NIPES

Journal of Science and Technology Research

Journal homepage: www.nipesjournals.org.ng

# Investigating the Performance of Solar System Using Simulation in Nigeria

***Omorogiuwa, O. S.[1] Akwenuke E. B,[1] Aliu J. A,[1] Oshoba O. E[1] and Tobi E. S.[1]***

Department of Electrical and Electronics Engineering University of Benin, Benin City[1], Nigeria.
Email: sam@uniben.edu

**Article Info**

***Keywords:*** *Solar panel, PVsyst, MATLAB, Simscape.*

*Received 9 October 2024*
*Revised 16 November 2024*
*Accepted 17 November 2024*
*Available online 8 December 2024*

https://doi.org/10.5281/zenodo.14317417

ISSN-2682-5821/

**Abstract**

*The study titled "Investigating the performance of solar system using simulation in Nigeria" envisions an innovative urban development model that integrates renewable energy solutions and smart infrastructure to create a thriving and eco-friendly urban environment. In response to the pressing global challenges of climate change and urbanization, this study explores the feasibility and benefits of a small-scale solar-powered system. This visionary undertaking seeks to address multiple facets of urban sustainability, starting with energy generation. The system will be primarily powered by solar energy, leveraging advanced photovoltaic technologies and energy storage systems to reduce reliance on non-renewable energy sources. The study encompasses three key components: site selection, energy demand analysis, and technology selection, based on data analysis. The methodology employed involves site analysis using energy irradiance data, energy needs calculation through PVsyst (Photovoltaic Software), data assessment, and analysis of PVsyst data to determine the most suitable system. Additionally, a circuit model is developed and simulated using MATLAB SIMULINK software, guided by the insights gained from PVsyst data. The results using analysis using energy irradiance data, energy needs calculation through PVsyst (Photovoltaic Software) noted that Jos has a global irradiation energy level of 2151.5kwh/m$^2$ while Kaduna and Maiduguri have a solar irradiation of 2131.6kwh/m$^2$ and 2113.5kwh/m$^2$ and results simulated using MATLAB SIMULINK software, guided by the insights gained from PVsyst data show a power factor to be 1.*

## 1.0. Introduction

The study presents an innovative urban development approach. It integrates renewable energy sources and advanced infrastructure to create a sustainable and prosperous urban environment. This initiative is a response to urgent global challenges such as climate change and rapid urban growth. It explores the practicality and benefits of a compact urban community powered by solar energy [1]. The primary focus of this study is on ensuring sustainability in urban areas, especially in how energy is generated. The main idea is to rely heavily on solar power by using cutting-edge photovoltaic technologies and advanced energy storage systems. This approach is aimed at reducing our dependence on traditional, non-renewable energy sources.

As the urgency to combat the effects of climate change and maintain clean air becomes increasingly vital, it is imperative to take immediate action to curb carbon emissions and prevent further deterioration [2]. For a country like Nigeria, solar power is what she must turn to, as it is the key to a clean, reliable and sustainable energy future. Science has shown that if the world population continuously uses oil and gas, they will run out in the next 50 years [3]. Besides, coal, oil and gas are polluting the planet earth and destroying its ozone layer, hence worsening the climate change crisis [4].

At the heart of "Solar System" lies the goal of building a city that is more environmentally friendly and better equipped to handle future challenges [5]. In this introductory context, embarking on a journey to understand the various steps involved, including site selection, estimating energy needs, and choosing the right technology to create a modern and sustainable urban community powered by solar energy.

In the 21st century, nations are faced with a complex triad of challenges - social and economic development, environmental sustainability, and energy management. Among these, energy management and independence are vital for any nation to achieve socioeconomic development. However, the primary means of achieving energy independence is through the burning of fossil fuels, which has led to the emergence of new problems that require continuous improvement.

According to [6], energy production and consumption are the primary human-caused sources of air pollution, resulting in the premature deaths of 6.5 million people annually. But that's not all; the ongoing climate crisis adds urgency to the need for action. To mitigate the damage and prevent further harm, it is imperative to reduce carbon emissions as soon as possible. And this is where renewable energy comes in as a solution.

The concept of a solar city is a relatively novel idea, but it has gained traction as the need for sustainable and renewable energy sources becomes increasingly urgent. A solar city is a community that is entirely powered by solar energy and is designed to be self-sufficient and sustainable [5]. This study aims to investigate the performance of a solar system using simulations in Nigeria, with a prototype designed for implementation in suburban or rural areas.

The objective of a solar city is to establish a community that is entirely reliant on solar energy. This is achieved by utilizing solar panels to generate electricity, which is then used to power homes, businesses, and public buildings. In addition to electricity generation, solar cities also employ solar thermal technology to heat water and provide space heating.

The advantages of a solar city are manifold. Firstly, it is a sustainable and renewable energy source, which does not deplete natural resources or contribute to climate change. Additionally, a solar city can be self-sufficient, eliminating the need for external sources of energy. This can be particularly beneficial in remote or rural areas, where access to electricity and other services may be limited [7]. As cities are responsible for a large share of the global energy consumption and they will continue growing, the urban fabric must be integrated with solar power and other renewable energy sources to meet the ever-growing energy demand in a sustainable manner [8].

The implementation of a small solar city presents a viable solution to the pressing issue of sustainable energy in the community. This solution involves designing, planning and executing a sustainable energy system that harnesses the power of the sun. The solar city will comprise of a network of solar panels that are strategically placed to optimize the capture of solar energy. Additionally, energy storage systems will be incorporated to store the energy generated during the day, allowing for its usage during the night or periods of low sunlight. Furthermore, a smart grid will be implemented to manage the flow of energy and ensure its efficient distribution throughout the community. This solution aims to provide a reliable and sustainable source of energy that helps to reduce the community's dependence on fossil fuels and decrease its carbon footprint. Furthermore, by providing a sustainable and affordable source of energy, the solar city study can enhance the quality of life for residents in the community and promote the development of a green economy.

### 1.1. Literature Review

The importance of beginning a solar power development study with a clear concept is emphasized in the book "Project Development in the Solar Industry" by [9]. The authors examine the typical difficulties encountered during the development process and provide advice on how to resolve them. They advise starting with site selection, where variables like topography, solar irradiance, land size, location, project size, interconnection distance, proximity to substation, and project size must be considered.

