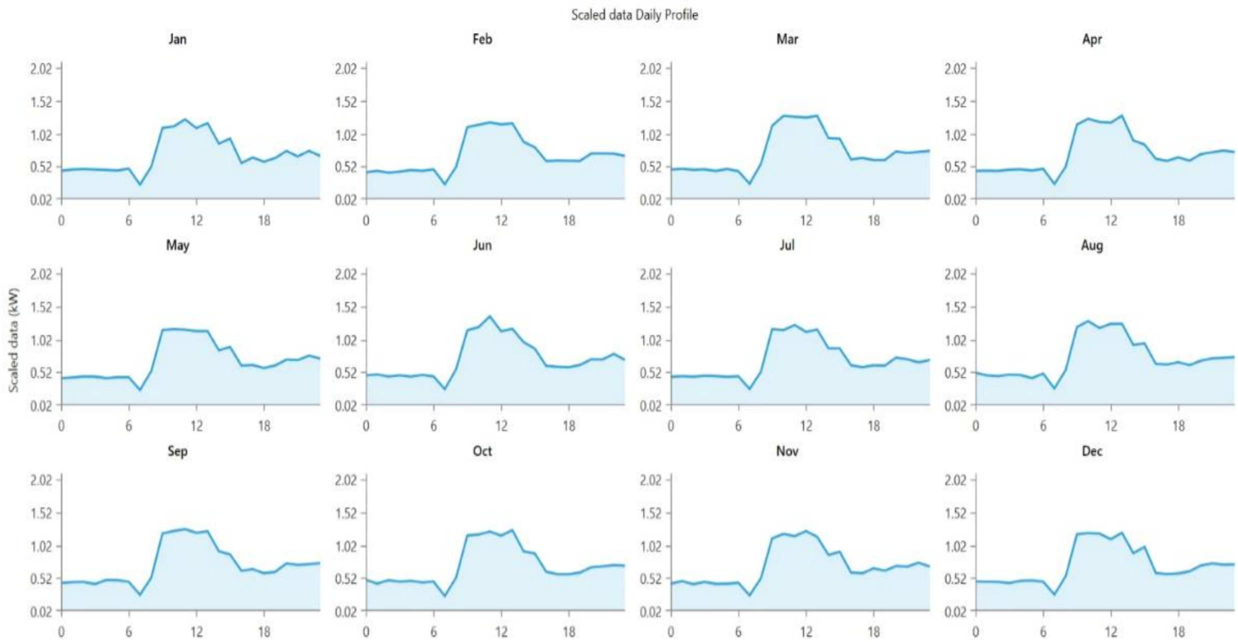


Figure 2. Monthly energy consumption pattern of Bells University clinic

performance of PV is largely dependent on the location's solar energy and the ambient temperature where the PV modules are to be installed. The average values of the solar irradiation and the ambient temperature of the two locations under consideration are shown in Figures 3 and 4, respectively. The average solar irradiance and the average ambient temperature obtained for the two study locations are 5.38 kWh/m^2/day and 21.84°C; respectively.

Environmental effect of the monocrystalline solar photovoltaic cells

With the prevailing environmental condition, the behavior of monocrystalline solar photovoltaic cells (Fronius Symo 20.0.3-M PV) was investigated in terms of electrical energy produced, the economic analysis of energy yield, and the state of charge of the battery. To be able to examine the effect of environmental conditions on the performance of monocrystalline solar photovoltaics, five different scenarios were investigated using two locations as test cases - Ogun State and Bayelsa State. The first case represents the baseline scenario for the two locations; the remaining four cases represent the sensitivity analyses for the study as the solar radiation and temperatures are varied.

Case I: Baseline evaluation of the effect of locations' solar radiation and ambient temperature data on the 20 kW PV

Starting with the location in Ogun State, and using a 20-kW PV as a test, the monthly average electric power generation is presented in Figure 5(a), the excess electricity is 21,553 kWh/y, the unmet electric load is 4.71kWh/y which is approximately 0.0747 %. Also, the capacity shortage is about 6.27 kWh/y, which is 0.0995%. Shown in Figure 5(b) is the power output of the 20-kW rated PV, where the mean output is 3.27 kW and/or a mean daily energy output of 78.5 kWh; the capacity factor of the PV array is 16.4 % with a yearly production of 28, 659 kWh. The battery parameters are; the quantity of battery required is 14, string size is 1, the number of strings in parallel is 14, and bus voltage is 12 V. The number of days of autonomy is 1.5 days, the lifetime throughput is 2,975 kWh as shown in Figure 5(c). From an economic perspective; the Initial cost, net present cost,

