NURA YUNUSA

EXPLORING SOLAR AND WIND ENERGY AS A ALTERNATIVE POWER SOURCES FOR SOLVING THE ELECTRICITY CRISIS IN NIGERIA

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# EXPLORING SOLAR AND WIND ENERGY AS A POWER GENERATION SOURCE FOR SOLVING THE ELECTRICITY CRISIS IN NIGERIA

**A THESIS SUBMITTED TO THE INSTITUTE OF GRADUATE STUDIES OF NEAR EAST UNIVERSITY**

**By**
**NURA YUNUSA**

**In Partial Fulfilment of the Requirement for the Degree of Masters in Science in Civil Engineering**

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**Approval of Director of Graduate School of Applied Sciences**

**Prof. Dr. K. Hüsnü Can Başer**

**We certify this thesis is satisfactory for the award of the degree of Master in Science in Civil Engineering**

Thesis defence was held online. The jury members declared their acceptance verbally which is recorded.

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I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all materials and results to this work.

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Date: 20/08/2021

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**Dedicated to My Parents…**

## ABSTRACT

The present study examines the economic effect of installing grid-connected solar and wind power plants in fifteen locations across Nigeria. In assessing the wind energy potential, the Nigerian Meteorological Agency (NiMET)'s wind speed data between 1951-2016 measured at 10m height used by different studies were adapted for this study. Only 8 locations found suitable high-capacity wind turbines project and ideal for generating electricity. For the for prospective Photovoltaic system installation in Nigeria, the potential of solar energy of selected locations were assessed using monthly solar radiation data collected from the database of the National Aeronautics and Space Administration (NASA) database. The locations appeared to have sufficient solar resources based potential classification. Additionally, the solar resources of Sokoto, Yobe and Zamfara states belong to superb and Outstanding classes. Although, the finding of the analysis evinced that the wind plant project is more economically viable than the PV plant project in some locations while in other locations CdTe PV system project is economically viable than the project of wind and two PV systems because of the lower EP values and higher NPV, ALCS and LCOE of wind/PV. The analysis further indicates that harnessing wind and solar energy cuts greenhouse gas emissions dramatically. Therefore, the findings of this study will guide decision-makers large-scale PV/wind power plant design and installation in Nigeria to complement the current electricity shortfall in the country.



***Keywords:*** Nigeria, Wind potential, Solar potential, NIMET, Economic feasibility analysis, NASA database; Large-scale grid-connected;

# ÖZET

Bu çalışma, Nijerya genelinde on beş yerde şebekeye bağlı güneş ve rüzgar enerjisi santralleri kurmanın ekonomik etkisini incelemektedir. Rüzgar enerjisi potansiyelinin değerlendirilmesinde Nijerya Meteoroloji Ajansı'nın (NiMET) 1951-2016 yılları arasında farklı çalışmalarda kullanılan 10m yükseklikte ölçülen rüzgar hızı verileri bu çalışmaya uyarlanmıştır. Analiz sonucuna göre seçilen on beş yerden sadece sekiz yer yüksek kapasiteli rüzgar türbinleri projesine uygun ve elektrik üretimi için ideal bulmuştur. Ayrıca, Nijerya'da ileriye dönük Fotovoltaik sistem kurulumu için, Ulusal Havacılık ve Uzay Dairesi (NASA) veri tabanından toplanan aylık güneş radyasyonu verileri kullanılarak seçilen 15 bölgenin güneş enerjisi potansiyeli değerlendirildi. Elde edilen bulgulara göre, seçilen yerler yeterli güneş kaynaklarına sahiptir ve güneş potansiyeli sınıflandırmasına göre kabul edilebilir niteliktedir. Ayrıca Sokoto, Yobe ve Zamfara eyaletlerinin güneş kaynakları da üstün ve Muhteşem sınıflarına aittir. Her ne kadar analizin bulgusu, rüzgar santrali projesinin bazı yerlerde PV santral projesinden ekonomik olarak daha uygun olduğunu, diğer yerlerde ise CdTe PV sistem projesinin daha düşük EP nedeniyle rüzgar ve iki PV sistem projesinden daha ekonomik olduğunu göstermiştir. değerleri ve daha yüksek NPV, ALCS ve LCOE rüzgar/PV. Analiz ayrıca rüzgar ve güneş enerjisinin kullanılmasının sera gazı (GHG) emisyonlarını önemli ölçüde azalttığını gösteriyor. Bu nedenle, bu çalışmanın bulguları, ülkedeki mevcut elektrik açığını tamamlamak için Nijerya'da karar vericilere büyük ölçekli PV/rüzgar santrali tasarımı ve kurulumuna rehberlik edecektir.

***Anahtar Kelimeler:*** Nijerya, Rüzgar potansiyeli, Güneş potansiyeli, NIMET, Ekonomik fizibilite analizi, NASA veri tabanı; Büyük ölçekli şebekeye bağlı;

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## LISTS OF ABBREVIATION

| | |
|---|---|
| **AEF** | Annual Energy Production |
| **AF** | Availability Factor |
| **ALCS** | Annual Life Cycle Savings |
| **AT** | Atmospheric Temperature |
| **B-C** | Benefit-Cost Ratio |
| **CdTe** | Cadmium telluride |
| **CEDRAL** | CANMET Energy Diversification Research Laboratory |
| **CF** | Capacity Factor |
| **COE** | Cost of Electricity |
| **DC** | Direct Current |
| **DNI** | Direct Normal Irradiation |
| **EP** | Equity Payback |
| **EPV** | Energy Required from Solar |
| **ESE** | Earth Science Enterprise |
| **FGE** | Power Generating Factor |
| **FITs** | Feed-in-Tariffs |
| **FS** | Factor of Safety |
| **GHG** | Greenhouse Gas |
| **GHI** | Global Horizontal Irradiation |
| **GRC** | GHG Emission Reduction |
| **GW** | Giga Watt |
| **HOMER** | Hybrid Optimization of Multiple Energy Resources |
| **IRR** | Internal Rate of Return |
| **kW** | Kilowatt |
| **kWh** | Kilowatt-hour |
| **LCOE** | Levelized Cost of Energy |

| | |
|---|---|
| **MW** | Megawatt |
| **MWh** | Megawatt-hour |
| **NASA** | National Aeronautics and Space Administration |
| **NERC** | Nigerian Electricity Regulatory Commission |
| **NiMET** | Nigerian Meteorological Agency |
| **NPC** | Net Present Costs |
| **NPV** | Net Present Value |
| **O&M** | Operation and Maintenance |
| **PB** | Payback Period |
| **PCF** | Prototype Carbon Fund |
| **PDF** | Probability Density Function |
| **PHCN** | Power Holding Company of Nigeria |
| **PPAs** | Power Purchase Agreements |
| **PV** | Photovoltaic |
| **R&D** | Research and Development |
| **RE** | Renewable Energy |
| **REEEP** | Renewable Energy and Energy Efficiency Partnership |
| **UNEP** | United Nations Environment Program |
| **WPC** | Wind Power Class |
| **WPD** | Wind Power Density |
| **WPP** | Wind Power Plant |

## LISTS OF SYMBOLS

| | |
|---|---|
| **%** | Percentage |
| **$(P/A)_A$** | Actual Wind Power Density |
| **$CO_2$** | Carbon dioxide |
| **IV** | Peak Energy Requirement |
| **kg** | Kilogram |
| **$kWh/m^2$** | Kilowatt per Metre Square |
| **m** | Metre |
| **$^oC$** | Degree Celcius |
| **$^oE$** | Degree East |
| **$^oN$** | Degree North |
| **$P_w$** | Wind Power Turbine |
| **v** | Wind Speed |
| **$Vmax_E$** | Maximum energy-carrying wind speed |
| **Vmp** | Probable wind speed |
| **z** | Height |
| **$\alpha$** | Surface Roughness Coefficient |
| **$\rho$** | Air Density |

# CHAPTER 1
# INTRODUCTION

## 1.1. Overview

The role of energy in any nation's socio-economic development cannot be overemphasized because it is a cornerstone of civilization, growth, security and a powerful instrument for any industrial society. Energy is necessary for modern societies to achieve their interconnected goals; to meet domestic human consumption in buildings, the utility of energy in their daily activities needs; such as domestic and industrial activities.

The electricity generation share illustrated in Figure 1.1 shows that fossil fuel dominated the global electricity generation; represent two-third of the entire world electricity production. Despite being the world's major energy source, it is a finite energy source that will only last for a short time (Ozorhon et al., 2018) and their negative impact is climate change and air pollution. Furthermore, nuclear energy constitutes 11% of electricity generation shares considered not safe, while hydroelectricity which defends on water flow does not appear to be practical because of a water shortage caused by climate change (Ajayi, 2009). Relying on these sources is not a viable option for both sustainability and environmental concerns, given the environmental implications and resource depletion (Ozorhon et al., 2018). Thus, the energy sector's focus has changed to renewable energy sources (RE). Participants in the market, including the authority, have acknowledged the problem and have begun to reshape their policies to increase the total energy production with renewable energy share (Ozorhon et al., 2018). As a result, RE investments have recently increased. Figure 1.2 shows the distribution of additional power capacity in 2015 where renewables account for 53% of overall additions, excluding large-scale hydropower projects. Wind Power Plants (WPP) account for 62 gigawatts (GW), while Solar Power Plants (SPP) account for 56 GW of those renewable investments (McCrone et al., 2016). Environmental consciousness, technological advancements, and policies from the government department have all contributed to the increased use of RE sources in the energy production sector (Ozorhon et al., 2018). Reviewed publications by different institutions have all helped to raise environmental awareness around the world. Thus, in the field of renewable energy technologies, there have also been tremendous technological advancements (Ozorhon et al., 2018). Performance, investment cost, including initial and operation and maintenance (O&M) costs, and reliability have all improved significantly (Dinçer, 2000). Advances in research and development (R&D) have made renewable energy solutions more cost-effective than fuel-based solutions (Ozorhon et al., 2018). Government policies can influence all of the aforementioned indicators, as well as the prices at which RE projects are sold. There are a few policies that are enforced all over the world (Ozorhon et al., 2018). Funding for R&D investments like low-interest guarantees, environment and tax incentives like accelerated depreciation, tariff incentives like feed-in tariffs (FITs), and tradable certificates are only a few of them (Johnstone, et al., 2010).