Before beginning the design of the solar farm, the authors stress the value of assessing the essential supporting infrastructure, such as the power transmission and distribution lines. The selection of the photovoltaic inverter, photovoltaic module, project requirements, and module mounting structure should all be considered during the design phase [10].

When designing an effective utility scale photovoltaic (PV) project, the authors stress the importance of understanding the project requirements, limitations, and interconnection characteristics. The nominal power of the photovoltaic module determines a PV plant's direct current (DC) capacity, while the inverter's nominal alternating current (AC) power determines the plant's AC capacity. The authors advise the design team to maximize the system's tilt and orientation while keeping cost-effectiveness in mind to maximize energy output [11].

The inverter, which transforms DC power into usable AC power in a photovoltaic system, is another important component highlighted in the book. The conversion efficiency should be taken into account by the design team, as it depends on the inverter's design, input voltage, and operating temperature. Modern inverters can perform tasks like data acquisition, telemetry, and control thanks to their sophisticated electronics [11].

The crucial steps needed in a solar power study have been examined by [12], the author of the article "Solar Power in Building Design." The site evaluation, feasibility study, site shading analysis, photovoltaic mapping or configuration analysis, DC-AC power conversion calculations, PV module and inverter system selection, and total solar power array electric power calculations are among the key steps he evaluated in the engineering design of solar power systems.

The importance of having a fundamental understanding of insolation concepts, shading analysis, and various design parameters that impact the overall output performance and efficiency of the solar power system is emphasized by [12]. The amount of energy that the earth's surface receives from the sun is known as insolation. It is also referred to as isolation or irradiation. The author claims that the sun's energy output, which is 1366 $w/m_2$, is reduced to 1000 W/m2 on the surface of the earth due to scattering.

The author of [12] advises that the PV array be tilted to the ideal tilt angle and exposed directly to the sun's rays for maximum energy output. The author emphasizes the significance of checking for obstacles like high-voltage alternating current (HVAC) units, trees, and buildings that may cast shadows, as well as evaluating the structural integrity of the roof, during the site evaluation and shading analysis stages of the design process. The designer of a grounded mounted system must consider floods, earthquake fault lines, and soil erosion.

The designer must select the best PV product and build the topology configuration of the array for maximum energy harvest after evaluating the site and analyzing shading. The various losses that may occur as a result of design features and environmental factors must be taken into account when calculating the net energy output production in the solar power system [12].

The steps necessary for designing a fruitful solar project are stressed by [8]." He categorizes these steps into seven categories, which are: defining the project's scope; determining the project's energy requirements; determining the amount of solar energy that is available; surveying the site; sizing the solar electric system; choosing the appropriate components; and determining the project's total costs.

The author of [8] emphasizes the significance of project scoping by identifying the rationale for the solar design and extending the scope to precisely define the objectives of the design. In order to properly size the photovoltaic (PV) array, he also stresses the significance of conducting a power analysis to determine the project's energy consumption.

It's crucial to gather the site's solar irradiation data because the amount of solar energy that can be harvested from the location depends on the number of hours of midday solar irradiation that are available. In order to avoid inefficiencies, the author suggests using Maximum Power Point Tracking (MPPT) to adjust the voltage from the solar array. Shade is mentioned as having the biggest detrimental effect on solar energy production. By surveying the site to find potential sources of shading, the output voltage fluctuation of the arrays caused by shade can be decreased [13]. The authors of [13] stress the significance of beginning a solar power project with a distinct concept and provide advice on how to overcome typical difficulties encountered throughout the development process. They advise starting with site selection, where variables like topography, solar irradiance, land size, location, project size, interconnection distance, proximity to substation, and project size must be taken into account. Before beginning the design of the solar farm, the authors of [7] stress the significance of assessing the essential supporting infrastructure, such as power transmission and distribution lines.

[13] Advice taking into account a number of variables when designing a solar project, including solar resources, photovoltaic module choice, project requirements, photovoltaic inverter choice, and module mounting structure choice. The inverter's role in converting DC power into usable AC power is also highlighted. The design team is advised to take this into account, as conversion efficiency depends on a number of variables, including the inverter's design, input voltage, and operating temperature.

The author of [12] emphasizes the crucial phases of designing solar power systems, such as site evaluation, feasibility study, site shading analysis, photovoltaic mapping or configuration analysis, calculations of DC-AC power conversion, and total electric power generated by solar power arrays. The author stresses how crucial it is to have a fundamental understanding of insolation concepts, shading analysis, and various design parameters that impact the overall output performance and efficiency of the solar power system.

The steps involved in designing a successful solar project are broken down into seven categories by the author of [8]: scoping the project, determining the project's energy needs, determining the amount of solar energy available, surveying the site, sizing the solar electric system, choosing the right components, and determining the project's total costs. Also stresses the significance of defining the project's scope, figuring out the rationale for the solar design, and gathering information on the site's solar irradiation. The author claims that shade has the biggest detrimental effect on the production of solar energy, and suggests using Maximum Power Point Tracking (MPPT) to regulate the voltage from the solar array in order to avoid inefficiencies.

## 2.0. Methodology

In this study, an effective plan for designing a sustainable solar-powered city using modern technology was introduced. The aim is to showcase the potential of sustainable solar-powered cities and their significance in our future. PVsyst simulation software and MATLAB Simulink software were used for all simulations involved in this study.

### 2.1 Proposed design for solar power city

The study design was based on the model, while also ensuring that the analysis and design of the solar city are thoroughly accomplished. The energy requirement of the solar city should first be determined to determine the size of the solar farm to be designed for the system.

### 2.2 Energy consumption of a modern home

The energy consumption for a typical modern home is as shown in Figure 1 which is an average of home checked. From Figure 1, it shows that the energy requirement for a home is about 15kwh/day, so the need to design a solar plant that can meet this daily energy requirement.