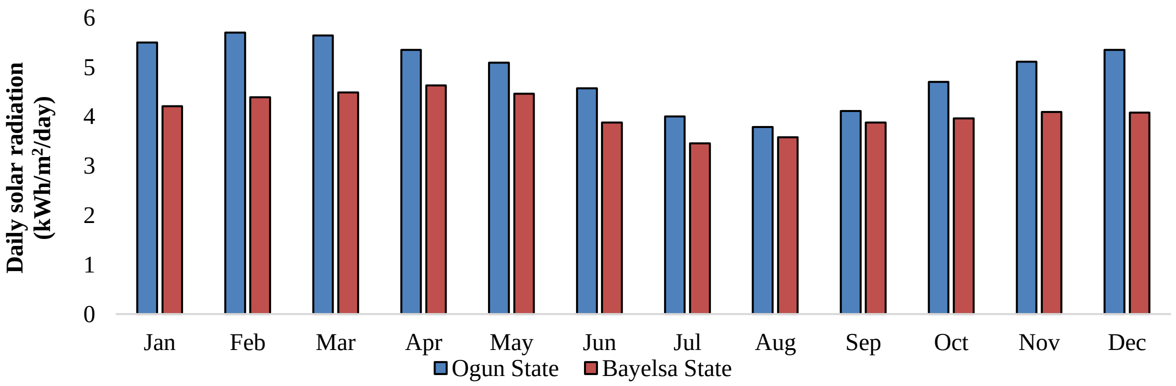


Figure 3. Daily solar radiation for locations in Ogun and Bayelsa State

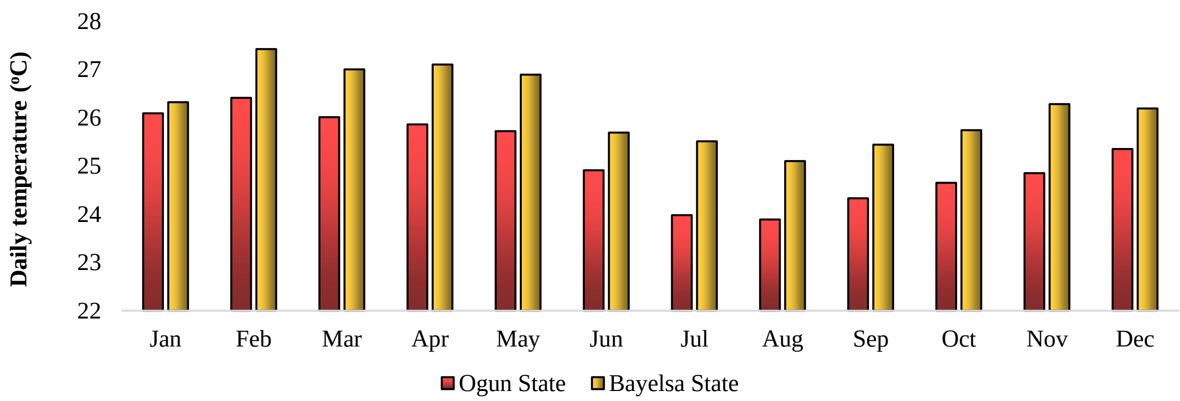


Figure 4. Daily temperature for locations in Ogun and Bayelsa State

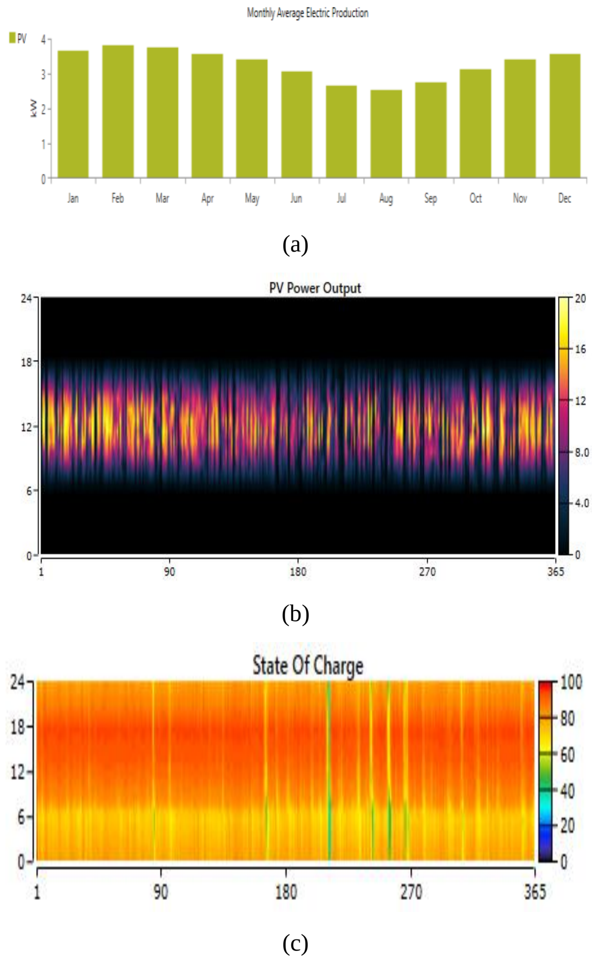


Figure 5. (a) Baseline monthly average electric energy production for Ogun location, (b) Baseline power output of the 20 kW PV at Ogun location, and (c) Baseline state of charge of the battery at Ogun location

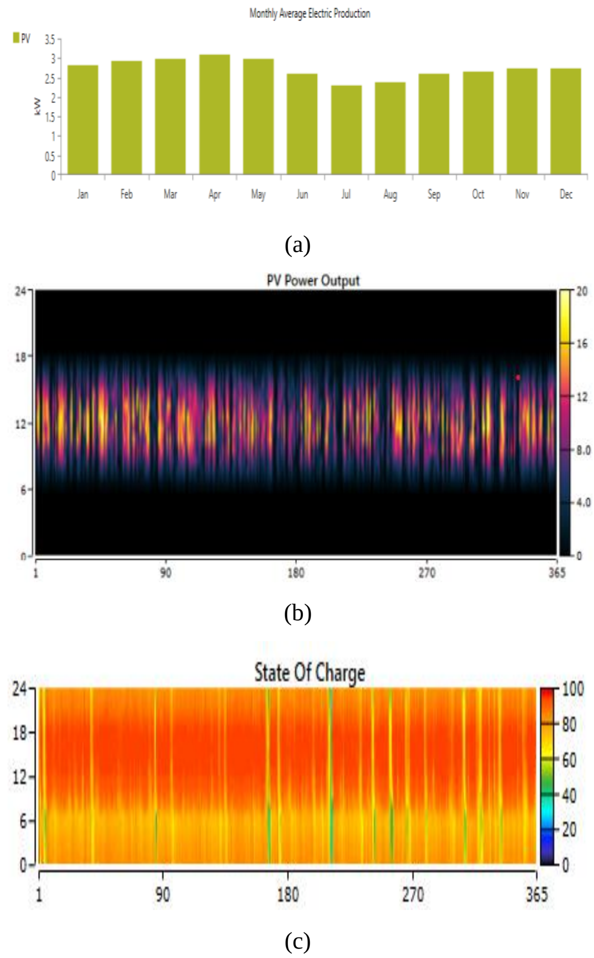


Figure 6. (a) Baseline monthly average electric production by 20 kW PV for Bayelsa location, (b) Baseline power output of the 20 kW PV for Bayelsa location, and (c) Baseline state of charge of the battery for Bayelsa location

levelized cost of energy, and the operating cost is $ 10,028, $13, 537, $0.166, and $271.43, respectively.

For the location in Bayelsa State, the monthly electric power generation by the 20 kW PV is presented in Figure 6(a); the excess electricity is 16,566 kWh/y, unmet electric load is 4.8 kWh/y which is approximately 0.0761 %. Also, the capacity shortage is about 6.24 kWh/y, which is 0.0990 %. Figure 6(b) shows the power output of the 20-kW rated PV, where the mean output is 2.73 kW and/or a mean daily energy output of 65.5 kWh; the capacity factor of the PV array is 13.6 % with a yearly production of about 23,890 kWh. The battery parameters are; the quantity of battery required is 14, string size is 1, the number of strings in parallel is 14, and bus voltage is 12 V. The number of days of autonomy is 1.5 days, the lifetime throughput is 3,044 kWh as shown in Figure 6(c). From an economic perspective; the Initial cost, net present cost, levelized cost of energy, and the operating cost is $ 10,551, $14,009, $0.172, and $267.52, respectively.

Case II: PV performance when solar radiation data is increased by 30 % and temperature values remain unchanged

For the location in Ogun, the solar radiation data for January to December is increased by 30 % with unchanged ambient temperature values shown in Figure 7 (Baseline values overrated by 30 %) to investigate how the 20-kW monocrystalline solar PV modules will behave. The monthly electric power generation is presented in Figure 8(a), in which case the excess electricity is 30,161 kWh/y, the unmet electric load is 1.63 kWh/y which translates to 0.0258 %. Also, the capacity shortage is about 6.15 kWh/y, which is 0.0975 %. Figure 8(b) shows the power output of the 20-kW rated PV, where the mean output is 4.25 kW and/or a mean