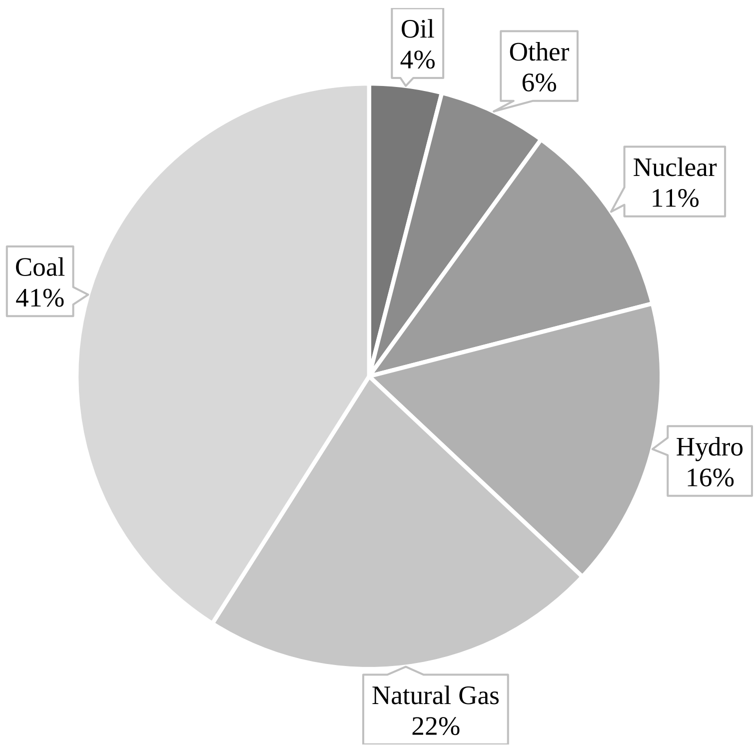



**Figure 1. 1**: Share of Electricity Production (International Energy Agency, 2016)

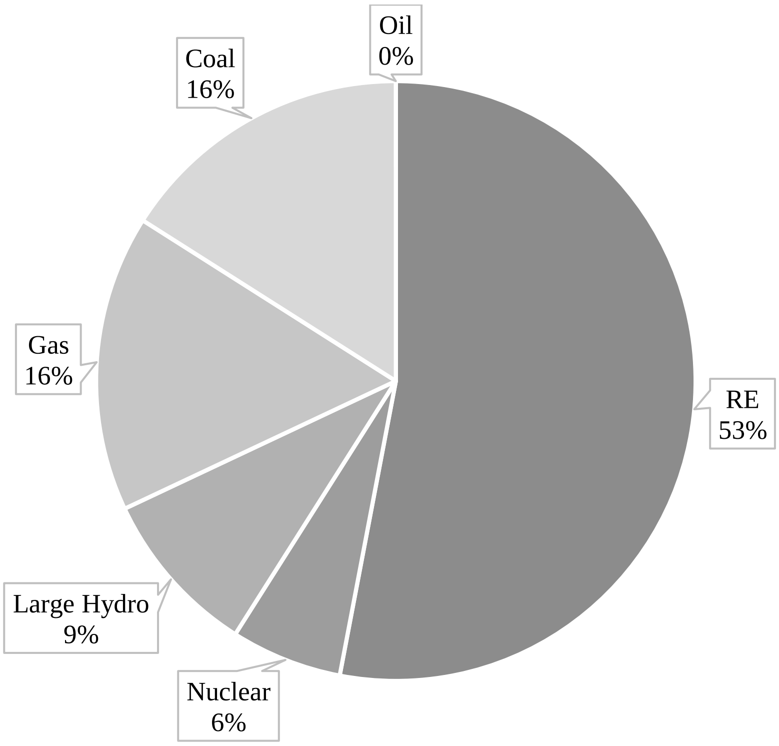



**Figure 1. 2**: 2015 Added Net Power Production Capacity by Main Technology (McCrone, 2016)

### 1.2. Problem Statement

Despite its importance, it is alarming that about 40% of the Nigerian population do not have access to the power supply (Aliyu et al, 2013). Even though several days can pass with no power supply, the estimated average daily power supply in the country is four hours at most (PwC, 2016). This energy supply crisis is complicated, arises from several causes that lasted for decades which crippled the following industries in the country: manufacturing, agriculture and mining (Aliyu et al, 2013; Kaseke and Hoskin, 2013), thus impeding the country's ongoing economic growth and development. Most Nigerian businesses and households can afford to utilize one or more diesel-fueled generators to supplement the erratic supply. To increase Nigerians with access to power, the government adopted recent changes in 2005 to improve its power supply. The privatization of generation and distribution properties, as well as the promotion of private investment in the power sector, were the main goals of these reforms. The government retains control over transmission assets while making little headway in developing a regulatory framework that is attractive to foreign investors (Ogunleye and Kehinde, 2017). However, the reform made little headway in the average daily power supply in the country because the power production remains the same. After all, the further development of the major country's power sources; hydroelectricity does not appear to be practical because of the fluctuating seasonal water supply (Ajayi, 2009) and water shortage cause climate changes. Furthermore, the predicted rise in seawater level as a result of climate changes may flood the low-lying natural gas area (Gujba, Mulugetta & Azapagic, 2011) which is another source of power supply in the country, thus, impede the power supply progress from these sources. Moreover, Nigeria has abundant uranium deposited in-country and have easy access to it been mined in its neighbouring country Niger if needed for nuclear energy plant (Ejiogu, 2013) and could be a viable solution for the country's power shortage, although it seems not reliable because it's not clean energy sources. Therefore, renewable energy has been abundant in the country identified as a clean and safe energy source (Gujba, Mulugetta & Azapagic, 2011) for the country. Harnessing these energy sources will be a perfect way to increase the country's energy production, thus, improve the country's energy supply and satisfy the energy needs of the country. However, lack of certainty on return has remained the major hindrance to the renewable energy investment in the renewable energy sector in the country despite partial privatization of the country's power sector to create a competitive market to improve management and performance, attracting private investment, growing generation, and providing a stable and cost-effective power supply (Akanonu, 2019). Because renewable energy investors must choose between various technologies, each with its cost structure and output uncertainty (Reuter, 2012). They must select those that provide the highest return for a given amount of risk (Wüstenhagen, 2012). Making an acceptable choice among many choices is not a simple job. Investment decisions in renewable energy are primarily influenced by a variety of factors, including economic, environmental, and technological considerations. As a result, there is a pressing need to build resources that assist potential renewable energy investors in making informed decisions (Ozorhon et al., 2018). Hence, it is vital to provide a clear investment view in renewable energy technologies based on the region/state with abundant but under-utilized renewable energy that will inform the decision-maker in installing renewable energy power plants as alternative energy sources and inform the energy investors of Nigeria's renewable energy opportunity. This includes a thorough feasibility analysis of renewable energy's technological, economic, risk, sensitivity, and environmental impact in the most suitable zone.

### 1.3. Aims of the Study

This thesis aims to evaluate the techno-economic feasibility of a large-scale PV/wind plant construction in Nigeria using RETScreen Expert V6.0 to assist renewable energy investment decisions for Nigeria.

### 1.4. Objectives of the Study

- To identify and classify solar and wind potential regions of the country.
- To validate the technological, economic, and environmental viability of establishing a grid-connected PV/wind system in the most suitable location of the country.
- To compare different PV modules and identify the best module for the suitable solar energy region.
- To identify the region for small scale wind turbines and the region for large-scale wind turbines.
- To use the findings of the feasibility study to persuade and entice energy investors to engage in renewable energy projects in the country.

### 1.5. Hypothesis

- If Nigeria adopts large-scale renewable energy generation, it will complement or reverse the current power shortfall in the country.
- Techno-economic feasibility and environmental sustainability validation will help in attracting renewable energy investors.
- Renewable energy in Nigeria can provide the country with millions of jobs and other economic benefits.

### 1.6. Significance of the Study

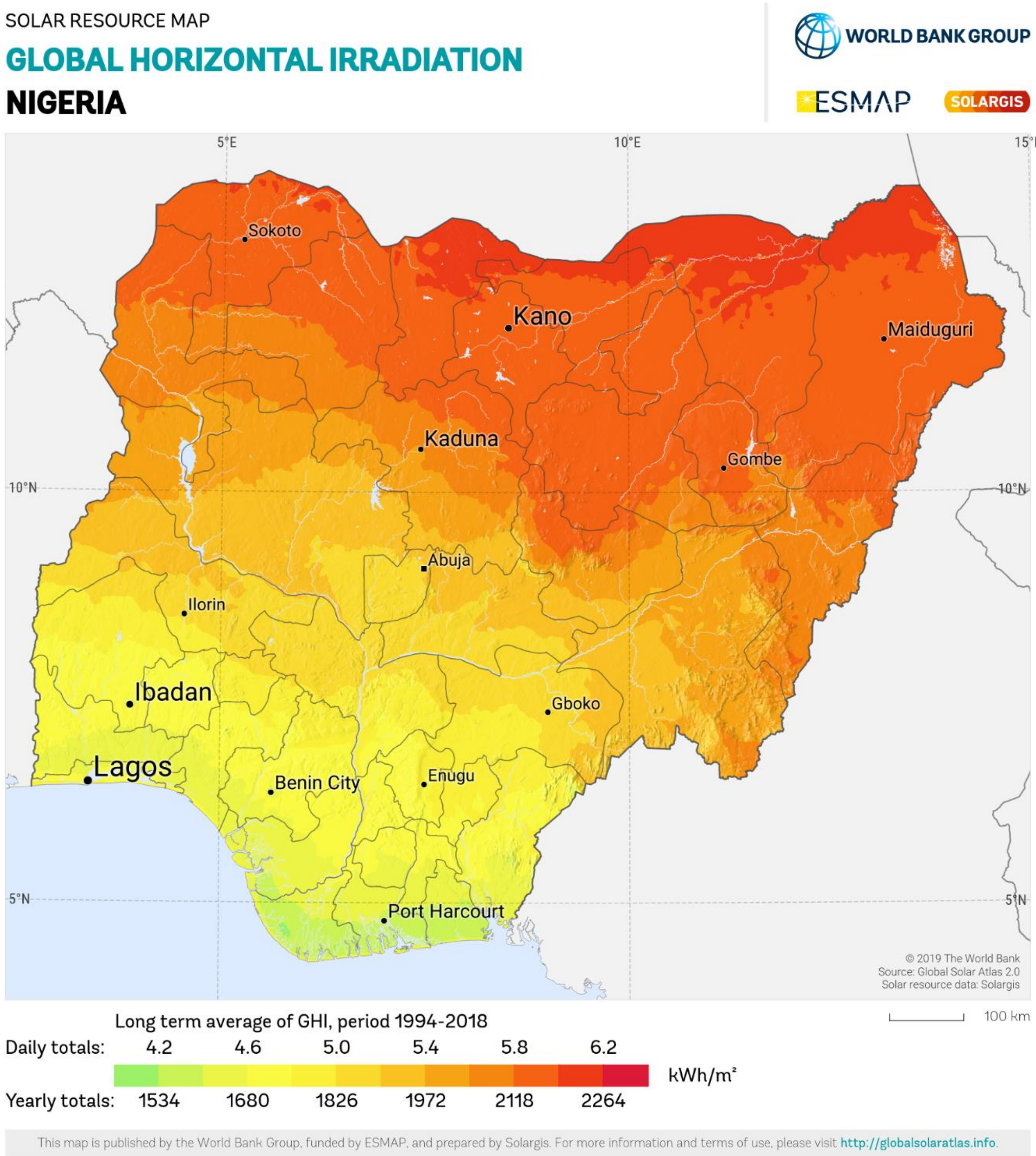
The findings can aid decision-makers in the design and installation of renewable energy power plants as future alternative energy sources, as well as inform energy investors about Nigeria's renewable energy prospect. In addition to the important significance of this study is an investment in renewable energy in Nigeria will create millions of jobs and provide other economic benefits. Finally, the study may serve.

# CHAPTER 2
# LITERATURE REVIEW

## 2.1. Wind and Solar Potential in Nigeria

Because solar radiation and wind are abundant in Nigeria, they are one of the renewable energy resources that can be used to ease the country's current electricity shortage. Nigeria is located in a high-sunshine area, which means it has tremendous solar energy potential. Nigeria, especially the Northern region (Figure 2.1) receives solar irradiation between 1826kWh/$m^2$ and 2264kWh/$m^2$. The region was further identified (Ayodele et al., 2018) to have a huge wind energy potential than any other region in the country ranging from 4 m/s to greater than 7 m/s (Figure 2.2) and suitable areas to harvest the electricity are illustrated in Figure 2.3.

This abundant renewable energy present in the country which often considered as future energy sources alternative (Ishaq et al, 2018; Razmajoo et al, 2017; Woldeyohannes et al, 2016; Owusu and Asumadu-Sarkodie, 2016;); clean energy sources with no carbon emissions (Best and Burke, 2018) can complement the energy crisis in the country to suffice her energy needs. the current country's power generation capacity is 12,522 MW from hydropower and fossil (gas) thermal power (Figure 2.4, Table 2.1) which account for 12.5% and 87.5% country's power generation respectively (Get-Invest, Online, 2020). However, only 4,000MW is available for onward transmission (Figure 2.4) to consumers (Nigeria, Power Africa Fact Sheet, USAID). These significant power losses are caused by the non-availability of installed capacity and the high frequency of serious technical and non-technical problems throughout the power supply value chain. The transmissions are done through grid-mode connection (Figure 2.6), which resulted in regular constant outrage posing a challenge to the consumers as a result of low transmitted estimated as 107 kWh and 12 W per capital (Ibikunle, et al., 2019) which is the lowest in Africa (Get-Invest, Online, 2020). Many businesses closed or moved out of the country because of this shortfall.


SOLAR RESOURCE MAP
GLOBAL HORIZONTAL IRRADIATION
NIGERIA
WORLD BANK GROUP
ESMAP
SOLARGIS
5°E
10°E
15°E
10°N
5°N
Sokoto
Kano
Maiduguri
Kaduna
Gombe
Abuja
Ilorin
Ibadan
Gboko
Lagos
Benin City
Enugu
Port Harcourt
© 2019 The World Bank
Source: Global Solar Atlas 2.0
Solar resource data: Solargis
100 km
Long term average of GHI, period 1994-2018
Daily totals: 4.2 4.6 5.0 5.4 5.8 6.2
kWh/m²
Yearly totals: 1534 1680 1826 1972 2118 2264
This map is published by the World Bank Group, funded by ESMAP, and prepared by Solargis. For more information and terms of use, please visit http://globalsolaratlas.info.