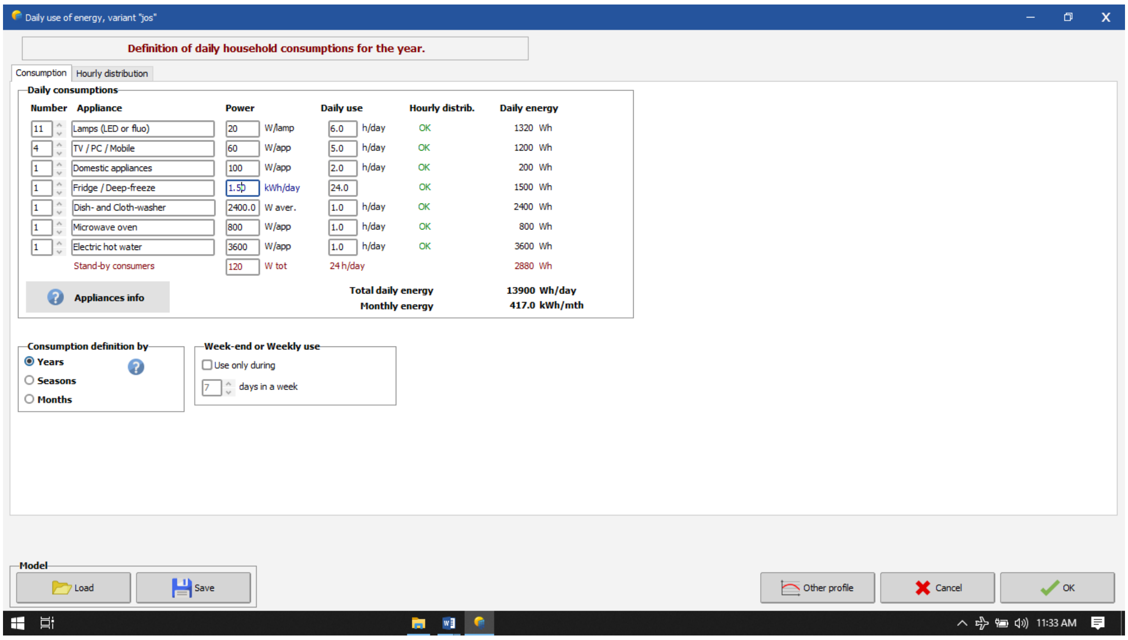


Figure 1: Energy consumption of a typical modern home

For economic efficiency of the solar farm, the solar city should be located in a region of high solar irradiation energy; this reduces the number of panels needed to operate the farm.

### 2.3 Site Location

The location of a solar city is a critical factor in determining its success. The ideal location for a solar city is chosen based on solar irradiance data and charts. Figure 2 is an example of a solar irradiance chart of Nigeria.

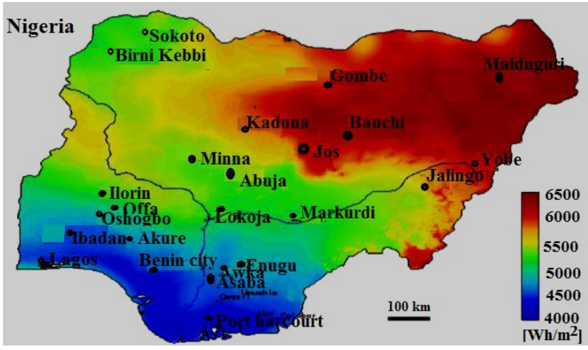


Figure 2: Solar irradiation data for Nigeria

According to the solar irradiance chart, the optimal location for a sustainable solar city in Nigeria is in the northern region, where the solar irradiation energy is abundant. The chart identifies several potential cities, including Kaduna, Jos, Bauchi, Gombe, Maiduguri, Yobe, and Jalingo. This study runs simulations using the solar irradiation data of each site to determine the best site location for the solar city.

## 2.4 Smart Solar plant (grid) technology

The solar plant includes the solar panel, inverter system, MPPT system, battery bank system and other accessories required for efficiency and sustainability of a solar city. The solar city was modelled in PVsyst simulation software. The model shows the design of a 15kW solar plant, examining the behavior of the plant with different parameters and operating conditions. Figure 3 shows the simplified schematics of the simulation model.