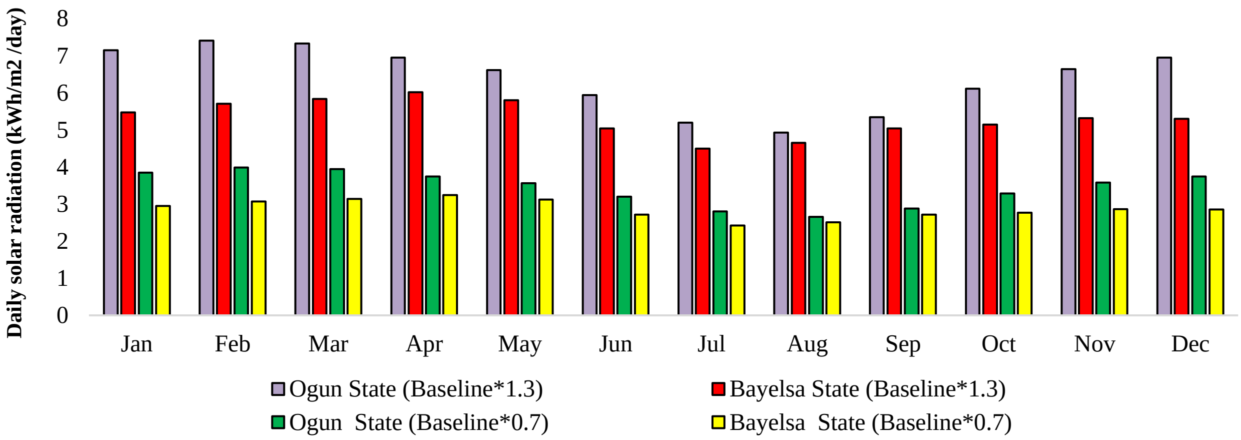
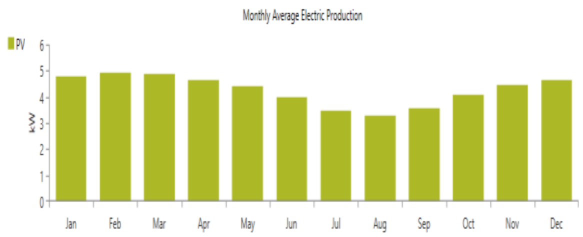
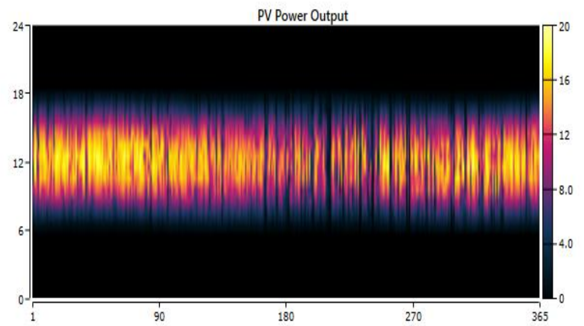


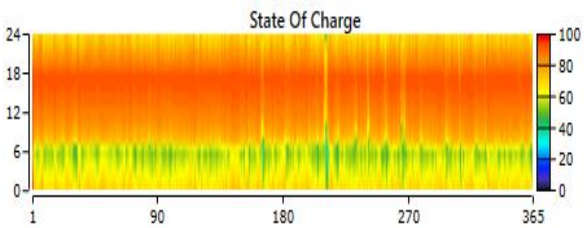
Figure 7. Changed values of solar radiation with temperature unchanged for Ogun and Bayelsa



(a)



(b)



(c)

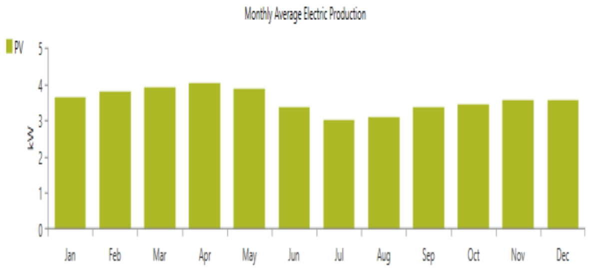
Figure 8. (a) Monthly average electric production by 20 kW PV for Ogun location with increased solar radiation and temperature unchanged, (b) Power output of the 20 kW PV for Ogun location with increased solar radiation, and (c) State of charge of the battery for Ogun location with increased solar radiation

daily energy output of 102 kWh; the capacity factor of the PV array is 21.3 % with a yearly production of about 37,260 kWh. The battery parameters are; the quantity of battery required is 7, string size is 1, the number of strings in parallel is 7, and bus voltage is 12 V. The number of days of autonomy is 1.5 days, the lifetime throughput is 2,909 kWh as shown in Figure 8(c). From an economic perspective; the Initial cost, net present cost, levelized cost of energy, and the operating cost are $ 8,662, $12,417, $0.152, and $290.42

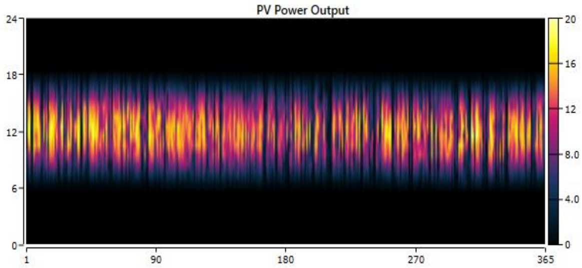
Considering the location in Bayelsa, the solar radiation data is increased by 30 % with unchanged ambient temperature values shown in Figure 9(a) to ascertain how the 20-kW monocrystalline solar PV modules will behave. The monthly electric power generation is presented in Figure 9(b), in which case the excess electricity is 23,955 kWh/y, the unmet electric load is 2.01 kWh/y which translates to 0.0319 %. Also, the capacity shortage is about 6.24 kWh/y, which is 0.0991 %. Figure 9(c) shows the power output of the 20-kW rated PV, where the mean output is 3.55 kW and/or a mean daily energy output of 65.1 kWh; the capacity factor of the PV array is 17.7 % with a yearly production of about 31,060 kWh. The battery parameters are; the quantity of battery required is 9, string size is 1, the number of strings in parallel is 9, and bus voltage is 12 V. The number of days of autonomy is 1.5 days, the lifetime throughput is 2,946 kWh. From an economic perspective; the Initial cost, net present cost, levelized cost of energy, and the operating cost are $ 9,195, $12,847, $0.158, and $282.55, respectively.

Case III: PV performance when solar radiation data is decreased by 30 % and temperature values unchanged

Considering the location in Ogun State, the solar radiation data for January to December is decreased by 30 % with the unchanged initial ambient temperature values shown



(a)



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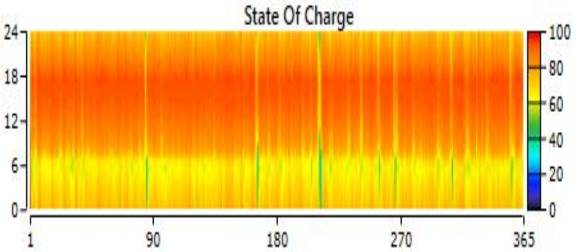
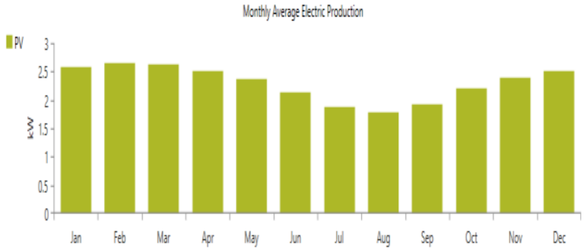
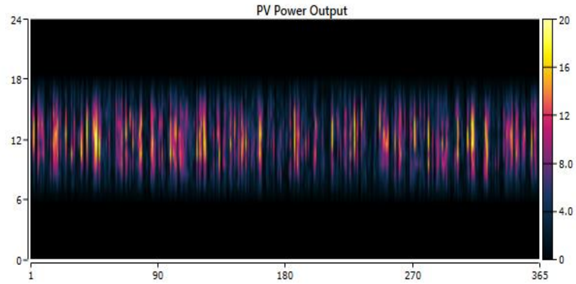


(c)

Figure 9. (a) Monthly average electric production by 20 kW PV for Bayelsa location with increased solar radiation and temperature unchanged, (b) Power output of the 20 kW PV for Bayelsa location with increased solar radiation, and (c) State of charge of the battery for Bayelsa location with increased solar radiation



(a)