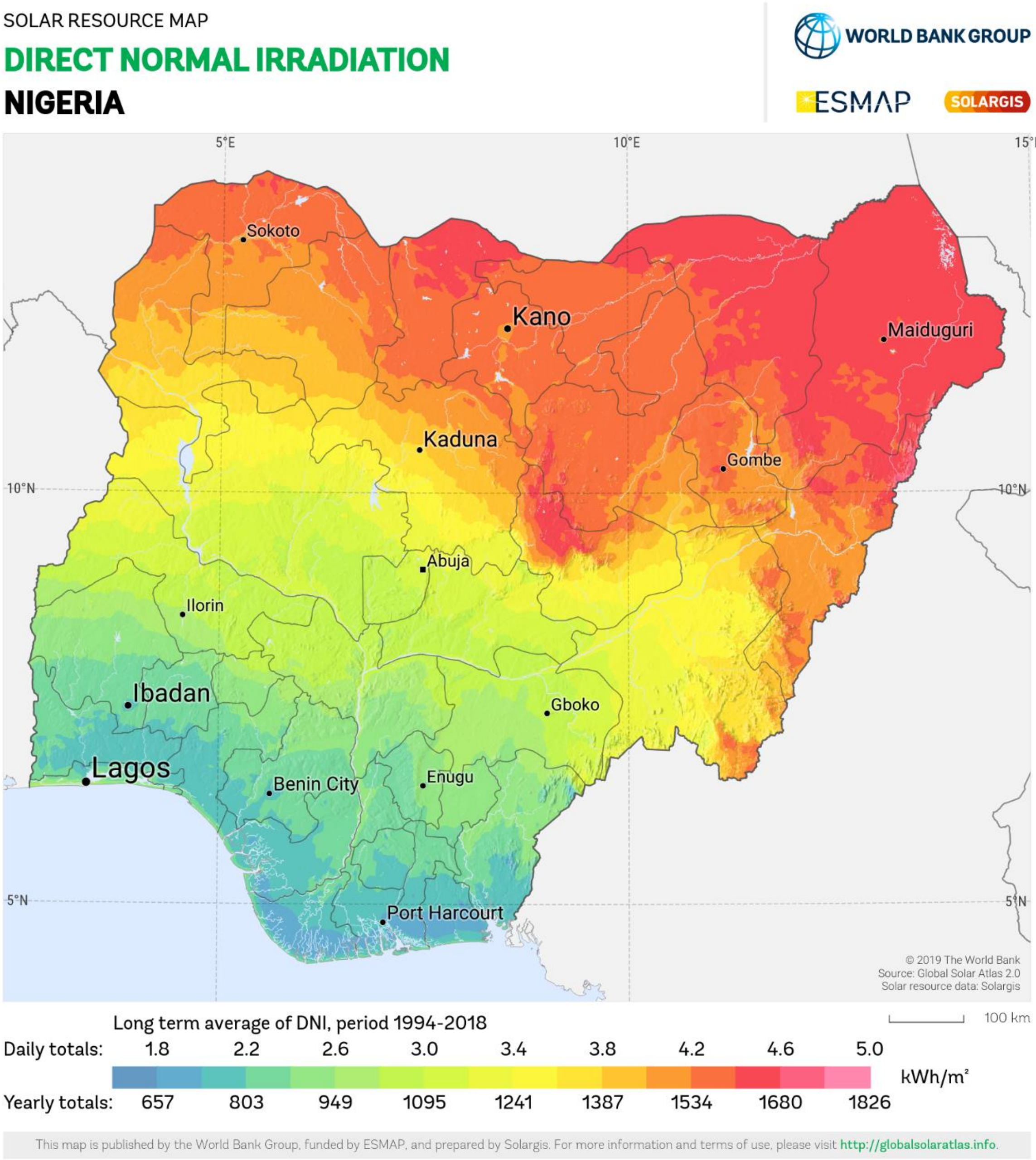



**Figure 2. 1**: Nigeria's GHI and DNI (Global Solar Atlas, n.d)

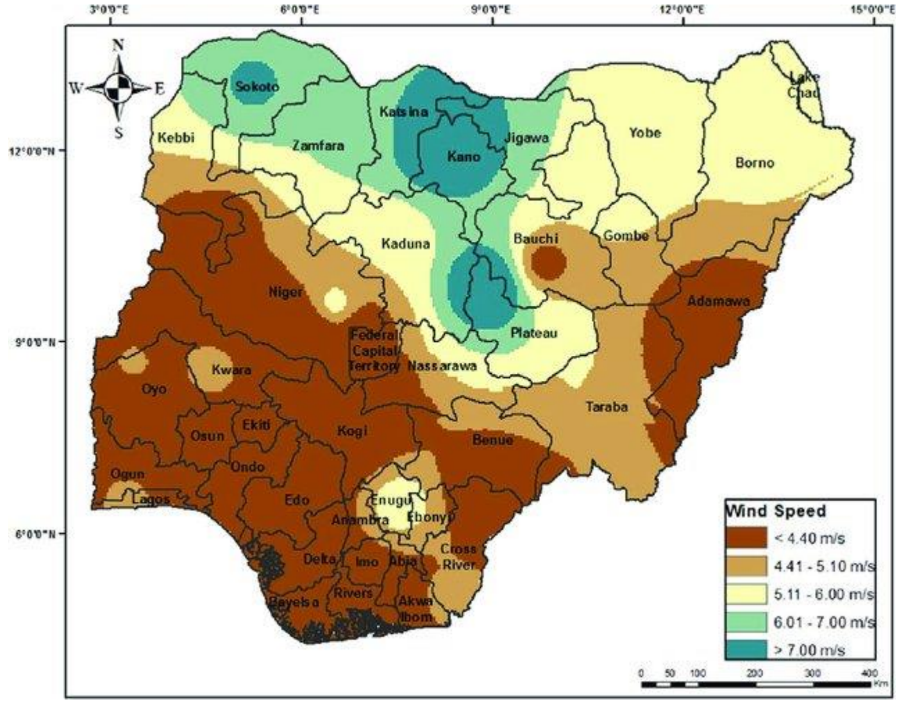



**Figure 2. 2**: Nigeria Horizontal Irradiation (Ayodele et al., 2018)

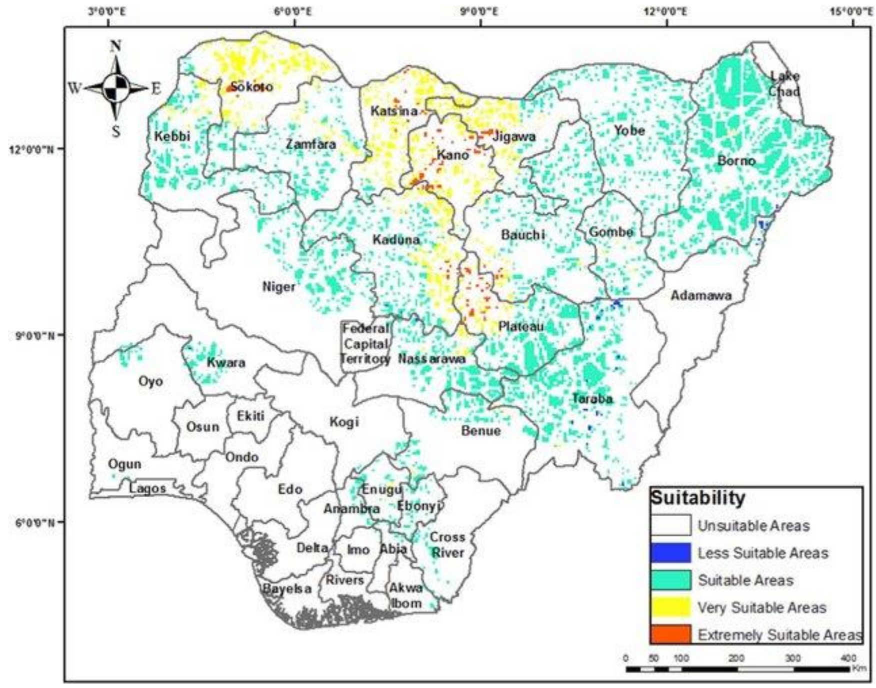



**Figure 2. 3**: Nigeria Horizontal Irradiation (Ayodele et al., 2018)

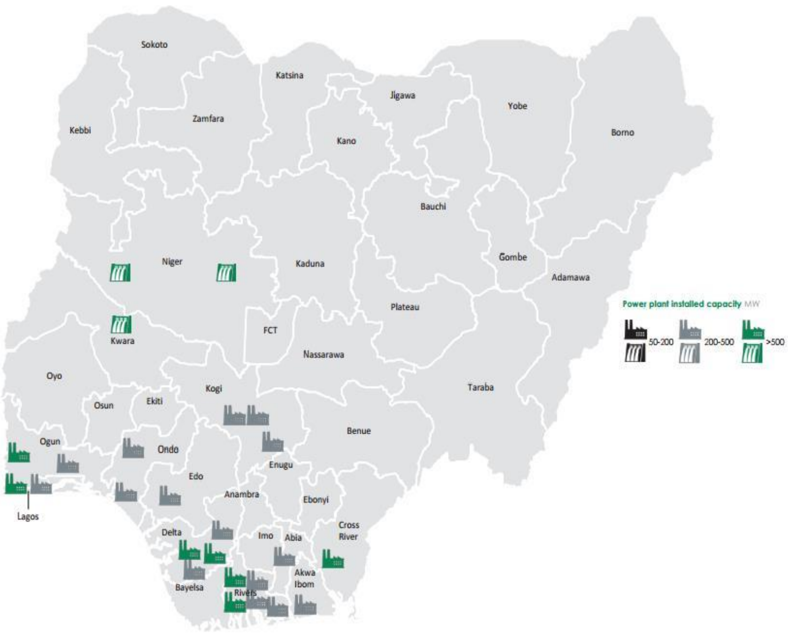



**Figure 2. 4**: Power Plants in Nigeria (Get-Invest, Online, 2020)

**Table 2. 1**: Installed generation capacity per Power Station (MW) (Get-Invest, Online, 2020)

| **Power Station** | **Production Capacity (MW)** | | |
|---|---|---|---|
| | **Installed** | **Average Available** | **Average Operational** |
| EGBIN | 1,320 | 941 | 539 |
| AFAM VI | 685 | 587 | 455 |
| OKPAI | 900 | 536 | 375 |
| TRANSCORP UGHELLI | 480 | 463 | 374 |

**Table 2.1. continued**

| Power Station | Installed | Average Available | Average Operational |
|---|---|---|---|
| JEBBA | 570 | 431 | 262 |
| OLORUNSOGO GAS | 335 | 277 | 189 |
| IHOVBOR NIPP | 434 | 374 | 182 |
| GEREGU NIPP | 450 | 328 | 179 |
| KAINJI | 720 | 444 | 173 |
| OLORUNSOGO NIPP | 760 | 260 | 171 |
| OMOTOSHO NIPP | 500 | 306 | 169 |
| OMOTOSHO GAS | 335 | 280 | 163 |
| SHIRORO | 600 | 508 | 153 |
| GEREGU GAS | 414 | 159 | 131 |
| SAPELE NIPP | 450 | 184 | 111 |
| IBOM | 190 | 91 | 76 |

**Table 2.1. continued**

| Power Station | Installed | Average Available | Average Operational |
|---|---|---|---|
| SAPELE | 504 | 219 | 69 |
| ALAOJI NIPP | 720 | 158 | 67 |
| ODUKPANI NIPP | 561 | 234 | 64 |
| AFAM IV-V | 724 | 3 | 2 |
| ASCO | 294 | 270 | 0 |
| OMOKU | 110 | 0 | 0 |
| TRANS AMADI | 150 | 0 | 0 |
| AES GAS | 180 | 175 | 0 |
| RIVERS IPP (Independent Power Producer) | 136 | 0 | 0 |
| TOTAL | 12,522 | 7,141 | |