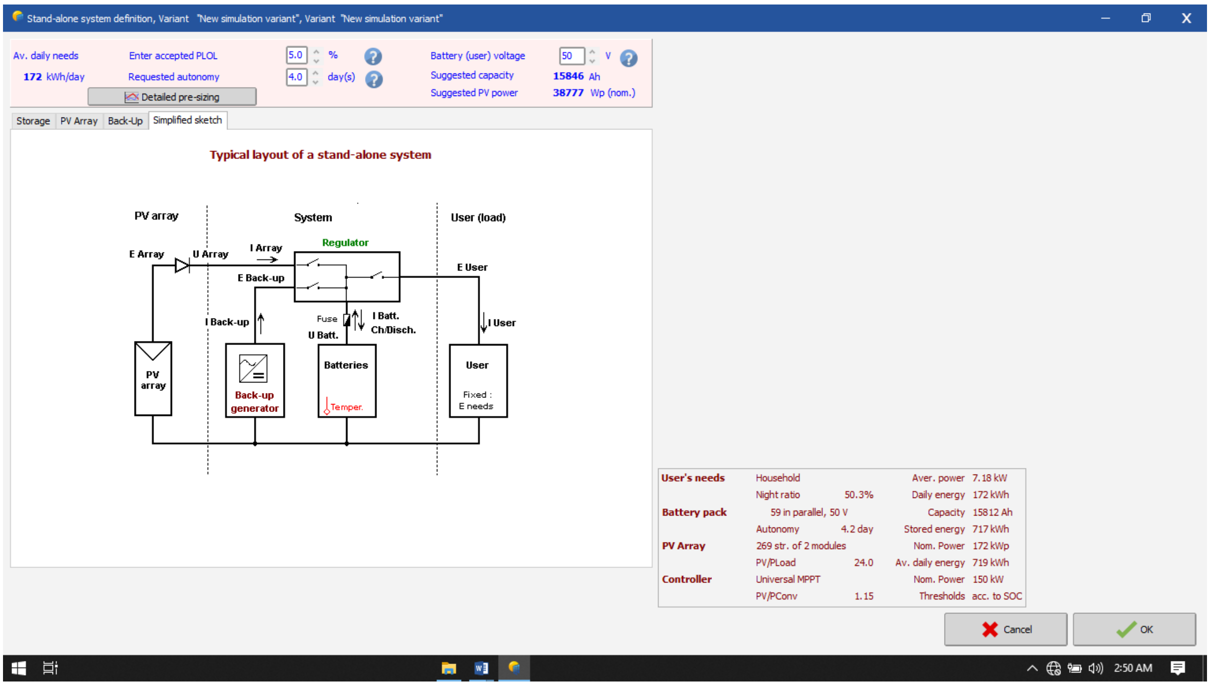


Figure 3: PVsyst Simulation model

## 2.5 PV technology

The types of PV technology used determine the efficiency of the system. The two most common photovoltaic technologies are Monocrystalline silicon (mono-si) and Polycrystalline silicon (poly-si). Solar plants usually involve arrays of solar panel to harvest a large amount of energy from the sun. However, each PV module is inefficient i.e. there are some losses associated with them. These losses can be in form of ohmic wire loss, module mismatch loss, module quality loss etc. The simulation presented compares 2 different PV technology manufactured by Felicity. The simulation using 320Wp 31V si-mono PV modules while the simulation using 320Wp 31V si poly PV module. Data obtained from this simulation is presented in Table 4 and Table 5.

## 2.6 Controller Technology

Controller technology plays an important role in solar power plants as it helps optimize the performance, efficiency and reliability of the solar plant. A few common controller technologies are MPPT (maximum power point Tracking) and PWM dc-dc converter. The simulation of the solar system using both technologies, result is shown in Table 6 and Table 7.

## 2.7 Storage Technology

The most common technology for storage used in solar plants is batteries. They are used to store excess energy during the day for use at night. Batteries come in two forms of technology, lead acid and lithium ion was investigated to choose a suitable one is efficient for this study; data obtained from the simulation is presented in Table 8 and Table 9.

## 2.8 Simscape Model

From the simulations carried out using PVsyst and the analysis of result in section 3.2 of the study, a simscape model of the solar system has been built in MATLAB Simulink. The solar technologies used in the model are monocrystalline silicon PV, lithium-ion batteries, MPPT charge controller and boost converter. The solar panel used in the model is rated 450W. The solar panels are arranged so as to supply a voltage of 82.50V and 45kW power. The numbers of PV strings are calculated as shown in equation (1).

$$number\ of\ strings = \frac{supply\ voltage}{open\ circuit\ voltage} \quad (1)$$

$$number\ of\ strings = \frac{82.50}{41.25} = 2$$

The number of PV panels in parallel is calculated as shown in equation (2)

$$PV\ panel\ in\ parallel = \frac{Required\ power}{power\ rating * number\ of\ strings} \quad (2)$$

$$= \frac{45000}{450 * 2} = 50$$

The batteries used in the model are rated 48V 200Ah, these batteries should be able to supply 45kW for 4 days when fully charged. The number of batteries in parallel needed to achieve this is calculated as shown in equation (3).

$$Number\ of\ batteries\ in\ parallel = \frac{Required\ power}{power\ of\ a\ single\ battery} \quad (3)$$

$$= \frac{45000*4*24}{48*200} = 450$$

The MPPT charge controllers use in the model are rated 120A 48V 6800W. The number of MPPT controller to be connected in parallel for this system to function correctly is calculated as shown in equation (4).

$$Number\ of\ MPPT\ in\ parallel = \frac{Required\ power}{Power\ of\ MPPT} \tag{4}$$

$$= \frac{45000}{6800} = 7$$

i.e for every 50 PV array in parallel there is an MPPT controller.
The boost converts steps up the voltage form the battery 48Vdc to 220Vdc, this voltage is then fed into a 3-phase full bridge inverter to obtain an alternating voltage. The duty cycle of the boost converts control voltage transformation in the converter circuit. The relationship between input voltage, output voltage and duty cycle of a boost converter is shown in equation (5).

$$Output\ voltage = \frac{Input\ voltage}{1 - duty\ cycle} \tag{5}$$

Hence, making duty cycle subject of the equation gives,

$$Duty\ cycle = 1 - \frac{Input\ voltage}{Output\ voltage}$$

$$= 1 - \frac{48}{220} = 0.78$$

The simulation model is shown in Figure 4. The calculation in equation (5) result the parameters are input to the various subsystems in the model.

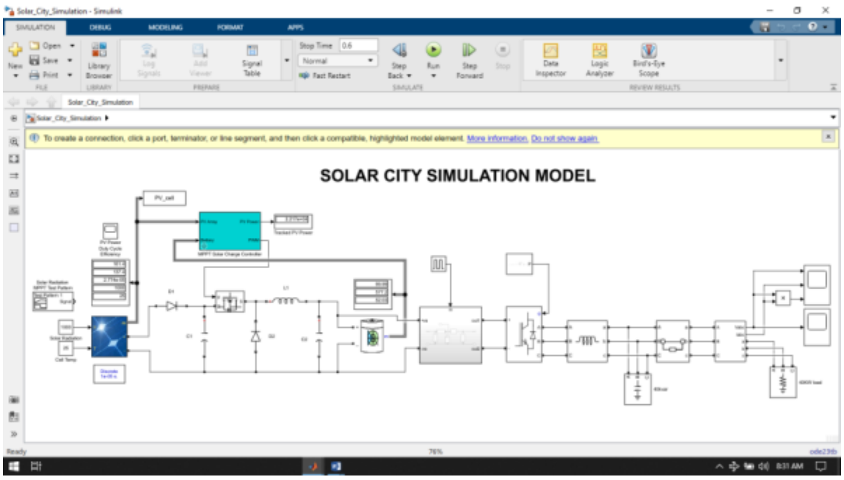


Figure 4: Simscape Model of a solar City

The model in Figure 4 is used for the simulation of the efficiency, power factor and response of the system to various loads, data obtained from these simulations for the efficiency and power factor, analysis of the result is also discussed.

## 3. Results and Discussion

### 3.1 Results of PVsyst simulation comparing some technology

Result show in Table 1, Table 2 and Table 3 are the data obtained from the simulation of solar energy available in Kaduna, Jos and Maduguri, Nigeria.