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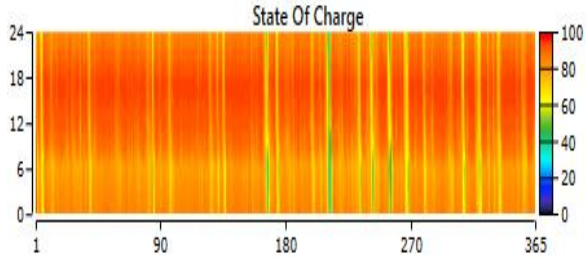
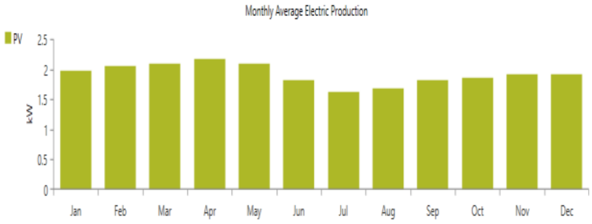


(c)

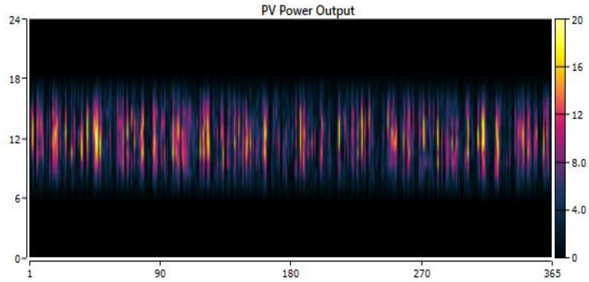
Figure 10. (a) Monthly average electric production by 20 kW PV for Ogun location with decreased solar radiation and temperature unchanged, (b) Power output of the 20 kW PV for Ogun location with decreased solar radiation, and (c) State of charge of the battery for Ogun location with decreased solar radiation

in Figure 7 (Baseline values minimized by 30 %) to ascertain how the 20-kW monocrystalline solar PV modules will behave. The monthly electric power generation is presented in Figure 10(a), in which case the excess electricity is 12,927 kWh/y, the unmet electric load is 3.22 kWh/y which translates to 0.0511 %. Also, the capacity shortage is about 5.93 kWh/y, which is 0.094 %. Also, Figure 10(b) shows the power output of the 20-kW rated PV, where the mean output is 2.29 kW and/or a mean daily energy output of 55 kWh; the capacity factor of the PV array is 11.4 % with a yearly production of about 20,058 kWh. The battery parameters are; the quantity of battery required is 19, string size is 1, the number of strings in parallel is 19, and bus voltage is 12 V. The number of days of autonomy is 1.5 days, the lifetime throughput is 3,124 kWh as shown in Figure 10(c). From an economic perspective; the Initial cost, net present cost, levelized cost of energy, and the operating cost are $ 11,873, $15,663, $0.192, and $293.14, respectively.

For the location in Bayelsa, the solar radiation data is decreased by 30 % with the initial ambient temperature values in Figure 4 to ascertain how the 20-kW monocrystalline solar PV modules will behave. The monthly electric power generation is presented in Figure 11(a), in which case the excess electricity is 9,584 kWh/y, the unmet electric load is 5.11 kWh/y which translates to 0.0811 %. Also, the capacity shortage is about 6.28 kWh/yr, which is 0.0997 %. Figure 11(b) shows the power output of the 20-kW rated PV, where the mean output is 1.91 kW and/or a mean daily energy output of 45.8 kWh; the capacity factor of the PV array is 9.54 %



(a)



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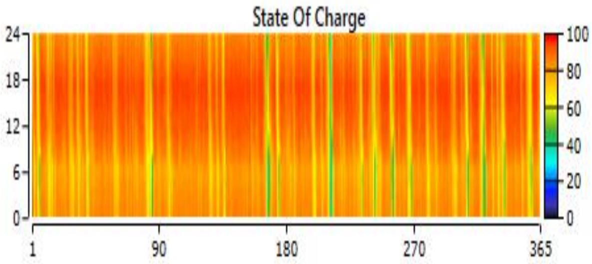


(c)

Figure 11. (a) Monthly average electric production by 20 kW PV for Bayelsa location with decreased solar radiation and temperature unchanged, (b) Power output of the 20 kW PV for Bayelsa location with decreased solar radiation, and (c) State of charge of the battery for Bayelsa location with decreased solar radiation

with a yearly production of about 16,720 kWh. The battery parameters are; the quantity of battery required is 19, string size is 1, the number of strings in parallel is 19, and bus voltage is 12 V. The number of days of autonomy is 1.5 days, the lifetime throughput is 3,196 kWh as shown in Figure 11(c). From an economic perspective; the Initial cost, net present cost, levelized cost of energy, and the operating cost are $ 11,897, $15,710, $0.193, and $294.96, respectively.

Case IV: PV performance when solar radiation data remains unchanged and temperature values are increased by 30 %

The daily temperature data for January to December is increased by 30 % with unchanged solar radiation values shown in Figure 12 (Baseline values overrated by 30 %) to investigate the behaviour of the 20-kW monocrystalline solar array. The monthly electric power generation is presented in Figure 13(a), in which case the excess electricity is 21,553 kWh/y, the unmet electric load is 4.71 kWh/y which translates to 0.0747 %. Also, the capacity shortage is about 6.27 kWh/y, which is 0.0995 %. Figure 13(b) shows the power output of the 20-kW rated PV, where the mean output is 3.27 kW and/or a mean daily energy output of 78.5 kWh; the capacity factor of the PV array is 16.4 % with a yearly production of 28,659 kWh. The battery parameters are; the quantity of battery required is 12, string size is 1, the number of strings in parallel is 12, and bus voltage is 12 V. The number of days of autonomy is 1.5 days, the lifetime throughput is 2,975 kWh as shown in Figure 13 (c). From an economic perspective; the initial cost, net present cost, levelized cost of energy, and the operating cost is $ 10,028, $13,537, $0.166, and $271.43, respectively.

For the Bayelsa location also, the solar radiation data remains unchanged while the daily temperature values are increased by 30 % as shown in Figure 14(a) (Baseline values minimized by 30 %) to ascertain the performanc