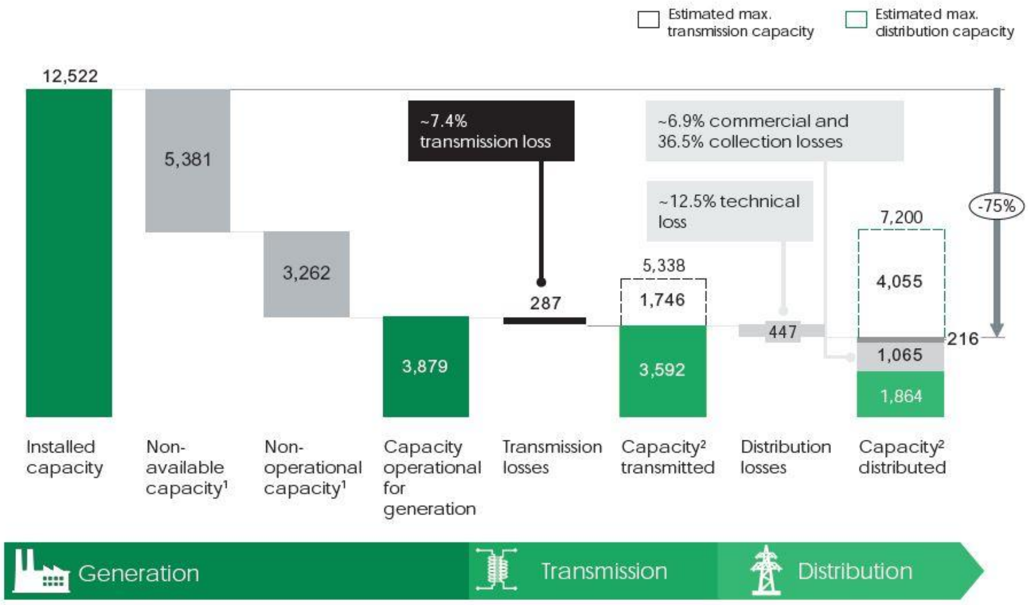



**Figure 2. 5**: Nigeria Power Sector Energy Flow (MW) (Get-Invest, Online, 2020a)

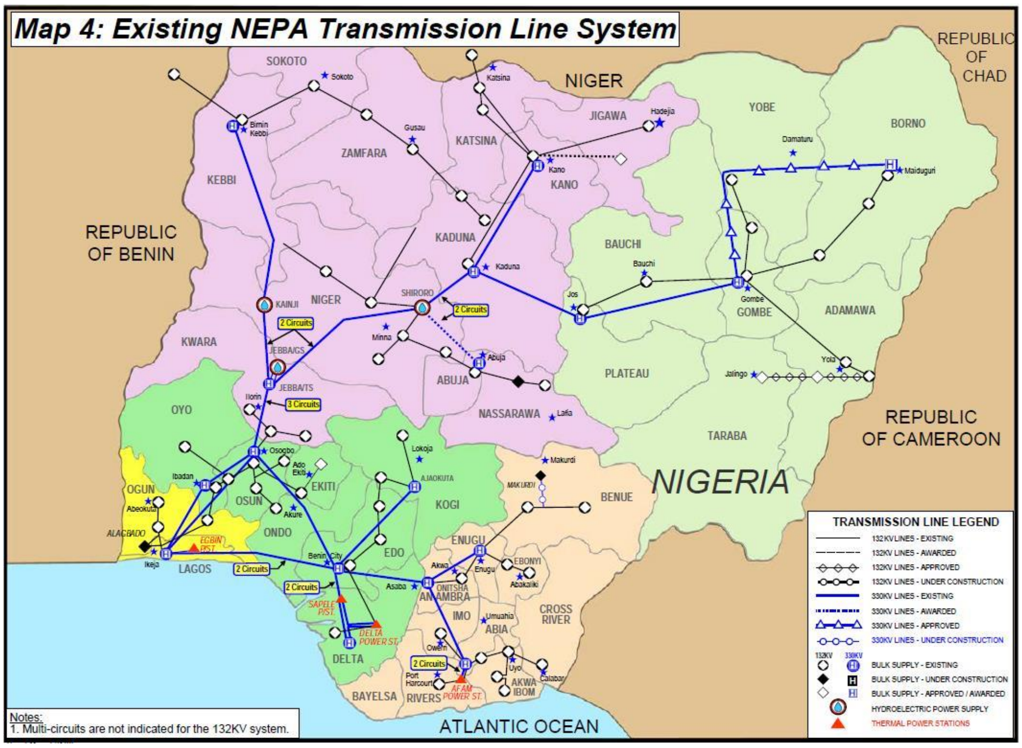



**Figure 2. 6**: Power Transmission Line System (Get-Invest, Online, 2020a)

These alternative energy sources are now considered extensively by India, Pakistan, Turkey and Saudi Arabia (Khare et al., 2013; Kamran, 2018; Kaplan, 2015; Düştegör, 2018) to increase their citizens with access to electricity.in regards to Nigeria's wind and solar potential, researchers have conducted several studies. The instance of those researchers was an evaluation of Nigeria's wind energy potential by Ayodele et al. (2018) considering important factors such as environmental, social, and economic. Similarly, Ajayi et al. (2014) performed an economic benefit analysis on the wind energy potential of ten sites in Nigeria's southwestern geopolitical zone, using wind speed data from the Nigerian meteorological agency between 1987 and 2010 (24 years) at 10 m height to classify the sites wind profiles for electricity generation. Furthermore, Bamisile et al. (2017) examined Nigeria's alternative renewable energy potentials, paying specific emphasis to the past, present, and future of solar energy development. Moreover, Adedipe et al. (2018) look into the possibilities of offshore and onshore wind energy in Nigeria for electricity generation. The research looked at the development and design of small-scale wind turbines, as well as their use in small-scale power generation. These assessments and studies of Nigeria's renewable energy potential drew several scholars to explore the country's renewable energy potential, as well as the techno-economic feasibility and viability of doing so. Johnson and Ogunseye (2017) designed a grid-connected 148.5kWp Photovoltaic System with Energy Storage for use in a Local Government Secretariat in Nigeria, and Musa et al., (2016) designed a 3.8 MW solar PV power plant to meet the 3.44 energy demand of two industries in the Bompai industrial area of Kano State Nigeria.

## 2.2. Techno-Economic Feasibility Analysis of PV/Wind System in Nigeria

In government effort to reintegrate Nigeria into the global economy through foreign direct investment through power sector reforms by unbundling the PHCN (Power Holding Company of Nigeria) to make room for private sector investment in the fields of electricity generation, transmission and distribution and creating the NERC (Nigerian Electricity Regulatory Commission) an independent body to regulate the power generation, power distribution networks, standardize the customer service and tariff pricing and rating, however, the power shortfall in the country as a result of poor maintenances facilities and gas pipeline vandalism activities impaired the constant power supply in the country as well as its economic growth and development of (Ileberi, 2015) meanwhile the country is blessed with renewable energy resources as an alternative energy source which is now an important part of many countries policies of mitigating the greenhouse gas (GHG) emission.

Furthermore, the Nigerian renewable energy sources present an opportunity for energy investors. However, external costs and benefits of renewable energy initiatives in Nigeria must be considered in order to create socially optimum investments. This recent trend of connecting Nigeria's energy system with renewable energy resources cannot be achieved without assessing the economic viability of the investment which depends on the technical assessment and economic feasibility of grid-connected renewable energy power supply (Nweke et al., 2020) also depends on the National Electricity Regulation Commission's (NERC) technical and distribution regulations and legal framework that accommodate them (Akorede et al., 2017; Carolina et al., 2016). Many studies have been conducted in this area; for example, Oladigbolu et al. (2019) used HOMER Pro software to assess the negative technical-economic and environmental impact of a combined conventional and renewable energy (diesel generator and photovoltaic system) that is adaptable enough to operate in grid-connected and off-grid to provide electricity to a remote Nigerian village. The effects of shifting load demand, grid energy and resale prices, diesel costs, and solar radiation levels on system performance were discussed. The ideal design in both circumstances is a 12 kW diesel generator with a 54 kW photovoltaic (PV) panel, a 70 battery pack (nominal battery capacity 484 kWh), and a 21 kW converter, according to the findings. In all configurations, electricity expenses (COE) and net current costs (NPCs) varied from $ 0.1 to $ 0.218 per kWh and $ 117,598 to $ 273,185, respectively, with CO2 emissions ranging from 5963 to 49,393 kg per year. These findings give a broad knowledge and idea for developing a flexible and stable power system to ensure that customers have access to electricity at all times. Ajayi and Ohijeagbo (2015) went on to analyze the viability and economic feasibility of solar and wind energy resources as a renewable source of power in non-grid-connected rural regions. In rural regions, there are 200 dwellings, a school, and a health facility. With the main peak load of 46 kW and a reportable peak load of 20 kW, the basic electric load profile of 358 kWh per day has been designed to fulfil the demands of rural communities. The design evaluation took into account three stand-alone photovoltaic (PV), wind, diesel, and wind-hybrid photovoltaic applications, all of which would best meet the daily load requirement with a load probability decrease of 0.01. These and related studies, such as Oladigbolu et al. (2020), Salisu et al. (2019), and others, have limitations in that they focus on feasibility analyses and economic evaluations for rural electrification.

Owolabi et al., (2019) conducted technical-economic analyses of the region to attract solar investors to invest in renewable energy technology using the underutilized and abundant solar energy in the North-East part of Nigeria to help reduce the impact of global warming caused by wood-burning and to boost the region's sustainable technological development, which was harmed by the Boko-Haram Uprising. Similarly, However, this study and similar studies limit to a particular region of the country only a few studies found studying investigating the techno-economic viability such as 10 MW wind, PV and gas turbine plant by Christopher et al., (2019). A similar study by Nweke et al., (2020) on the possibility of integrating grid-conned power plants with Nigeria power system focusing on its economic viability, however, both studies conducted couldn’t identify the best region where PV or wind power plant should be installed in the country which can help in attracting the renewable energy investors in the country. Thus, necessitate new study to identify the best locations in Nigeria where PV/wind plants should be installed with their techno-economic validation that provide a clear road map that can attract RE investors to the country to enable the country access to efficient and reliable electricity, and further help in decision making. Kassem et al. (2020) did similar research with this perspective, assessing the optimal location for the future installation of a large-scale grid-connected wind/photovoltaic facility, as well as the technical-economic feasibility of the proposed facility, utilizing RETScreen software.

## 2.3. Renewable Energy Technology with RETScreen Software

### 2.3.1. RETScreen Expert Overview

RETScreen Expert is a cutting-edge, one-of-a-kind RE education, decision-making, and capacity-building platform. It is developed and operated by Natural Resources Canada's CANMET Energy Diversification Research Laboratory (CEDRL), which has its headquarters in Varennes, Quebec (Amir et al., 2014; Thevenard et al., 2000; NRCAN, n.d). The software was created by a group of more than 307 experts from industry, government, and academia, with contributions from NASA, the Association for Renewable Energy and

Energy Efficiency (REEEP), the United Nations Environment Program (UNEP), the Global Environment Facility (GEF), the World Bank's Prototype Carbon Fund (PCF), and the Energy + Environment Initiative (NRCAN, nd). The program is open source and may be used to assess the viability of clean energy projects such as energy efficiency and renewable energy projects like solar PV, wind, and hydropower (Lee et al., 2012).

The software can be utilized to conduct feasibility studies for energy projects, as well as evaluate the performance of new and retrofit projects, as well as monitor and evaluate existing projects. Each technological project follows the same five-step energy model analysis approach, which includes cost analysis, GHG analysis, financial summary, and sensitivity and risk analysis. Each technology project has a standard procedure with the same five-step energy model analysis, including cost analysis, gas analysis, greenhouse effect (GHG), financial summary, and sensitivity and risk analysis. Users can choose each technology project based on the intent of their feasibility or performance assessment report, and each technology project has a standard procedure with the same five-step energy model analysis, including cost analysis, gas analysis, greenhouse effect (GHG), financial summary, and sensitivity and risk analysis. The program assists decision-makers in determining the viability of various energy initiatives in order to execute them quickly and at a reasonable cost. This is accomplished by dramatically decreasing the costs and time associated with identifying and analyzing possible energy projects in phases, such as pre-feasibility, feasibility, development, and engineering (Amir et al., 2014; NRCAN, n.d). The software's three core analytical tools are the benchmark analysis process, the feasibility analysis workflow, and the performance analysis workflow (NRCAN, n.d; Clean Energy Management Software – energypedia, n.d).

**A. Benchmark Analysis Workflow**

The benchmark table allows users to quickly evaluate the energy performance of a facility by establishing the conditions for climate reference at a facility at any location on the globe and comparing the power output of various types of benchmark equipment with the annual estimated or measured energy consumption of the same facility (NRCAN, n.d; (NRCAN, n.d; Clean Energy Management Software – energypedia, n.d). The benchmark includes two worksheets: a location worksheet and a facility worksheet.