**Kaduna**
**Balances and main results**

| | GlobHor kWh/m² | GlobEff kWh/m² | E_Avail kWh | EUnused kWh | E_Miss kWh | E_User kWh | E_Load kWh | SolFrac ratio |
|---|---|---|---|---|---|---|---|---|
| January | 168.0 | 188.5 | 28007 | 22049 | 0.000 | 5344 | 5344 | 1.000 |
| February | 159.7 | 168.4 | 24655 | 19526 | 0.000 | 4827 | 4827 | 1.000 |
| March | 195.6 | 195.9 | 28391 | 22692 | 0.000 | 5344 | 5344 | 1.000 |
| April | 201.5 | 190.2 | 27717 | 22214 | 0.000 | 5172 | 5172 | 1.000 |
| May | 193.0 | 172.0 | 25448 | 19768 | 0.000 | 5344 | 5344 | 1.000 |
| June | 176.1 | 152.8 | 22960 | 17474 | 0.000 | 5172 | 5172 | 1.000 |
| July | 177.9 | 155.5 | 23500 | 17826 | 0.000 | 5344 | 5344 | 1.000 |
| August | 161.2 | 148.0 | 22309 | 16650 | 0.000 | 5344 | 5344 | 1.000 |
| September | 174.0 | 168.4 | 25258 | 19767 | 0.000 | 5172 | 5172 | 1.000 |
| October | 185.2 | 193.5 | 28645 | 22951 | 0.000 | 5344 | 5344 | 1.000 |
| November | 183.1 | 206.3 | 30303 | 24783 | 0.000 | 5172 | 5172 | 1.000 |
| December | 167.4 | 192.0 | 28532 | 22830 | 0.000 | 5344 | 5344 | 1.000 |
| Year | 2142.8 | 2131.6 | 315723 | 248531 | 0.000 | 62926 | 62926 | 1.000 |

Table 1: Solar irradiation Energy in Kaduna, Nigeria

**jos**
**Balances and main results**

| | GlobHor kWh/m² | GlobEff kWh/m² | E_Avail kWh | EUnused kWh | E_Miss kWh | E_User kWh | E_Load kWh | SolFrac ratio |
|---|---|---|---|---|---|---|---|---|
| January | 176.2 | 199.1 | 30096 | 24145 | 0.000 | 5344 | 5344 | 1.000 |
| February | 168.6 | 179.8 | 26835 | 21674 | 0.000 | 4827 | 4827 | 1.000 |
| March | 202.3 | 203.1 | 30042 | 24355 | 0.000 | 5344 | 5344 | 1.000 |
| April | 195.1 | 183.2 | 27275 | 21763 | 0.000 | 5172 | 5172 | 1.000 |
| May | 185.5 | 163.6 | 24685 | 19001 | 0.000 | 5344 | 5344 | 1.000 |
| June | 173.9 | 149.6 | 22880 | 17392 | 0.000 | 5172 | 5172 | 1.000 |
| July | 178.2 | 154.7 | 23711 | 18038 | 0.000 | 5344 | 5344 | 1.000 |
| August | 157.4 | 143.3 | 22036 | 16361 | 0.000 | 5344 | 5344 | 1.000 |
| September | 170.3 | 166.0 | 25116 | 19616 | 0.000 | 5172 | 5172 | 1.000 |
| October | 186.9 | 195.0 | 28983 | 23276 | 0.000 | 5344 | 5344 | 1.000 |
| November | 190.1 | 213.1 | 31637 | 26104 | 0.000 | 5172 | 5172 | 1.000 |
| December | 174.7 | 201.0 | 30334 | 24638 | 0.000 | 5344 | 5344 | 1.000 |
| Year | 2159.2 | 2151.5 | 323631 | 256364 | 0.000 | 62926 | 62926 | 1.000 |

Table 2: Solar irradiation energy in Jos, Nigeria

**maiduguri**
**Balances and main results**

| | GlobHor kWh/m² | GlobEff kWh/m² | E_Avail kWh | EUnused kWh | E_Miss kWh | E_User kWh | E_Load kWh | SolFrac ratio |
|---|---|---|---|---|---|---|---|---|
| January | 160.5 | 180.4 | 27165 | 21214 | 0.000 | 5344 | 5344 | 1.000 |
| February | 157.6 | 167.3 | 24758 | 19616 | 0.000 | 4827 | 4827 | 1.000 |
| March | 196.0 | 197.6 | 28667 | 22986 | 0.000 | 5344 | 5344 | 1.000 |
| April | 197.1 | 187.3 | 27062 | 21559 | 0.000 | 5172 | 5172 | 1.000 |
| May | 194.9 | 175.0 | 25535 | 19862 | 0.000 | 5344 | 5344 | 1.000 |
| June | 181.0 | 158.9 | 23585 | 18097 | 0.000 | 5172 | 5172 | 1.000 |
| July | 182.0 | 161.2 | 24126 | 18448 | 0.000 | 5344 | 5344 | 1.000 |
| August | 163.9 | 151.2 | 22766 | 17100 | 0.000 | 5344 | 5344 | 1.000 |
| September | 173.4 | 170.1 | 25200 | 19711 | 0.000 | 5172 | 5172 | 1.000 |
| October | 181.8 | 191.2 | 27969 | 22276 | 0.000 | 5344 | 5344 | 1.000 |
| November | 172.5 | 194.2 | 28538 | 23016 | 0.000 | 5172 | 5172 | 1.000 |
| December | 156.6 | 179.2 | 26888 | 21177 | 0.000 | 5344 | 5344 | 1.000 |
| Year | 2117.3 | 2113.5 | 312258 | 245064 | 0.000 | 62926 | 62926 | 1.000 |

Table 3: Solar irradiation energy in Maiduguri, Nigeria

Table 4 and Table 5 show the module losses and efficiency of mono-si and poly-si solar system technology. These data are results obtained from the simulation in section 2.5.