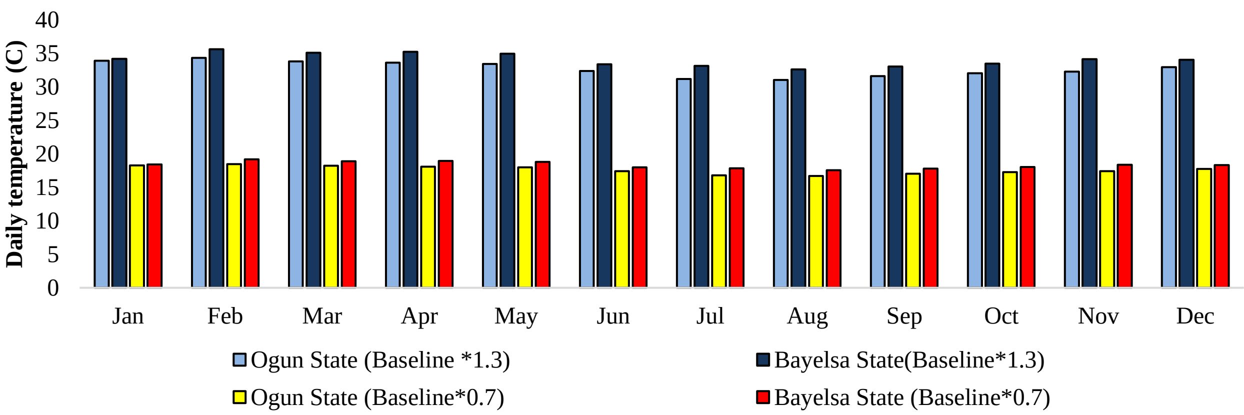


Figure 12. Changed values of daily temperature for Ogun and Bayelsa

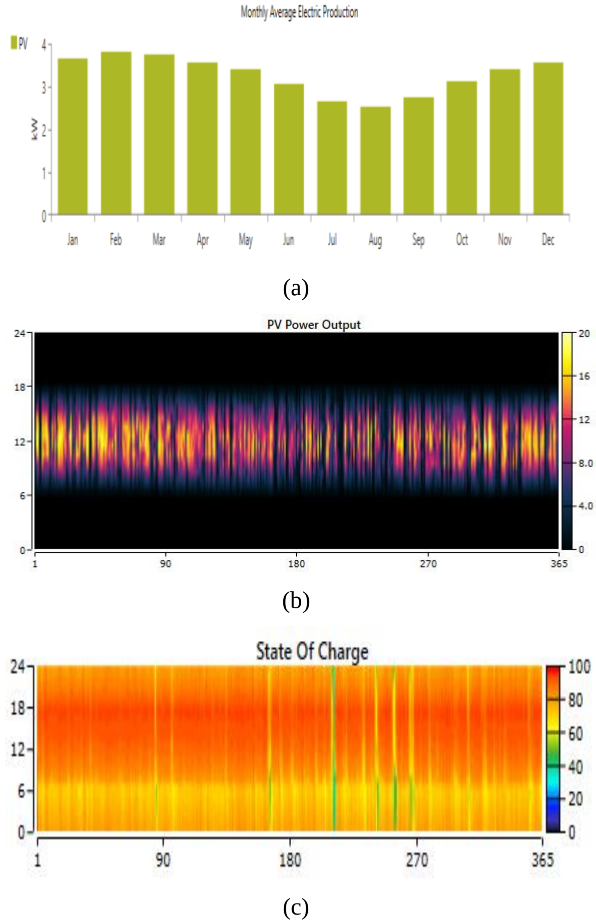


Figure 13. (a) Monthly average electric production by 20 kW PV for Ogun location with increased daily temperature with solar radiation unchanged, (b) Power output of the 20 kW PV for Ogun location with increased daily temperature with solar radiation unchanged, and (c) State of charge of the battery for Ogun location with increased daily temperature with solar radiation unchanged

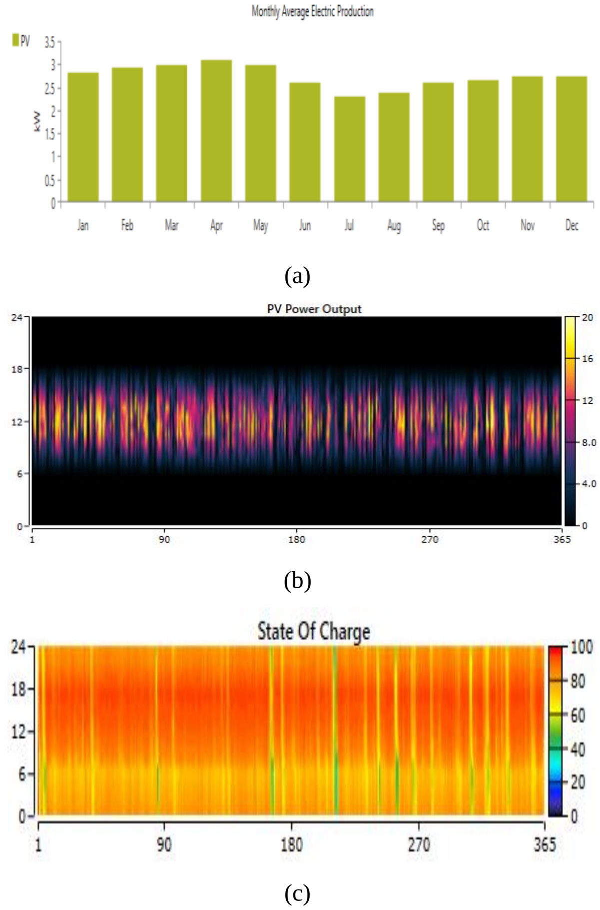
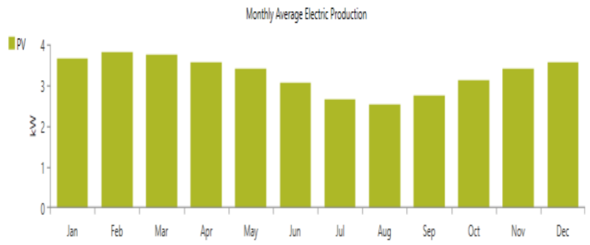


Figure 14. (a) Monthly average electric production by 20 kW PV for Bayelsa location with increased daily temperature with solar radiation unchanged, (b) Power output of the 20 kW PV for Bayelsa location with increased daily temperature with solar radiation unchanged, and (c) State of charge of the battery for Bayelsa location with increased daily temperature with solar radiation unchanged

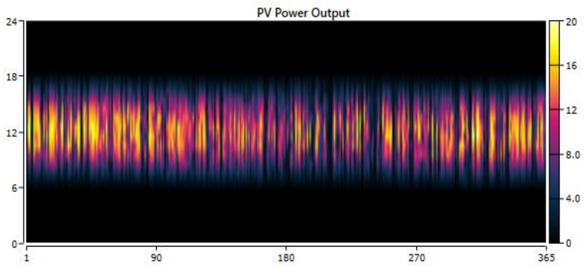
of the 20-kW monocrystalline solar PV array. The monthly electric power generation is presented in Figure 14(a), in which case the excess electricity is 16,773 kWh/y, unmet electric load is 4.34 kWh/y which translates to 0.0689 %. Also, the capacity shortage is about 6.15 kWh/y, which is 0.0976 %. Figure 14(b) shows the power output of the 20-kW rated PV, where the mean output is 2.73 kW and/or a mean daily energy output of 65.5 kWh; the capacity factor of the PV array is 13.6 % with a yearly production of 23,890 kWh. The battery parameters are; the quantity of battery required is 14, string size is 1, the number of strings in parallel is 14, and bus voltage is 12 V. The number of days of autonomy and the lifetime throughput are 1.5 days and, and 3, 044 kWh respectively. From an economic perspective; the Initial cost, net present cost, levelized cost of energy, and the operating cost is $ 10,551, $ 14,009, $0.172, and $267.52, respectively.

Case V: PV performance when solar radiation data remains unchanged and temperature values are decreased by 30 %

The daily temperature data for January to December is decreased by 30 % with unchanged solar radiation values shown in Figure 12 (Baseline values minimized by 30 %) to investigate the behavior of the 20-kW monocrystalline solar array. The monthly electric power generation is presented in Figure 15(a), in which case the excess electricity is 21,553 kWh/y, the unmet electric load is 4.71 kWh/y which translates to 0.0747 %. Also, the capacity shortage is about 6.27 kWh/y, which is 0.0995 %. Figure 15(b) shows the power output of the 20-kW rated PV, where the mean output is 3.27 kW and/or a mean daily energy output of 78.5 kWh; the capacity factor of the PV array is 16.4 % with a yearly production of 28,659 kWh. The battery parameters are; the quantity of battery required is 12, string size is 1, the number of



(a)