**B. Feasibility Analysis Workflow**

The feasibility study worksheet is completed with an exhaustive and extensive study. Users can apply the five-step standard study that comprises energy, cost, emission and financial and sensitivity/risk analysis to model any clean energy project. The analysis (NRCAN, n.d). The workbook includes benchmarking databases, goods, projects, hydrology and climate, linkage to global energy resource maps, a large database of general templates and case studies for clean energy project planners (Clean Energy Management Software, n.d.).

**C. Performance Analysis Workflow**

The performance analytics sheet allows users to monitor and assess essential data on energy performance, including actual vs projected energy performance, for the facilities' owners, managers and decision-makers. The worksheet compares the real output of a plant to its predicted output using complex regression and prediction models that take account of normalized energy performance utilizing multiple criteria such as NASA weather data (NRCAN, n.d; Clean Energy Management Software, n.d).

### 2.3.2. Previous Works Using RETScreen Expert

Many scholars outside of Nigeria have used RETScreen and other equivalent technologies to evaluate the viability and decision making in government implementation of grid power plants. An example of such research was an environmental and economic feasibility assessment on the transposition into renewable energies by Rashwan et al of a modest building in Saudi Arabia's power system (2017). The analysis analyzed the solar power plant and based on the feasibility report on the new government and commercial energy rates at 4 cents and 8.0 kWh, compared with 12 kW of capacity under the worldwide photovoltaic model. Similarly, Shafiqur et al. (2017) used the program RETScreen to identify a potential location for the construction of 10MW grid-connected photovoltaic power plants in Saudi

Arabia in terms of technology, environment and economy. Saudi Arabia utilized weather data such as global solar radiation, sunlight, dry bulb temperature and relative humidity for the feasibility study on energy production, greenhouse gas (GHG) emissions and financial aspects. Saudi Arabia also used weather data. The study picked a photovoltaic module after the analysis (Shafiqur et al., 2017).

Furthermore, Amir et al. (2014) use the program to simulate photovoltaic solar systems for the domestic demand for Pakistan. The study studied the influence of solar irradiation and the load correlation in the environment and the solar percentage by assessing the model using Net Present Value (NPV), Internal Return Rate (IRR) and payback periods. The study found that a stand-alone 5kW solar PV system in different locations of Pakistan may, subject to present climatic circumstances, cut GHG emissions by 0.6–0.7 $tCO^2$. In addition, for the effectiveness of the program, the user may help in designing their systems by providing early estimations of the collection, battery or pump size. By adopting a few of the system's characteristics to analyze the renewable energy potential projects, users can simply screen the most suited technology and device size depending on load, weight and season (Thevenard et a., 2000). But most Nigerian academics working on the RETScreen utilized it to analyze hydro or wind energy's economics and sustainability (Otuagoma et al., 2016; Adejumo et al., 2015; Dioha et al., 2016; Ikeagwuani et al., 2016). While Homer software or other approaches were used to examine the profitability and feasibility of solar PV projects in Nigeria (Ikeagwuani et al., 2016; Okoye et al., 2015; Adaramola, 2015; Uduak et al., 2013; Akinyele and Rayudu, 2013). The aforesaid study of Owolabi et al. and the work of Ahmed and Gidado (2008) evaluated the potential for photovoltaic systems with the development of performance data for a variety of products and sites using TRNSYS simulation. Few studies were found using RETScreen software to estimate the technological and economic feasibility and feasibility of solar photovoltaic projects in Nigeria. The results of the study showed that PV systems have great potential in buildings and other areas as standalone applications.

# CHAPTER 3
# MATERIALS AND METHODOLOGY

## 3.1. Data Collection and Proposed Methodology

For this thesis, 14 Northern states of Nigeria and FCT (Figure 3.2) are done in wind and solar potential economic analysis. The Weibull distribution function and the power approach have been used to analyze the wind potential, based on observed meteorological data modified from different research, in order to analyse wind speed properties at various heights. Furthermore, data from NASA have been used to examine the solar potential of the location selected. Figure 3.2 presents the analytical process for this thesis. Satellite systems and climate processing data sources for study have been sponsored by NASA's Earth Science Enterprise (ESE). These statistics give long-term weather predictions and solar surface energy flows. The Surface weather and solar energy (SSE) dataset offers internet access to characteristics tailored to renewable energy system design requirements, including solar and wind energy systems (Chandler et al., 2003). These have proved to be precise enough to offer trustworthy data on solar resources in places that have scarce or non-existent surface measurements (Whitlock, 2001; Perez et al., 2002).

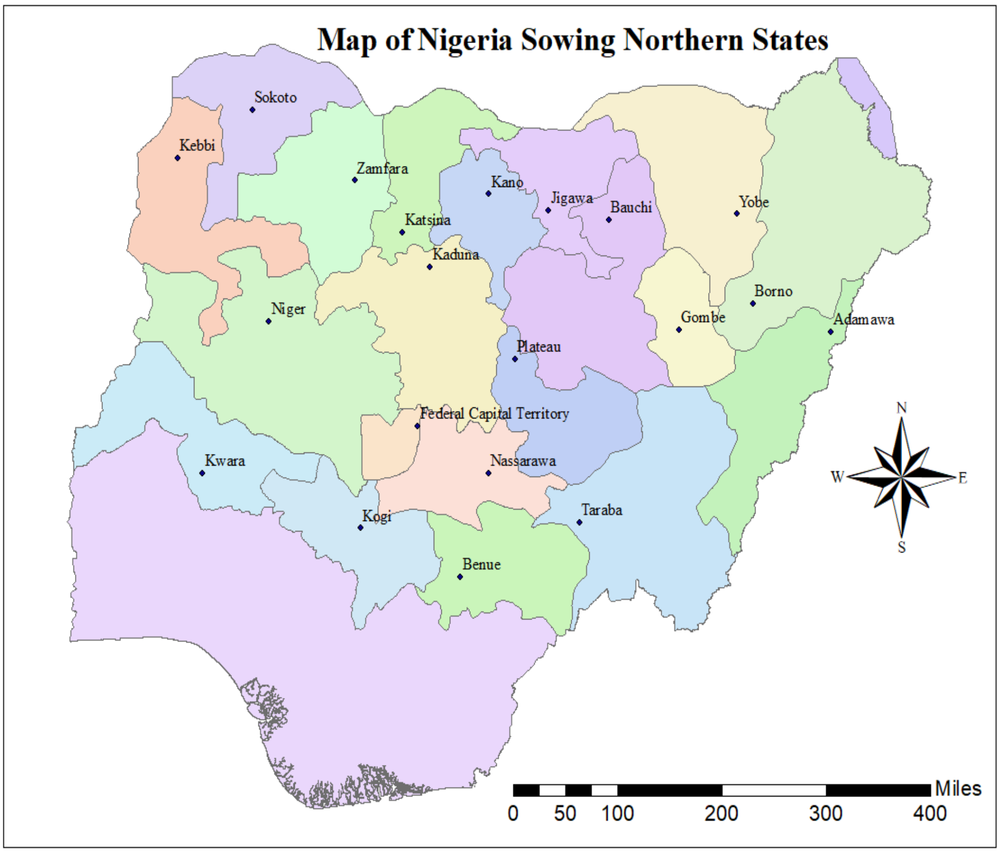



**Figure 3. 1**: Map of Nigeria showing the Northern State.

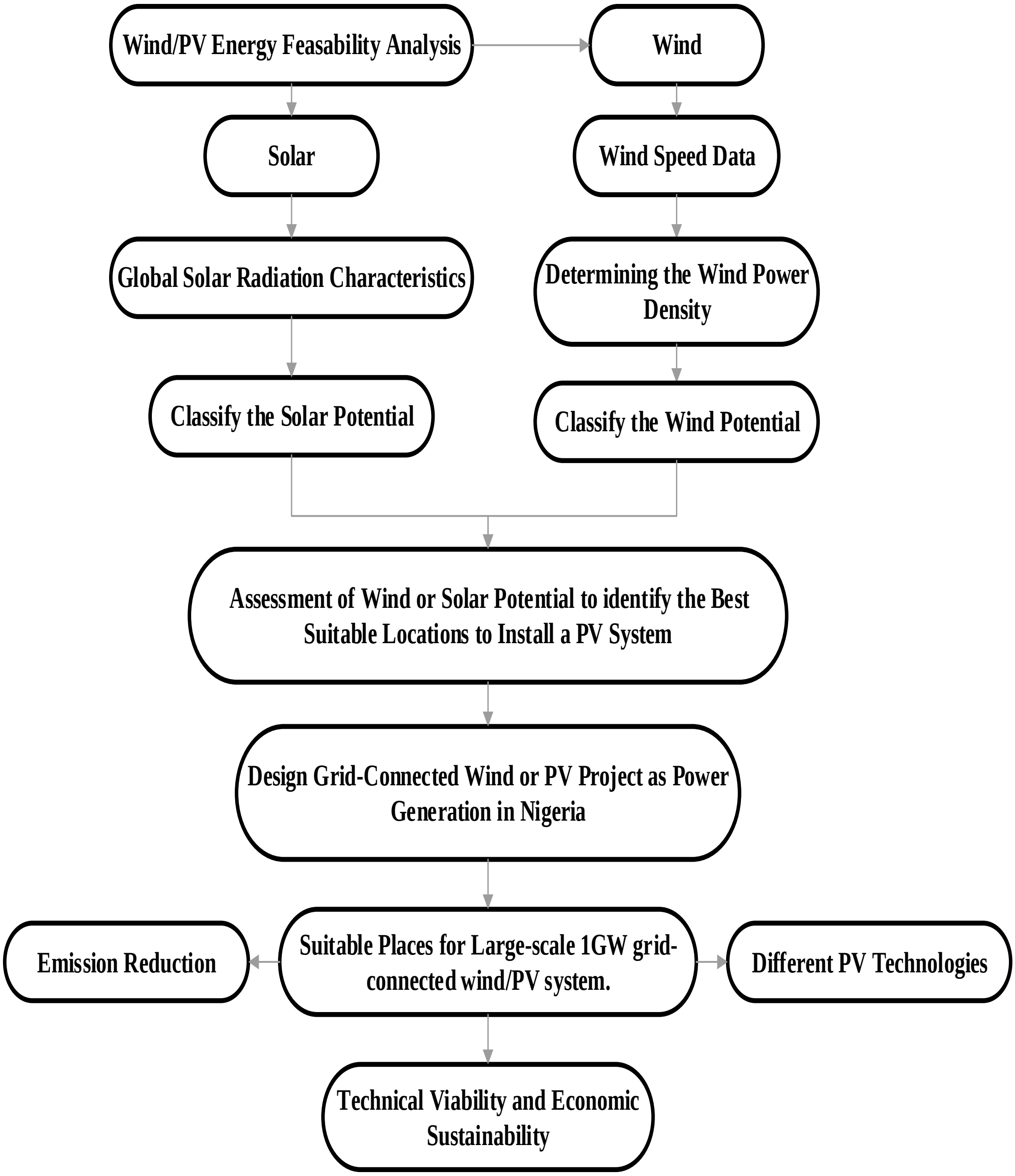



**Figure 3. 2**: Illustrative Description for the Proposed Methodology

### 3.1.1. Procedure for Analyzing Wind Data

**A. Data on Wind Speed.**

The Nigerian Meteorological Agency's (NiMET) wind speed data of between 1951-2016 measured at 10m height used by different studies (Okoye et al., 2020; Audu et al., 2019; Abdullahi and Bashir, 2019; Oyewole and Aro, 2018; Olomiyesan et al., 2017; Owoeye et al., 2017; Dogara et al., 2016; Solomon and Sunday, 2015; Usman et al., 2014; Ahmed et al., 2014; Dan-Isa and Kadandani, 2013; Ahmed et al., 2013; Ohunakin et al., 2012; Ohunakin, 2011) adapted for purpose of this study. The selected locations information is presented in Table 3.1 and Figure 3.1.