**Si-MONO PV MODULE**
**Losses in the PV system**

| | ModQual kWh | MisLoss kWh | OhmLoss kWh | EArrMPP kWh | EArUfix kWh | EUnused kWh | EArray kWh |
|---|---|---|---|---|---|---|---|
| January | -232.963 | 219.1 | 713.6 | 30362 | 30362 | 29575 | 781.4 |
| February | -207.827 | 195.4 | 650.4 | 27072 | 27072 | 26567 | 505.0 |
| March | -232.589 | 218.7 | 735.2 | 30291 | 30291 | 29748 | 542.3 |
| April | -211.208 | 198.6 | 634.9 | 27539 | 27540 | 26991 | 547.4 |
| May | -191.302 | 179.9 | 535.5 | 24983 | 24985 | 24398 | 585.3 |
| June | -177.363 | 166.8 | 475.2 | 23184 | 23185 | 22610 | 574.0 |
| July | -183.799 | 172.8 | 492.2 | 24025 | 24025 | 23433 | 592.5 |
| August | -170.853 | 160.7 | 449.8 | 22341 | 22342 | 21763 | 578.0 |
| September | -194.815 | 183.2 | 573.5 | 25413 | 25413 | 24854 | 551.2 |
| October | -224.989 | 211.6 | 717.5 | 29295 | 29295 | 28711 | 564.9 |
| November | -245.245 | 230.6 | 804.7 | 31909 | 31910 | 31349 | 517.5 |
| December | -234.584 | 220.6 | 725.8 | 30566 | 30566 | 30042 | 523.7 |
| Year | -2507.538 | 2357.9 | 7508.3 | 326980 | 326987 | 320041 | 6863.2 |

Table 4: Energy losses and Efficiency of si-mono PV module

**Si-POLY PV MODULE**
**Losses in the PV system**

| | ModQual kWh | MisLoss kWh | OhmLoss kWh | EArrMPP kWh | EArUfix kWh | EUnused kWh | EArray kWh |
|---|---|---|---|---|---|---|---|
| January | -279.207 | 262.5 | 855.8 | 36388 | 36388 | 35556 | 826.0 |
| February | -249.079 | 234.2 | 780.0 | 32445 | 32445 | 31930 | 515.3 |
| March | -278.756 | 262.1 | 881.7 | 36302 | 36303 | 35751 | 551.2 |
| April | -253.139 | 238.0 | 761.4 | 33006 | 33007 | 32446 | 559.7 |
| May | -229.290 | 215.6 | 642.2 | 29943 | 29946 | 29341 | 602.5 |
| June | -212.586 | 199.9 | 569.8 | 27788 | 27790 | 27197 | 591.1 |
| July | -220.300 | 207.2 | 590.3 | 28796 | 28796 | 28186 | 609.9 |
| August | -204.785 | 192.6 | 539.3 | 26778 | 26779 | 26186 | 591.2 |
| September | -233.491 | 219.6 | 687.8 | 30458 | 30458 | 29883 | 565.2 |
| October | -269.642 | 253.6 | 860.5 | 35108 | 35108 | 34507 | 580.3 |
| November | -293.912 | 276.4 | 965.1 | 38241 | 38242 | 37666 | 526.2 |
| December | -281.148 | 264.4 | 870.4 | 36633 | 36633 | 36103 | 529.7 |
| Year | -3005.336 | 2826.0 | 9004.5 | 391886 | 391895 | 384752 | 7048.3 |

Table 5: Energy losses and Efficiency of si-poly PV module

**MPPT CONTROLLER**
**Balances of Currents in the system**

| | IArray Ah | IBatCh Ah | IBatDis Ah | IBGass Ah | IBSelf Ah | EffBatI % | EffBatE % |
|---|---|---|---|---|---|---|---|
| January | 11867.7 | 13136.8 | 7437.5 | 0.0 | 628.4 | 51.8 | 52.1 |
| February | 7387.9 | 7590.3 | 6701.7 | 0.0 | 567.5 | 81.0 | 80.3 |
| March | 7961.0 | 8386.1 | 7439.8 | 0.0 | 628.4 | 81.0 | 80.7 |
| April | 7773.5 | 8125.8 | 7193.0 | 0.0 | 608.1 | 81.0 | 80.4 |
| May | 8646.2 | 8341.8 | 7378.9 | 0.0 | 628.4 | 80.9 | 80.3 |
| June | 8471.2 | 8059.3 | 7127.4 | 0.0 | 608.1 | 80.9 | 80.3 |
| July | 8733.1 | 8332.7 | 7370.1 | 0.0 | 628.4 | 80.9 | 80.3 |
| August | 8136.3 | 8383.0 | 7419.1 | 0.0 | 628.4 | 81.0 | 80.5 |
| September | 7940.8 | 8117.0 | 7176.8 | 0.0 | 608.1 | 81.0 | 80.1 |
| October | 8210.8 | 8396.1 | 7418.9 | 0.0 | 628.4 | 81.0 | 79.9 |
| November | 7205.3 | 8158.0 | 7234.7 | 0.0 | 608.1 | 81.1 | 80.1 |
| December | 7443.0 | 8428.4 | 7467.5 | 0.0 | 628.4 | 81.1 | 80.4 |
| Year | 99776.8 | 103455.4 | 87365.5 | 0.0 | 7398.3 | 77.3 | 76.8 |

Table 6: Efficiency of MPPT controller

**DC-DC PWM**
**Balances of Currents in the system**

| | IArray Ah | IBatCh Ah | IBatDis Ah | IBGass Ah | IBSelf Ah | EffBatI % | EffBatE % |
|---|---|---|---|---|---|---|---|
| January | 12705.2 | 13137.4 | 7435.5 | 0.0 | 628.4 | 51.8 | 52.1 |
| February | 7931.5 | 7587.4 | 6700.1 | 0.0 | 567.5 | 81.0 | 80.4 |
| March | 8481.3 | 8382.5 | 7438.0 | 0.0 | 628.4 | 81.0 | 80.7 |
| April | 8020.2 | 8148.3 | 7214.4 | 0.0 | 608.1 | 81.1 | 80.4 |
| May | 8297.1 | 8420.1 | 7454.1 | 0.0 | 628.4 | 81.1 | 80.4 |
| June | 8207.8 | 8135.1 | 7200.2 | 0.0 | 608.1 | 81.0 | 80.5 |
| July | 8553.1 | 8400.5 | 7435.2 | 0.0 | 628.4 | 81.0 | 80.5 |
| August | 8551.9 | 8399.4 | 7434.7 | 0.0 | 628.4 | 81.0 | 80.5 |
| September | 8049.6 | 8156.3 | 7214.5 | 0.0 | 608.1 | 81.1 | 80.2 |
| October | 8186.7 | 8437.8 | 7465.8 | 0.0 | 628.4 | 81.1 | 80.1 |
| November | 7792.1 | 8164.7 | 7234.3 | 0.0 | 608.1 | 81.1 | 80.1 |
| December | 8144.9 | 8427.0 | 7466.2 | 0.0 | 628.4 | 81.1 | 80.4 |
| Year | 102921.4 | 103796.5 | 87693.1 | 0.0 | 7398.3 | 77.4 | 76.8 |