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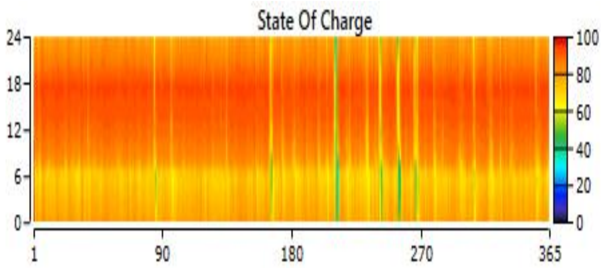
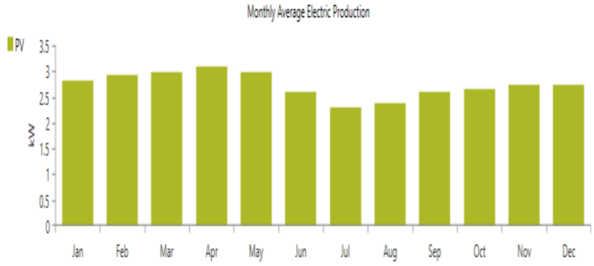
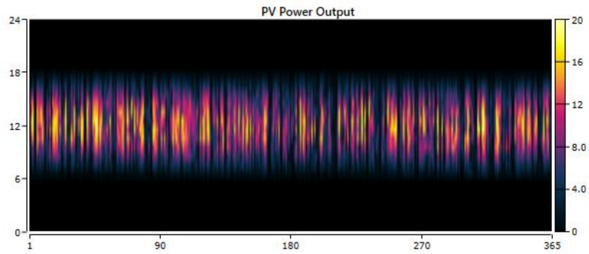


(c)

Figure 15. (a) Monthly average electric production by 20 kW PV for Ogun location with decreased daily temperature with solar radiation unchanged, (b) Power output of the 20 kW PV for Ogun location with decreased daily temperature with solar radiation unchanged, and (c) Battery state of charge for Ogun location with decreased daily temperature with solar radiation unchanged



(a)



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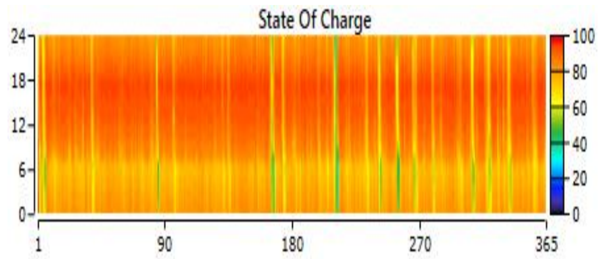

(c)

Figure 16. (a) Monthly average electric production by 20 kW PV for Bayelsa location with decreased daily temperature with solar radiation unchanged, (b) Power output of the 20 kW PV for Bayelsa location with decreased daily temperature with solar radiation unchanged, and (c) State of charge of the battery for Bayelsa location with decreased daily temperature with solar radiation unchanged

strings in parallel is 12, and bus voltage is 12 V. The number of days of autonomy is 1.5 days, the lifetime throughput is 2,975 kWh as shown in Figure 15(c). From an economic perspective; the initial cost, net present cost, levelized cost of energy, and the operating cost is $ 10,028, $13,537, $0.166, and $271.43, respectively.

For the Bayelsa location also, the solar radiation data remains unchanged while the daily temperature values are decreased by 30 % as shown in Figure 16(a) (Baseline values minimized by 30 %) to ascertain the performance of the 20-kW monocrystalline solar PV array. The monthly electric power generation is presented in Figure 16(a), in which case the excess electricity is 15,773 kWh/y, unmet electric load is 4.10 kWh/y which translates to 0.0689 %. Also, the capacity shortage is about 5.15 kWh/y, which is 0.0976 %. Shown in Figure 16(b) is the power output of the 20-kW rated PV, where the mean output is 2.73 kW and/or a mean daily energy output of 63.5 kWh; the capacity factor of the PV array is 12.6 % with a yearly production of 22,890 kWh. The battery parameters are; the quantity of battery required is 14, string size is 1 the number of strings in parallel is 14, and bus voltage is 12 V. The number of days of autonomy is 1.5 days, the lifetime throughput is 3, 044 kWh as shown in Figure 16(c). From an economic perspective; the Initial cost, net present cost, levelized cost of energy, and the operating cost are $ 10,200, $14,000, $0.172, and $257.52, respectively.

Tables 3 and 4 presented the summary of simulation results of the 20-kW PV system for the two locations under varying solar irradiance and daily temperature.

Table 3. The comparison of results for system technical performance for cases I to V

Cases	Locations	Electrical Energy Yield (kWh/y)	Unmet Load (kWh/y)	Excess Electricity (kWh/y)	Mean day Energy Output (kWh)	Capacity Shortage (kWh/y)	Life Throughput	Capacity factor of PV (%)
Case I	Ogun (Ota)	28,659	4.71	21,553	78.5	6.27	2,975	16.4
	Bayelsa (Otuasega)	23,890	4.80	16,566	65.5	6.24	3,044	13.6
Case II	Ogun (Ota)	37,260	1.63	30,161	102	6.15	2,909	21.3
	Bayelsa (Otuasega)	31,060	2.01	23,955	65.1	6.24	2,946	17.7
Case III	Ogun (Ota)	20,058	3.22	12,927	55.0	5.93	3,124	11.4
	Bayelsa (Otuasega	16,720	5.11	9,584	45.8	6.28	3,196	9.54
Case IV	Ogun (Ota)	28,659	4.71	21,553	78.5	6.27	2,975	16.4
	Bayelsa (Otuasega	23,890	4.34	16,773	65.5	6.15	3,044	13.6
Case V	Ogun (Ota)	28,659	4.68	21,553	78.5	6.27	2,975	16.4
	Bayelsa (Otuasega	22,890	4.10	15,773	63.5	5.15	2,044	12.6

Table 4. The comparison of results for system economic performance for cases I to V

Cases	Locations	NPC ($)	LCOE ($)	OC ($)	Initial Cost ($)
Case I	Ogun (Ota)	13,537	0.166	271.43	10,028
	Bayelsa (Otuasega)	14,009	0.172	267.52	10,551
Case II	Ogun (Ota)	12,417	0.152	290.42	8,662
	Bayelsa (Otuasega)	12,847	0.158	282.55	9,195
Case III	Ogun (Ota)	15,663	0.192	293.14	11,873
	Bayelsa (Otuasega)	15,710	0.192	294.96	11,897
Case IV	Ogun (Ota)	13,537	0.166	271.43	10,028
	Bayelsa (Otuasega)	14,009	0.172	267.52	10,551
Case V	Ogun (Ota)	13,437	0.156	261.43	10,000
	Bayelsa (Otuasega)	14,000	0.150	247.52	10,200

Comparative analyses of PV and other resources

Use of diesel energy resource

The HOMER tool was also used to simulate a Diesel Generator that may be able to run that same load for the two locations. The Diesel Generator size obtained is 3 kW, which has been based on the peak load of 2.12 kW. The idea is to ensure that the generator is at least a little above the users' peak load. The electrical energy yield of the gen is 7,634 kWh/y; the unmet load is 0; the excess energy is 1331 kWh/y; mean electrical output is 0.871 kW, while the maximum electrical output is 2.12 kW; the capacity shortage is 0 while the capacity factor is 29 %. Figure 17 (a) shows the monthly average power by the 3 kW Diesel Gen, while Figure 17(b) represents the generator power output, and Figure 17(c) shows the fuel consumption profile of the generator. The total operating hours of 8760 has been assumed for the generator operation.