**Table 3. 1**: Information for the Selected States

| States | Latitude (ºE) | Longitude (ºN) | Altitude (m) | Refrences |
|---|---|---|---|---|
| Abuja | 7.3986 | 9.0765 | 360[a] | Usman et al., 2014 |
| Adamawa | 10.27034 | 13.27003 | 599[a] | Usman et al., 2014 |
| Bauchi | 11.68041 | 10.19001 | 615[b] | Ahmed et al., 2014 |
| Benue | 7.1904 | 8.129984 | 112.9[c] | Ohunakin, 2011 |
| Borno | 10.62042 | 12.18999 | 299[b] | Ahmed et al., 2014 |
| Kaduna | 11.07998 | 7.71001 | 645[d] | Olomiyesan et al., 2017 |
| Kano | 11.99998 | 8.520038 | 481[e] | Oyewole and Aro, 2018 |
| Katsina | 11.52039 | 7.320008 | 517.6[f] | Dan-Isa and Kadandani, 2013 |

**Table 3.1. continued**

| States | Latitude (ºE) | Longitude (ºN) | Altitude (m) | Refrences |
|---|---|---|---|---|
| Kebbi | 12.45041 | 4.19994 | 244[d] | Olomiyesan et al., 2017 |
| Kogi | 7.800388 | 6.73994 | 62.1[c] | Ohunakin, 2011 |
| Kwara | 8.49001 | 4.549996 | 307.4[c] | Ohunakin, 2011 |
| Niger | 10.40036 | 5.46994 | 256.4[c] | Ohunakin, 2011 |
| Plateau | 9.929974 | 8.890041 | 1217[e] | Oyewole and Aro, 2018 |
| Sokoto | 13.06002 | 5.240031 | 895[g] | Ahmed et al., 2013 |
| Yobe | 11.749 | 11.966 | 414.8[h] | Ohunakin et al., 2012 |
| Zamfara | 12.17041 | 6.659996 | 463.9[d] | Olomiyesan et al., 2017 |

Table 3.2 shows that the adequacy/suitability of the selected wind energy source site to meet energy requirements is often categorized according to the wind power class (WPC) (Kalmikov, 2017).

**Table 3. 2**: The Wind Power Class (WPC)

| Wind Speed at 10m Height | | | |
|---|---|---|---|
| **Class** | **Wind Power Density** | **Wind Speed (m/s)** | **Resource Potential** |
| 1 | 100 | 4.4 | Not suitable |

**Table 3.2. continued**

| Class | Wind Power Density | Wind Speed (m/s) | Resource Potential |
|---|---|---|---|

| | | | |
|---|---|---|---|
| 2 | 150 | 5.1 | Marginal |
| 3 | 200 | 5.6 | Fair |
| 4 | 250 | 6.0 | Good |
| 5 | 300 | 6.4 | Excellent |
| 6 | 400 | 7.0 | Outstanding |
| 7 | 1000 | 9.4 | Superb |

**B. Weibull Probability Density Function**

According to earlier and recent studies, two parameters for the Weibull distribution function (2W) are used to examine the wind speed distribution (v) for the area specified. (Khan et al., 2018; Kassem et al., 2019; Alayat et al., 2019;): The 2W is represented as:

Probability distribution function (f(v)) (Equation 3.1):

$$f(v) = \left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1} e^{-\left(\frac{v}{c}\right)^{k}} \quad (3.2)$$

Cumulative distribution function (F(v)) (Equation 3.3):

$$f(v) = 1 - \exp\left[-\left(\frac{v}{c}\right)^{k}\right] \quad (3.3)$$

Besides, to determine the average speed according to the Weibull parameters ( Equation 3.4) is employed the equation:

$$\bar{v} = c\Gamma\left(1 + \frac{1}{k}\right) \quad (3.4)$$

where c is the scale parameter in m/s and k is the shape factor of the distribution.

The highest probability technique may be utilized for estimation of the following 2W parameters using Equation 3.5 and Equation 3.6 (Khan et al., 2018; Kassem et al., 2019a; Alayat et al., 2018; Kassem et al., 2019b):

$$k = \left( \frac{\sum_1^n v_i^k \ln(v_i)}{\sum_1^n v_i^k} - \frac{\sum_1^n \ln(v_i)}{n} \right)^{-1} \quad (3.5)$$

$$c = \left( \frac{1}{n} \sum_1^n v_i^k \right)^{\frac{1}{k}} \quad (3.6)$$

**C. Wind Power Density**

The wind energy quantitative measurement at any site is the value of wind energy density, which is typically regarded as a key indication of the wind power potential. In addition, two other critical wind speed indicators are available (Fazelpour et al., 2017; Pishgar-Komleh et al., 2015):

Probable wind speed (Vmp) (Equation 3.7):

$$V_{mp} = c \left( 1 - \frac{1}{k} \right)^{\frac{1}{k}} \quad (3.7)$$

Maximum energy-carrying wind speed (VmaxE) (Equation 3.8):

$$V_{maxE} = c \left( 1 + \frac{2}{k} \right)^{\frac{1}{k}} \quad (3.8)$$

The WPD typically assesses the availability of the wind at site (Mohammad et al., 2017). It is Equation 3.9 and Equation 3.10

$$\frac{P}{A} = \frac{1}{2} \rho v^3 \quad (3.9)$$

$$\frac{P}{A} = \frac{1}{2}\text{p}v^3 f(v) \tag{3.10}$$

As illustrated below, it may also be calculated as a function of the Weibull parameters using Equation 3.11. (Keyhan et al., 2014):

$$\left(\frac{P}{A}\right)_W = \int_0^\infty \frac{1}{2}\rho v^3 f(v)dv = \frac{1}{2}\rho c^3 \Gamma\left(1 + \frac{3}{k}\right) \tag{3.11}$$

Furthermore, Equation (3.12) is used to calculate the mean WPD (Irwanto et al., 2014):

$$\frac{\bar{P}}{A} = \frac{1}{2}\text{p}\bar{v}^3 \tag{3.12}$$

When P is the Watt/$m^2$ wind power density, A is the $m^2$ swept area; ρ is the kg/$m^3$ air density; f(v) is the PDF and v is the mean wind speed at m/s.

### D. Wind Data Adjustment

The model power law is used for measuring the wind velocity at numerous wind turbine heights (z). expressed in Equation 3.13 according to Fazelpour et al., 2017; Pishgar-Komleh et al., 2015; Mohammad et al., 2017; Irwanto et al., 2014:

$$\frac{v}{v_{10}} = \left(\frac{z}{z_{10}}\right)^a \tag{3.13}$$

where $v_{10}$ is the wind speed at the measured height $z_{10}$, and α is the surface roughness coefficient (Equation 3.14):

$$a = \frac{0.37 - 0.088\ln(v_{10})}{1 - 0.088\ln\left(\frac{z_{10}}{10}\right)} \tag{3.14}$$

### E. Wind Project Design

In the estimation of the wind power turbine, air flow over the interest zone is often seen as a significant component. ($P_w$), which may be calculated using Equation 3.15

$$P_w = \frac{dE}{dt} = 0.5 * v^2 * \frac{dm}{dt} \quad (3.15)$$

Where E is the Watt-energy, v is m/s, t is the second time and m is the kg mass flow.

The mass flow rate ($m$) is given by Equation 3.16

$$\frac{dm}{dt} = \rho * Af * \frac{dx}{dt} = \rho * Af * v \quad (3.16)$$

Where ρ (1.25 kg/m$^3$) air density, Af is the swept area at m$^2$ and x is the distance in m. The $P_w$ may be approximated as follows by combining Equations 3.17 and 3.18 (Mostafaeipour et al., 2014)):

$$P_w = 0.5 * \rho * Af * v^3 \quad (3.17)$$

The efficiency of the wind generator really depends on the site's wind speed; consequently, the Pw may be stated as a coefficient ($C_{max}$):

$$P_w = 0.5 * C_{max} * \rho * Af * v^3 \quad (3.18)$$

The computation of wind speed and features of the wind turbine generally constitute the important factors to choose the wind turbine. Furthermore, the availability factor (AF) is a crucial component in deciding how long power can be supplied by the device described throughout the inquiry period expressed in Equation 3.19

$$AF = 1 - \frac{n}{N} \quad (3.19)$$

When n is the number of months in which the wind speed is lower than the wind turbine's cut-in speed and N is the total number of months throughout the period of investigation.

### 3.1.2. Solar Data Analysis Procedure

#### A. Solar Radiation Data

In evaluating the available solar resources at the site, satellite data remain the resourceful materials used by many studies. An instance of such studies is the work of Owolabi et al., (2019) where he used NASA solar data to assess the solar potential of six (6) location in

Nigeria. In measuring the accuracy of satellite solar data, Kassem et al., (2020) compared the satellite imagery solar data with actual measured global solar radiation of Northern Cyprus and the result shows less significant differences. Similarly, many studies were conducted in this regards. In classifying the solar potential, Prăvălie et al., (2019) solar energy potential spatial assessment scale (Table 3.3).

**Table 3. 3**: Prăvălie et al. (2019) classification of solar potential on the basis of annual GHI and DNI. (Prăvălie et al., 2019)

| Class | Annual GHI ($kWh/m^2$) | Annual DNI ($kWh/m^2$) |
|---|---|---|
| 1 (Poor) | <1191.8 | <936.9 |
| 2 (Marginal) | 1191.8-1419.7 | 936.9-1255.7 |
| 3 (Fair) | 1419.7-1641.8 | 1255.7-1546.8 |
| 4 (Good) | 1641.8-1843.8 | 1546.8-1840.9 |
| 5 (Excellent) | 1843.8-2035.9 | 1840.9-2149.9 |
| 6 (Outstanding) | 2035.9-2221.8 | 2149.9-2533.7 |
| 7 (Superb) | >2221.8 | >2533.7 |

**B. Solar Radiation Data**

The important parameters considered when designing a PV power plant (Owolabi et al., 2019; Kassem et al., 2020) are:

Power generating factor (FGE) expressed in Equation 3.20:

$$PGE = \frac{(Solarirradiance)(Sunshinehours)}{Standard\ test\ condition\ irradiance} \quad (3.20)$$

The energy required from solar PV (EPV) expressed in Equation 3.21:

$$EPV = Peak\ energy\ requirement * Energy\ lost\ in\ the\ system \quad (3.21)$$

Sizing PV module expressed in Equation 3.22 and 3.23:

$$PGE = \frac{EPV}{panel\ generation\ factor} \quad (3.22)$$

$$Sizing\ PV\ module = \frac{Total\ Watt\ peak\ rating}{PV\ output\ power\ rating} \quad (3.23)$$

Sizing inverter; a function of the peak energy requirement and the factor of safety (FS) (Hussein et al., 2013), and it's computed in Equation 3.24:

$$IV = \text{Peak energy requirement } * FS \quad (3.24)$$

Where, FS= 1.3 (Chandel, et al., 2014)

### 3.1.3. Proposed Wind/PV System Specifications

This section contains an economic study of 50 MW wind/PV systems linked to the grid for all locations. In installing power plant technology in Nigeria, the investors are gratified with ample direct and indirect subsidies and for any new renewable energy projects to qualify for this Nigerian governments' subsidy or financial support; the project has to fit into tax or investment credit or favourable feed-in tariffs (FiTs) regulation (German Solar Association, 2018). The Fit regulation is the regulation approved in 2015 and enforced in 2016 by the federal government of Nigeria which provide added benefit to the solar, wind, all biomass and small schemes hydropower plant not exceeding 30 MW. Through this regulation, the government is obliged to purchase 50% while the investors should find the remaining 50%. However, with the power purchase agreements (PPAs) 2016 more than 30 MW power plant can also benefit from FiT but in a highly competitive bid process (German Solar Association, 2018). In case this study might be considered for real-life implementation in the future, the investors are provided with techno-economic feasibility of PV/wind power plant that can easily help them qualify for FiT benefit when auction.

The roof top grid-connected 148.5kWp Photovoltaic System for Energy Storage for usage in a Local Government office in Nigeria carried out by Johnson and Ogunseye (2017) was the kind of grid-connected PV/wind power plant that had limited investigations. While for the techno-economic validation or economic feasibility among the few studies found are 10-250 kW off-grid PV power plant, 2MW embedded PV power plant, 100 kW-1.5MW captive diesel-PV hybrid power plant and 25-50 MW PV power plant (German Solar Association, 2018).

This study of the economic feasibility of the proposed PV/wind projects in Nigeria determined using RETScreen software (discussed in the previous chapter).

**A. Grid-connected wind farm with a capacity of 50 MW.**

It is often considered that the larger wind turbines improve power output effectively and cheaply when selecting a wind turbine for a wind power plant project. A study by Sedaghat et al, (2018) reveals that the greater annual energy generation (AEP) and capacity factor (CF) of wind turbines may be implemented. Three (3) wind turbines used by previous studies, and considered for ongoing project in Katsina state (Dioha et al. 2016; Salisu and Garba, 2013) also considered in this study. The three (3) modules are: ENERCON-82 E2-85m, VESTAS V80-2.0MW-60m and VERGENT GEV MP R 30/275-32m. The number of turbines needed for the project are 22, 25 and 182 respectively. Tables 3.4 indicate the specified module.