Table 7: Efficiency of a DC-DC PWM controller

The results presented in Table 6 and Table 7 shows the performance of the solar city when MPPT or DC/DC PWM controller technology is used. These results are obtained from the simulation in section 2.6. The results presented in Table 8 and Table 9 shows the performance of the solar city when Lithium ion or lead acid battery is used as the energy storage technology in a solar system. These results are obtained from the simulation in section 2.7.

**LITHIUM ION**
**Battery operation and performances**

| | U_Batt V | SOCmean ratio | SOC_End ratio | MGass liter | EffBatI % | EffBatE % |
|---|---|---|---|---|---|---|
| January | 57.3 | 0.947 | 0.947 | 0.000 | 51.8 | 52.1 |
| February | 57.4 | 0.952 | 0.949 | 0.000 | 81.0 | 80.4 |
| March | 57.4 | 0.952 | 0.947 | 0.000 | 81.0 | 80.7 |
| April | 57.4 | 0.952 | 0.947 | 0.000 | 81.1 | 80.4 |
| May | 57.4 | 0.952 | 0.947 | 0.000 | 81.1 | 80.4 |
| June | 57.4 | 0.952 | 0.947 | 0.000 | 81.0 | 80.5 |
| July | 57.4 | 0.952 | 0.947 | 0.000 | 81.0 | 80.5 |
| August | 57.4 | 0.952 | 0.947 | 0.000 | 81.0 | 80.5 |
| September | 57.4 | 0.952 | 0.948 | 0.000 | 81.1 | 80.2 |
| October | 57.4 | 0.953 | 0.948 | 0.000 | 81.1 | 80.1 |
| November | 57.4 | 0.953 | 0.948 | 0.000 | 81.1 | 80.1 |
| December | 57.4 | 0.952 | 0.947 | 0.000 | 81.1 | 80.4 |
| Year | 57.4 | 0.952 | 0.947 | 0.000 | 77.4 | 76.8 |

Table 8: Efficiency of Lithuim ion battery

**LEAD ACID**
**Battery operation and performances**

| | U_Batt | SOCmean | SOC_End | MGass | EffBatI | EffBatE |
|---|---|---|---|---|---|---|
| | V | ratio | ratio | liter | % | % |
| **January** | 57.3 | 0.948 | 0.948 | 0.000 | 49.6 | 49.9 |
| **February** | 57.4 | 0.953 | 0.949 | 0.000 | 79.8 | 79.2 |
| **March** | 57.4 | 0.953 | 0.948 | 0.000 | 79.8 | 79.6 |
| **April** | 57.4 | 0.953 | 0.948 | 0.000 | 79.9 | 79.3 |
| **May** | 57.4 | 0.953 | 0.948 | 0.000 | 79.9 | 79.3 |
| **June** | 57.4 | 0.953 | 0.948 | 0.000 | 79.9 | 79.3 |
| **July** | 57.4 | 0.953 | 0.948 | 0.000 | 79.8 | 79.3 |
| **August** | 57.4 | 0.953 | 0.948 | 0.000 | 79.8 | 79.4 |
| **September** | 57.4 | 0.953 | 0.948 | 0.000 | 79.9 | 79.1 |
| **October** | 57.4 | 0.953 | 0.948 | 0.000 | 79.9 | 79.0 |
| **November** | 57.4 | 0.953 | 0.948 | 0.000 | 79.9 | 78.9 |
| **December** | 57.4 | 0.953 | 0.948 | 0.000 | 79.9 | 79.3 |
| **Year** | 57.4 | 0.952 | 0.948 | 0.000 | 75.9 | 75.5 |

Table 9: Efficiency of Lead acid battery

### 3.2 Discussion of the Analysis of PVsyst simulation result

From the results in Table 1, Table 2 and Table 3, it can be seen that Jos has higher solar irradiation energy among the three states compared. This is shown in the Global horizontal efficiency (GlobEff) column of the Table 2, where it was noted that Jos has a global irradiation energy level of 2151.5kwh/m$^2$ while Kaduna and Maiduguri have a solar irradiation of 2131.6kwh/m$^2$ and 2113.5kwh/m$^2$. Therefore, Jos is a suitable site location for a solar system.

Table 4 and Table 5 shows the efficiency and energy losses of the two most common PV technology. From Tables 4 - 5, it can be seen that si-mono PV technology has a better efficiency than si-poly PV technology due to the low losses (Ohm loss, MisLoss and ModQual loss). Si-mono is a preferred choice for any solar city, but the cost for poly is also cheaper than mono PV technology.

The essence of a controller is to ensure that most of the PV array current is available to the solar Plant. From Table 6 and Table 7, it can be seen that MPPT controller makes available most of the PV array current (Iarray) to the system (IBatCh) with very little energy loss in the MPPT module. However, the PWM module consumes internally a large amount of the array current compared to the MPPT charge controller. From this simulation result, it is preferable to use a MPPT charge controller for an efficient solar plant.

The type of battery technology used in a solar plant also affects its efficiency and sustainability. From the simulation results of Table 8 and Table 9, it can be seen that lithium-ion batteries have a better efficiency and a longer life than lead acid batteries, but the total cost of ownership per usable kWh is about 2.8 times cheaper for a lithium-based solution than for a lead acid solution. Note that despite the higher facial cost of Lithium technology, the cost per stored and supplied kWh remains much lower than for Lead-Acid technology. The reason is related to the intrinsic qualities of lithium-ion batteries but also linked to lower transportation costs.

The results from the PVsyst simulation are used in the design of a simscape model of the solar system.