The cost of Diesel per litre in Nigeria is about ₦1,150, which is about $0.77per litre (based on 1 USD = ₦1,500). The amount of fuel consumed is 2,952 L/y, which can be translated to 0.337 L/hr. With the assumption of a project lifetime of 25 years, the NPC, LCOE, OC and Initial Cost are $200,878, $ 2.47, $15,523, and $200, respectively. The quantity of CO_2, CO, unburned hydrocarbon, particulate matter, sulfur dioxide and nitrogen oxides generated by the Diesel Gen is 7, 726, 48.2, 2.13, 0.289, 18.9, and 45.3 kg/y, respectively.

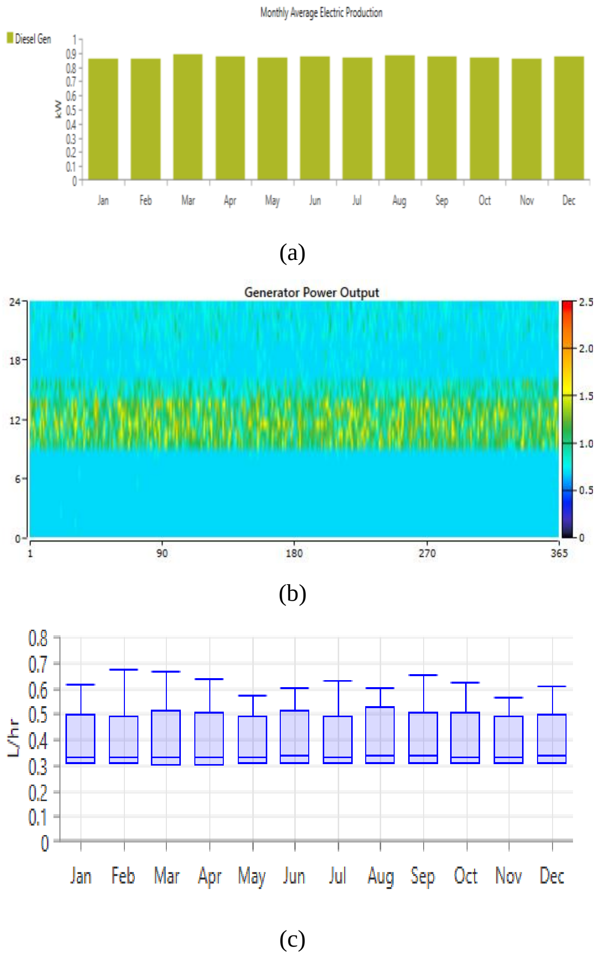

Figure 17. (a) Monthly average electric production by a 3 kW Diesel Generator, (b) Power output of the 3 kW Diesel Generator, and (c) Fuel consumed by the 3 kW Diesel Generator

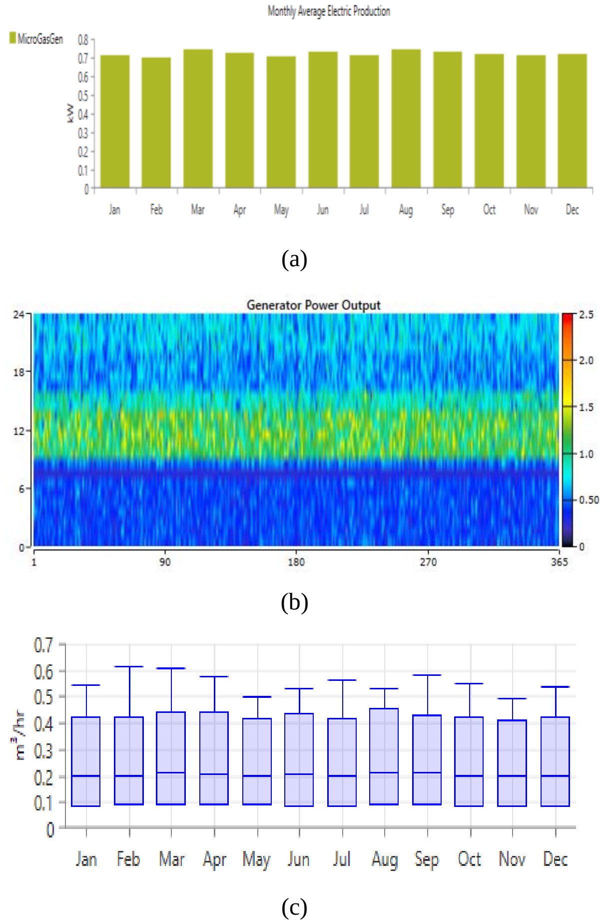

Figure 18. (a) Monthly average electric production by a 3 kW Microgas Generator, (b) Power output of the 3 kW Microgas Generator, and (c) Fuel consumed by the 3 kW Microgas Generator

Use of natural gas resource

The HOMER tool was also used to simulate a Microgas Generator that may be able to run that same load for the two locations. The Microgas Generator size is 3 kW. The electrical energy yield of the gen is 6,328 kWh/y; the unmet load is 0; the excess energy is 25.4 kWh/y; mean electrical output is 0.722 kW, while the maximum electrical output is 2.12 kW; the capacity shortage is 0 while the capacity factor is 24.1 %. Figure 18(a) shows the monthly average power by the 3 kW Microgas Gen, while Figure 18(b) represents the generator power output. Figure 18(c) shows the fuel consumption profile of the generator.

The cost of Gas per litre in Nigeria is about ₦1,250, which is about $0.833 per litre as established earlier on. The amount of fuel consumed is 1,835 m^3/y, which can be translated to 0.210 m^3/h. The NPC, LCOE, OC and Initial Cost values obtained are $190,294, $ 2.34, $14,705, and $200.1, respectively. The amount of CO_2, CO, unburned hydrocarbon, particulate matter, sulfur dioxide and nitrogen oxides generated by the Microgas Gen is 3,543, 11.8, 0, 0.332, 0, and 24.7 kg/y, respectively.

Use of supply from distribution grid

The cost per kilowatthour of energy (LCOE) in Ota, Ogun State for commercial users as provided by the Ibadan Electricity Distribution Company (IBEDC) is ₦ 74.43/kWh ($0.05). Supposed that the grid supply is reliable, the cost of energy purchased from the grid in a year by the clinic in Ogun State (commercial user) for energy demand of 6,303 kWh/y is $ 312.75. The cost per unit of energy supply (LCOE) by Port-harcourt Electricity Distribution Company (PEDC) is taken as ₦ 48.39/kWh ($0.032) for commercial users. The total electricity purchased from the grid by the clinic in Bayelsa will be $ 201.70 per year. Figure 19 shows the monthly average electric profile for the grid supply. On the environmental side for the grid supply option, Nigeria's emissions factor for power grid is 0.402 kg-CO_2/kWh (32). The CO_2 emissions to satisfy the energy demand requirements of 6,303 kWh/y by the clinic in Ogun or Bayelsa States is 2,534 kg/y.

There is the possibility to explore other resources such as biogas, biodiesel, etc. for generating energy for the clinics; however, the authors are limited by the biomass feedstock data for the locations that is not available at the time of writing this paper, without which the simulation and analysis cannot be carried. The study has considered the comparison of the solar PV energy with diesel, natural gas and the grid, which are available for the locations to deepen the analysis presented.