**B. 50 MW Grid-Connected PV Plant**

Based on previous studies (Ogunseye, 2017; Musa et al., 2016; Owolabi et al., 2019) there is no specific PV module recommended for Nigeria or been used in the country, the selection of PV modules varies by studies. Therefore, the projected 50 MW PV project and its performance were assessed utilizing three PV technologies, specifically Mono-Si and Poly-Si of Risen, Sharp-Solar, China-Sunenergy and Yingli Solar, Mono-Si of Sunpower and CdTe of First-Solar, available in Nigeria and employed by Kassem, et al. (2020), Owolabi (2019) and Ikeagwumi et at. (2015). The 50 MW grid-connected PV plant in the relevant region was to be constructed using between 144,928 and 500,000 aforementioned modules. The area needed for these modules has been estimated between 232,559 and 359,971 square meters depending on the module. In addition to this, the proposed PV system is considered a SMA Sunny 2500-EV inverter with a total capacity of 2500 kW. Tables 3.4 and Table 3.5 indicate the specified module and inverter specifications.

**Table 3. 4:** Parameters for the PV and Wind Turbine Modules

| PV Modules | | | |
|---|---|---|---|
| **Parameters** | **Mono-si** | **Poly-si** | **CdTe** |
| Manufacturer | Canadian Solar | Canadian Solar | First Solar |

**Table 3.4. continued**

| **Parameters** | **Mono-si** | **Poly-si** | **CdTe** |
|---|---|---|---|
| Model | Mono-si-CS6X-300M | Poly-si-CS6X-310P | CdTe-FS-4100 |
| Nominal Power (W) | 300 | 310 | 100 |
| Open-Circuit Voltage (V) | 45 | 44.9 | 87.6 |
| Short-Circuit Current (A) | 8.74 | 9.08 | 1.57 |
| Voltage at Point Maximum Power (V) | 36.5 | 36.4 | 69.4 |

| | | | |
|---|---|---|---|
| Current at Point Maximum Power (A) | 8.22 | 8.52 | 1.44 |
| Module Area ($m^2$) | 1.919 | 1.918 | 0.72 |
| Efficiency (%) | 15.63 | 16.16 | 13.89 |
| Warranty (Year) | 25 | 25 | 25 |
| **Parameters** | **Mono-si** | **Poly-si** | **Mono-si** |
| Manufacturer | Risen | Risen | Sharp |
| Model | Mono-si-SYP310M-310W | Poly-si-SYP310S-310W | Mono-Si-NU-U240F1 |
| Nominal Power (W) | 310 | 310 | 240 |
| Open-Circuit Voltage (V) | 36 | 36 | 37.0 |

**Table 3.4. continued**

| **Parameters** | **Mono-si** | **Poly-si** | **CdTe** |
|---|---|---|---|
| Short-Circuit Current (A) | 8.61 | 8.61 | 8.65 |
| Voltage at Point Maximum Power (V) | 44.8 | 44.8 | 30.1 |
| Current at Point Maximum Power (A) | 9.22 | 9.22 | 7.98 |
| Module Area ($m^2$) | 0.28 | 0.28 | 2.67 |
| Efficiency (%) | 15.98 | 15.98 | 14.7 |

| | | | |
|---|---|---|---|
| Warranty (Year) | 25 | 25 | 25 |
| Parameters | Poly-si | Mono-si | Poly-si |
| Manufacturer | Sharp | China Sunergy | China Sunergy |
| Model | Poly-si-NE-Q5E3H | Mono-si-CSUN320-72M | Poly-Si-CSUN310-72P |
| Nominal Power (W) | 240 | 320 | 310 |
| Open-Circuit Voltage (V) | 37.0 | 45.9 | 44.8 |
| Short-Circuit Current (A) | 8.65 | 9.01 | 9.04 |
| Voltage at Point Maximum Power (V) | 30.1 | 37.4 | 36.1 |
| Current at Point Maximum Power (A) | 7.98 | 8.56 | 8.58 |

**Table 3.4. continued**

| **Parameters** | **Mono-si** | **Poly-si** | **CdTe** |
|---|---|---|---|
| Module Area ($m^2$) | 2.67 | 1.94 | 1.94 |
| Efficiency (%) | 14.7 | 16.63 | 16 |
| Warranty (Year) | 25 | 25 | 25 |
| Parameters | Mono-si | Mono-si | Poly-si |
| Manufacturer | Sunpower | Yingli Solar | Yingli Solar |

| | | | |
|---|---|---|---|
| Model | Mono-Si-SPR-X21-345-COM | Mono-si-YLM72-YL335D-36b | Poly-Si-YGE 72-YL335P-35b |
| Nominal Power (W) | 345 | 335 | 335 |
| Open-Circuit Voltage (V) | 68.2 | 46.9 | 46 |
| Short-Circuit Current (A) | 6.39 | 9.32 | 9.35 |
| Voltage at Point Maximum Power (V) | 57.3 | 37.6 | 37.6 |
| Current at Point Maximum Power (A) | 6.02 | 8.91 | 8.91 |
| Module Area ($m^2$) | 1.63 | 0.314 | 0.314 |
| Efficiency (%) | 21.5 | 17.23 | 17.23 |
| Warranty (Year) | 25 | 25 | 25 |

**Table 3.4. continued**

**Wind Turbine Module**

| **Parameters** | **Enercon** | **Vestas** | **Vergent** |
|---|---|---|---|
| Manufacturer | Enercon | Vestas | Vergent |
| Model | ENERCON-82 E2-85m | VESTAS V80-2.0MW-60m | VERGENT GEV MP R 30/275-32m |

| | | | |
|---|---|---|---|
| Rated Power (kW) | 2,000 | 2,000 | 275 |
| Rotor Diametre (m) | 85 | 80 | 32 |
| Hub Height (m) | 82 | 60 | 30 |
| Swept Area ($m^2$) | 5,281.02 | 5,026,85 | 804.0 |
| Cut-in Wind Speed (m/s) | 2.0 | 4.0 | 3.5 |
| Rated WindSpeed (m/s) | 12.5 | 15.0 | 12.0 |
| Cut-out Wind Speed (m/s) | 34.0 | 25.0 | 205 |
| Survival Wind Speed (m/s) | - | 60.0 | 52.5 |
| Wind Zone (DIBt) | WZ 4 GK I | - | - |
| Wind Class ($m^2$) | IEC IIA | - | - |

**Table 3. 5**: The Selected Inverter's Technical Specifications

| **Input DC Parameters** | **Values** |
|---|---|
| MPP voltage range $V_{DC}$ (at 25 °C/at 50 °C) | 850 V to 1425 V/1275 V |
| Min. input voltage $V_{DC,min}$/Start voltage VDC,Start | 778 V/878 V |
| Max. input voltage $V_{DC, max}$ | 1500 V |
| Max. input current $I_{DC, max}$ (at 25 °C/at 50 °C) | 3000 A/2700 A |
| Max. short-circuit current rating | 4300 A |

| **Output DC parameters** | **Value** |
|---|---|
| Nominal AC power at cos φ =1 (at 25 °C/at 40 °C/at 50 °C) | 2500 kVA/2350 kVA/2250 kVA |
| Nominal AC power at cos φ =0.8 (at 25 °C/at 40 °C/at 50 °C) | 2000 kW/1880 kW/1800 kW |
| Nominal AC current IAC, nom = Max. output current $I_{AC,\ max}$ | 2624 A |
| Nominal AC voltage / nominal AC voltage range | 550 V/440 V to 660 V |
| Max. efficiency | 98.6% |

**3.2. Economic Analysis**

Different modeling techniques are examined by engineers and researchers or scientists for estimate of wind turbine and PV systems for monthly or yearly power output and the capability factor (Rafique et al., 2018). However, this thesis considers the program RETScreen to assess the technical, economic and environmental impacts of solar projects for the relevant Nigerian states, since this is the ideal instrument for the analysis and assessment of the viability of a RE grid-connected system (Rafique et al., 2018). Furthermore, the program RETScreen can estimate yearly and monthly generation of energy and the capacity of the installed system, using input data. The main economic metrics in this thesis were therefore calculated using the program RETScreen, for example the net current value (NPV), the internal rating of return (IRR), the levellised energy cost (LCOE), the payback time (PB), annual life cycle saving (ALCS), and the profit-cost ratio (B-C) expressed in Equation 3.25-3.32.

NPV,

$$NPV = \sum_{n=0}^{N} \frac{C_n}{(1+r)^n} \tag{3.25}$$

LCOE,

$$LCOE = \frac{Total\ cost\ over\ lifetime}{Total\ electricity\ generated\ over\ the\ lifetime} \tag{3.26}$$

IRR,

$$O = \sum_{n=0}^{N} \frac{C_n}{(1+IRR)^n} \tag{3.27}$$

payback period (SP),

$$SP = \frac{C - IG}{(C_{ener} + C_{capa} + C_{RE} + C_{GHG}) - (C_{o\&M} + C_{fuel})} \tag{3.28}$$

Equity Payback (EP),

$$EP = \sum_{n=1}^{2020} C_n \tag{3.29}$$

ALCS,

$$ALCS = \frac{NPV}{\frac{1}{r}\left(1 - \frac{1}{(1-r)^N}\right)} \tag{3.30}$$

GHG emission reduction (GRC):

$$GRC = \frac{ALCS}{\Delta_{GHG}} \tag{3.31}$$

B-C:

$$B - C = \frac{NPV + (1-f_d)C}{(1-f_d)C} \tag{3.32}$$

Where N is the lifetime of the project in years; $C_n$ is the cash flow for year n after tax; r is the rate of discount; C represents the project's entire starting cost; $f_d$ is the ratio of debt; B is the overall project benefit; Incentives and subsidies are the IG; Annual savings in energy or revenue are $C_{ener}$; Annual savings or revenue capacity; $C_{capa}$; The yearly credit for generation of renewable energy (RE) is $C_{RE}$; $C_{GHG}$ is the income to decrease GHG; $C_{O\&M}$ is the annual renewable energy project operating and maintenance costs; The yearly costs for fuel for renewable projects are $0; the alternative to GHG is the yearly decrease of GHG emissions.

Initial expenses, periodic cost (Table 3.7) and financial parameters (Table 3.8) required for the implementation of the economic feasibility analysis of a project for renewable energy using a RETScreen. Therefore, the high value of uncertainty is globally recognized in relation to these parameters. Therefore, the values used herein are primarily used for the execution of the financial indicators rather than for the accuracy of the financial indicator values, which, even if reliable input data is used, would suffer from uncertainty (EL-Shimy, 2008). An 80% investment loan with a 9% debt interest rate (Table 3.6) is included in this thesis's feasibility study of the planned 50 MW grid-connected PV system, taking into account the ongoing investment practice in Nigeria (German Solar Association, 2018).

**Table 3. 6**: PV/Wind Power Plant Initial and Periodic Costs

| **Description of the Cost Item** | **Total cost (%)** |
|---|---|
| **Initial Cost Items** | |
| Feasibility Study | 0.2% |
| Development | 0.2% |
| Engineering Design | 0.2% |
| PV/Turbine | 70.4% |

| | |
|---|---|
| System Balance | 24.0% |
| Miscellaneous | 5.0% |
| Sum of Initial Cost | 100% |

**Table 3. 7**: Financial Parameters

| **Parameter Description** | **Value (%)** |
|---|---|
| Inflation Rate | 2% |

**Table 3.7. continued**

| **Parameter Description** | **Value (%)** |
|---|---|
| Discount Rate | 12% |
| Life-spam of the Project | 25 year |
| Rate of Debt | 80% |
| Interest Rates on Debt | 9% |
| Loan Tenor | 10 year |
| Electricity Export Escalation Rate | 10% |

# CHAPTER 4

# RESULTS AND DISCUSSION

## 4.1. Potential of Wind Energy

### 4.1.1. Characteristics of Wind Speed

Based on the previous studies (Okoye et al., 2020; Abdullahi and Bashir, 2019; Audu et al., 2019; Oyewole and Aro, 2018; Owoeye et al., 2017; Solomon and Sunday, Olomiyesan et al., 2017; Dogara et al., 2016; 2015; Usman et al., 2014; Ahmed et al., 2014; Dan-Isa and Kadandani, 2013; Ahmed et al., 2013; Ohunakin et al., 2012; Ohunakin, 2011), Figure 4.1 depicts the data of the average monthly wind speed for all the selected locations. The Plateau State and Adamawa State reported to have the average maximum and minimum annual wind speeds of 9.828 m/s and 1.788 m/s, respectively (Table 4.1). The Plateau state highest and lowest average wind speeds in the Plateau State were reported in December (11.1 m/s) and September (7.95 m/s), respectively. Furthermore, the average monthly wind speeds for Adamawa, Kogi, Abuja, Kebbi, Niger, Bauchi, Kwara, Benue were between 1.788 and 4.77 m/s. Additionally, the minimum and maximum monthly mean wind speeds for Zamfara were 7.39 and 3.5833 m/s, Kaduna was 8.6 and 5.34 m/s, Sokoto was 8.95 and 5.26 m/s, Katsina was 9.84 and 5.344 m/s, Yobe was 9.07 and 6.29 m/s and Kano was 10.53 and 7.16 m/s (Figure 4.1). Furthermore, the highest wind recorded between December and August (Figure 4.2) in all the selected location, the highest wind speed occurred during April with 6.32m/s average while the lowest wind speed recorded during October with 4.42 m/s average wind speed (Figure 4.2).