Upon comparison and analysis of the results derived from these simulations, from the results it had been successfully identified the optimal site location, determined the energy requirements, and selected the most effective system. This comprehensive analysis forms the basis for developing an efficient and sustainable solar-powered system using modern technology, addressing the challenges of urbanization and climate change.

### 3.3 Results of Simscape simulation

Using the simulation results obtained from pvsyst, a simulation model was developed in MATLAB Simscape. Details of the process were presented in section 2.8 of the study. Figure 5, shows the efficiency of the design of solar plant of the solar system at various loads, while figure 6 shows the power factor to be 1.

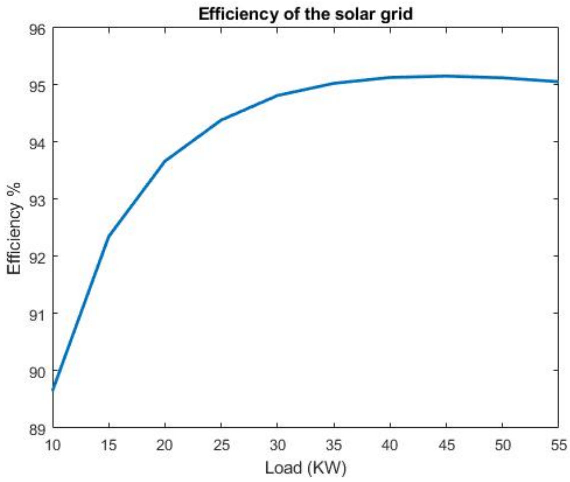


Figure 15: Efficiency of the design

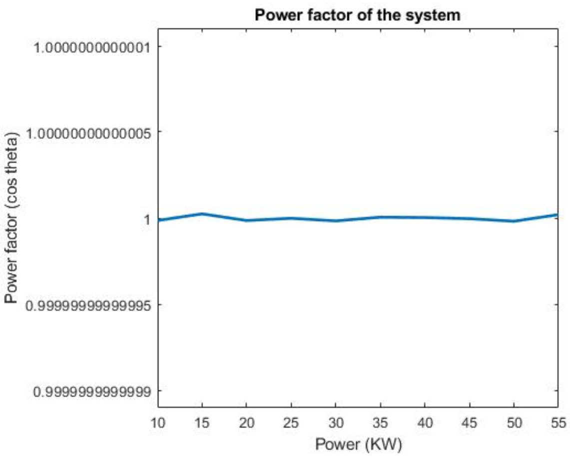


Figure 16: Power factor of model design

## 4. Conclusion

This study highlights the crucial steps and considerations necessary for designing and deploying an effective utility-scale solar power project. The main takeaway is the utmost importance of site selection, thorough planning, and understanding key parameters to maximize energy output and system efficiency. From the results shown in the table's sun radiation is better than others.

Selecting the right site for the project is emphasized, considering factors like topography, solar irradiance, land size, location, and proximity to substations. By optimizing the system's tilt and orientation, the design team can capture the most solar energy while maintaining cost-effectiveness. Understanding insolation concepts and shading analysis helps minimize the negative impact of shading on energy production. Using Maximum Power Point Tracking (MPPT) technology to adjust the voltage from the solar array further improves efficiency.

The inverter, responsible for converting DC power to usable AC power, is vital for conversion efficiency, which depends on its design, input voltage, and operating temperature. Modern inverters with advanced capabilities, such as data acquisition and control, contribute to system optimization.

Lastly, gathering site-specific solar irradiation data is crucial for efficient solar energy harvesting. Employing MPPT and mitigating shading effects contribute to avoiding inefficiencies.

To ensure success in the small solar system project, thorough planning and site evaluation are essential, collecting solar irradiation data to assess available solar energy for achieving sustainable and eco-friendly energy solutions.

For economic efficiency, the solar city should be located in a region with high solar irradiation energy. The PV array should be tilted in the most optimal way in order to maximize energy output and consider using MPPT charge controllers and si-mono PV technology for better system efficiency and reduced losses. These measures ensure a productive and financially viable solar farm. It is recommended that this study should be compared with real life scenario.

## Reference

[1] Mutezo, G., & Mulopo, J. (2021). A review of Africa's transition from fossil fuels to renewable energy using circular economy principles. Renewable and Sustainable Energy Reviews, 137, 110609.

[2] Gibson O. O., Babatunde Y. R., Samuel O. Y., Beatrice A. D., Somtochukwu G. N., Adaeze M. E., Chisom A. N., (2024). Exploring the Relationship between Climate Change, Air Pollutants and Human Health: Impacts, Adaptation, and Mitigation Strategies, Green Energy and Resources, 100074, ISSN 2949-7205.

[3] Emmanuel. P. A., Collins O. E., Thomas O. M., Armstrong O. N., Chris M. E., Hitler L., (2021) Solar energy: A panacea for the electricity generation crisis in Nigeria, Heliyon, Volume 7, Issue 5.

[4] Jiannan W., Waseem A., (2024) Natural resource scarcity, fossil fuel energy consumption, and total greenhouse gas emissions in top emitting countries, Geoscience Frontiers, Volume 15, Issue 2.

[5] Zou, Z., & Li, W. (2019). Small Solar Cities: A Conceptual Framework for Sustainable Urban Development. Sustainability, 11(4), 980

[6] International Energy Agency (IEA). (2021). Global Energy Review 2021

[7] Wheeler, S. M., & Beatley, T. (Eds.). (2019). Sustainable Urban Development Reader. Routledge.

[8] Boxwell, M. (2019). Solar Electricity Handbook 2019 Edition.

[9] Albie Fong, Jesse Tippett, 2012, Project Development in the Solar Industry, CRC Press

[10] IPCC. (2018). Global Warming of 1.5°C.

[11] Andrés Herrera Cedeño, 2021 Solar PV Potential on Site 4016 at Åsen and the Urban Fabric as the Future Solar Power Plant of Cities, University of Stavanger. Pp 29 -41.

[12] Peter Gevorkian’s Solar Power in Building Design by McGraw Hill 2008 PP 1-15.

[13] Nicholas Bailey, 2014, A Reliability Evaluation of Solar Power in South Africa’s Power System, Energy Research Centre - University of Cape Town.