Solar energy versus diesel, natural and grid energy resources

The values of NPC, LCOE, and OC for the 20-kW PV power are lower those values obtained for the 3 kW Diesel Generator, while the initial cost of the 20-kW PV is higher than the 3 kW Diesel Generator. The capacity factor of the Diesel Generator is higher than the value reported for the 20-kW PV array with lower excess energy and no unmet energy. The Diesel Generator is a source of CO_2, CO, unburned hydrogen, particulate matter, sulfur dioxide and nitrogen oxides emissions, which can be taken as the amount of emissions avoided by the 20-kW PV. Similarly, the values of NPC, LCOE, and OC for the PV are relatively high than those values obtained from the 3 kW Microgas Generator while the initial cost of the generator is lower than the value for the PV array. The Microgas Generator also has a relatively high-capacity factor with lower excess energy and no unmet energy. It is obvious that the emissions from the Microgas Generator are much lower than those values obtained for the Diesel Generator of the same rated capacity. The quantity of emissions from the Microgas Generator that runs on natural gas can also be taken as the amount of emissions avoided when the 20-kW PV array is used instead of the Microgas Generator. The values of LCOE for the grid supply for the two locations is very much lower than the values obtained for the 20-kW PV, 3 kW Diesel and 3-kW Microgas Generators. The carbon emissions associated with the grid supply are also lower than the emissions generated by the Diesel and Microgas Generators.

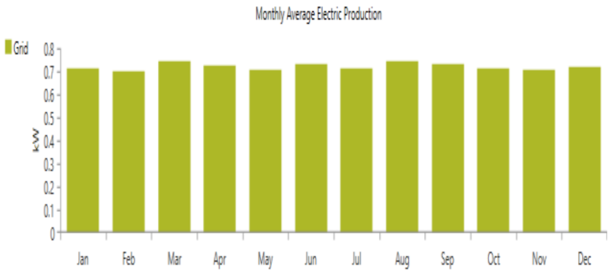

Figure 19. Monthly average electric supply from grid to the Clinics

The approach and analyses presented in this research work are comparable with some existing studies in the literature. For example, the standalone PV system for an emergency health clinic has been reported by Hassan et al. (33) based on HOMER simulation model. They presented an average load demand of 15.16 kWh/day compared to 17.27 kWh/day discussed in this current paper. With a PV array size of 3.3 kW designed for a location in Egypt, the initial capital cost is \$38, 700, while the NPC, LCOE and OC are \$48, 749, \$0.823 and 4941. The effect of different solar irradiation values has been presented on the variation of technical and economic feasibility of solar PV power generating system based on HOMER model (34). The authors also reported that the solar PV power and size increases as the solar irradiation of the location is being increased which also affects technical and economic aspects compared to when the solar irradiation is reduced. The design and analysis of an off-grid solar PV system is discussed for a rural setting in Guwahati city and Nigeria based on HOMER (35, 36). The authors simulated power system for a load demand of 6.698 kWh/day. The study also considered the possibility of using a generator as an alternative and/or a back-up for meeting energy needs of the users.

CONCLUSION

This study presents the analysis of the effect of varying average solar irradiance and the ambient temperature on the performance of monocrystalline photovoltaic (PV) modules subjected to the load profile of Bells University clinic. The load of the Bells University clinic was assessed through a site visit, the wattage rating of all the electrical appliances was taken and the duration of usage per day was noted and recorded in Microsoft Excel sheets for data preparation. The prevailing average solar irradiance and the ambient temperature of the study locations were obtained from the National Aeronautics and Space Administration website linked to HOMER software. Five different scenarios were investigated to analyze the environmental impact on the performance of monocrystalline photovoltaic modules; these were then compared with other energy resources such as diesel, natural gas and grid. Findings and conclusions of this study were summarized as follows:

- Optimal performance of the monocrystalline photovoltaic module occurred at a relatively high average daily radiation data for the months
- At a temperature lower than the standard test condition (STC) value of 25°C, the monocrystalline PV module demonstrated optimal performance in terms of electrical energy production and economic perspective.

- For optimal performance of PV modules, higher solar radiation and lower ambient temperature are desired, especially for the crystalline solar PV technology because of the real-life application that the solar PV array will be subjected to.
- Appreciable amounts of carbon footprints are avoided by running a solar PV power generating system
- The initial cost of solar PV power generating is relatively high than a conventional power generating system
- The levelized cost of energy of the PV power supply is higher than the cost of energy from grid, diesel and microgas generator.

Conclusively, the methodology and results of the study can be used for deeper understanding of the small-scale energy generation from solar, diesel, natural and grid resources. The results of this study can as be platform aiding strategic planning and development of working policies on alternative energy generation systems for commercial applications.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Persian Abstract

چکیده

تاثیر تابش خورشیدی و دمای محیط بر بازده انرژی PV خورشیدی و پیامد اقتصادی مربوطه آن مورد بررسی قرار گرفت. ارزیابی بار الکتریکی با بازرسی فیزیکی از طریق بازدیدهای دوره ای از محل مطالعه انجام شد. پنج سناریو مختلف برای دو مکان مورد بررسی قرار گرفت - ایالت اوگان و بایلسا: مورد اول عملکرد PV را بر اساس داده‌های تابش خورشیدی و دما تاریخی مکان‌ها در نظر می‌گیرد، مورد دوم ۳۰ درصد افزایش در داده‌های تابش خورشیدی را در نظر می‌گیرد در حالی که داده‌های دمای محیط ثابت می‌ماند. مورد سوم روی زمانی تمرکز دارد که داده‌های تابش خورشیدی ۳۰ درصد کاهش می‌یابد در حالی که داده‌های دمای محیط ثابت می‌مانند، مورد چهارم داده‌های تابش خورشیدی را ثابت می‌ماند در حالی که مقادیر دما ۳۰ درصد افزایش می‌یابد و مورد پنجم همان مقادیر تابش خورشیدی را بررسی می‌کند. با کاهش ۳۰ درصدی مقادیر داده های دما. HOMER pro به عنوان ابزار اجرا مورد استفاده قرار گرفت، بازده انرژی الکتریکی، بار الکتریکی برآورده نشده، هزینه فعلی خالص، هزینه تراز شده و هزینه عملیاتی برای موارد اول تا پنجم در Ota، ایالت اوگان به ترتیب به شرح زیر بود: ۲۸۶۵۹ کیلووات ساعت در سال، ۴/۷۱ کیلووات ساعت در سال، ۱۳۵۳۷ دلار، ۰/۱۶۶ دلار، ۲۷۱/۴۳ کیلووات ساعت در سال؛ ۳۷,۲۶۰ کیلووات ساعت در سال، ۱/۶۳ کیلووات ساعت در سال، ۱۲،۴۱۷ دلار، ۰/۱۵۲ دلار، ۲۹۰/۴۳ کیلووات ساعت در سال؛ ۲۰,۰۵۸ کیلووات ساعت در سال، ۳/۲۲ کیلووات ساعت در سال، ۱۵،۶۶۳ دلار، ۰/۱۹۲ دلار، ۲۹۳/۱۴ کیلووات ساعت در سال؛ ۲۸,۶۵۹ کیلووات ساعت در سال، ۴/۷۱ کیلووات ساعت در سال، ۱۳،۵۳۷ دلار، ۰/۱۶۶ دلار، ۲۷۱/۴۳ کیلووات ساعت در سال؛ و به ترتیب ۲۸۶۵۹ کیلووات ساعت، ۴/۶۱ کیلووات ساعت در سال، ۱۳،۴۳۷ دلار، ۰/۱۵۶ دلار، ۲۶۱.۴۳ کیلووات ساعت در سال، در حالی که روند مشابهی برای Otuasega در ایالت بایلسا مشاهده شد. نتایج تجزیه و تحلیل نشان داد که عملکرد بهینه ماژول PV در تابش خورشیدی بالاتر و دمای محیط پایین‌تر رخ می‌دهد.