The suitability of the selected location for exploiting wind as a source energy to meet the Nigerian need for power, the mean annual data on wind speed at 10 m height for all chosen locations are classified using wind power class (WPC) shown in Table 4.1. The following states identified not suitable for wind energy exploitation based on WPC (Kalmikov, 2017): Abuja, Adamawa, Bauchi, Benue, Kebbi, Kogi, Kwara and Niger. While Borno State classified marginal. However, the states that belong to suitable classes are as follows, Zamfara classified excellent, Kaduna, Kano, Katsina, Sokoto and Yobe classified outstanding, while Plateau State classified superb.

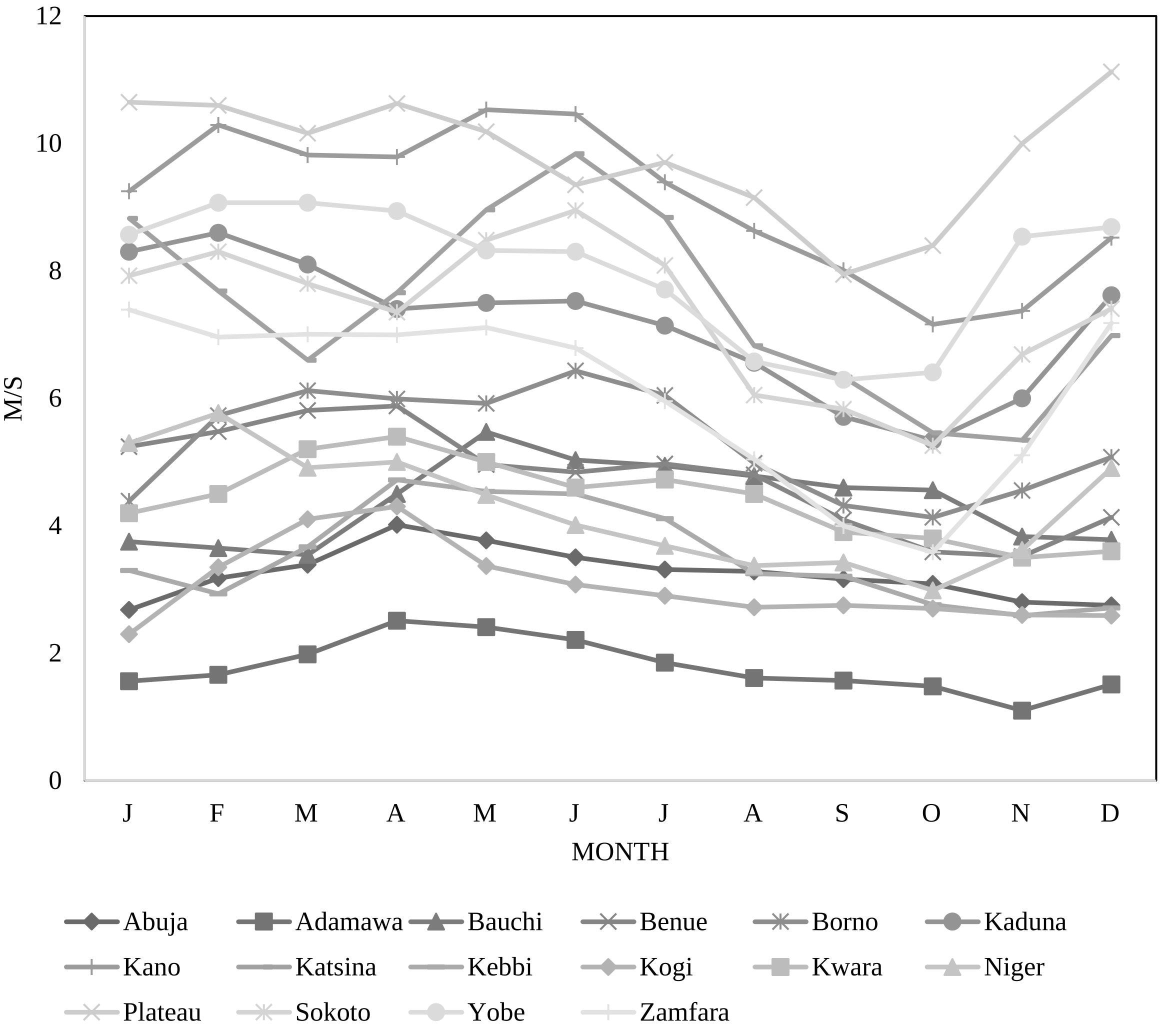



**Figure 4. 1**: Monthly Mean Wind Speed for Selected Nigerian Locations

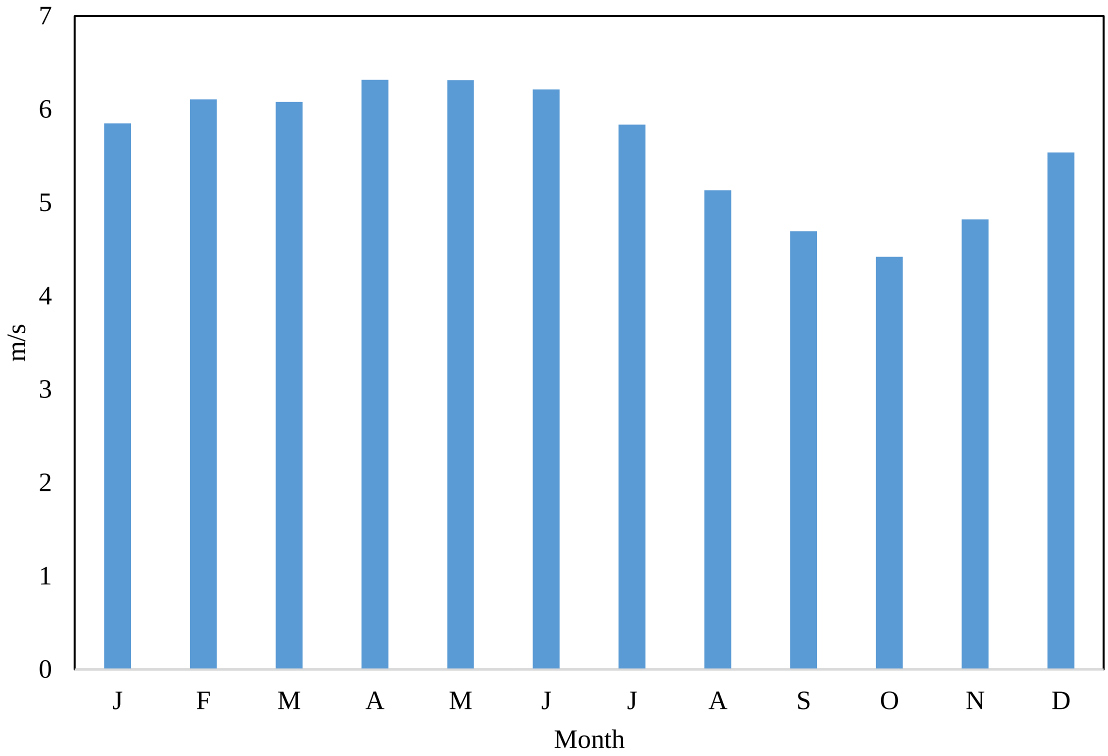



**Figure 4. 2**: Statistic Summary of Wind Speed in Nigeria at Selected Locations

**Table 4. 1**: Wind Power Class for the Selected Locations

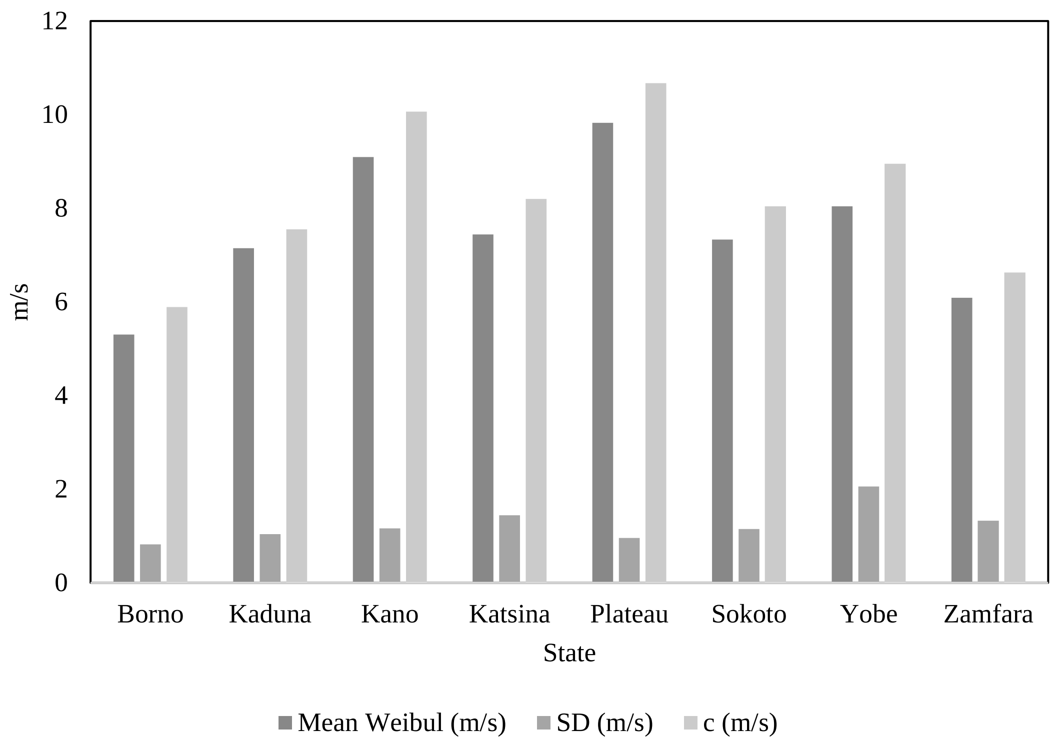
| Location | Wind Speed (m/s) | Classification |
|---|---|---|
| Abuja (FCT) | 3.245 | Not Suitable |
| Adamawa | 1.788 | Not Suitable |
| Bauchi | 4.37 | Not Suitable |
| Benue | 4.77 | Not Suitable |
| Borno | 5.307 | Marginal |

**Table 4.1. continued**

| Location | Wind Speed (m/s) | Classification |
|---|---|---|
| Kaduna | 7.15 | Outstanding |
| Kano | 9.102 | Outstanding |
| Katsina | 7.4461 | Outstanding |
| Kebbi | 3.524 | Not Suitable |
| Kogi | 3.063 | Not Suitable |
| Kwara | 4.411 | Not Suitable |
| Niger | 4.289 | Not Suitable |
| Plateau | 9.828 | Superb |
| Sokoto | 7.34 | Outstanding |
| Yobe | 8.041 | Outstanding |
| Zamfara | 6.0931 | Excellent |

#### 4.1.2. Wind Power Density and Weibull Parameters Determination at a Height of 10 m

Based on WPC (Table 4.1), eight locations; Zamfara, Kaduna, Katsina, Sokoto, Yobe, Kano and Plateau and Borno states identified as the suitable locations where wind can be exploited for high-energy production, i.e. for high-capacity wind turbines (MWs) or future wind power plant installation in Nigeria. The Weibull parameter means the velocity of Kano and Plateau State's wind speed adapted from the previous study, the standard deviation estimated using Eviews software and the estimated wind power density is illustrated in Figure 4.3. The results indicated that Plateau and Kano States has WPD of 647 W/m$^2$ and 554 W/m$^2$ respectively.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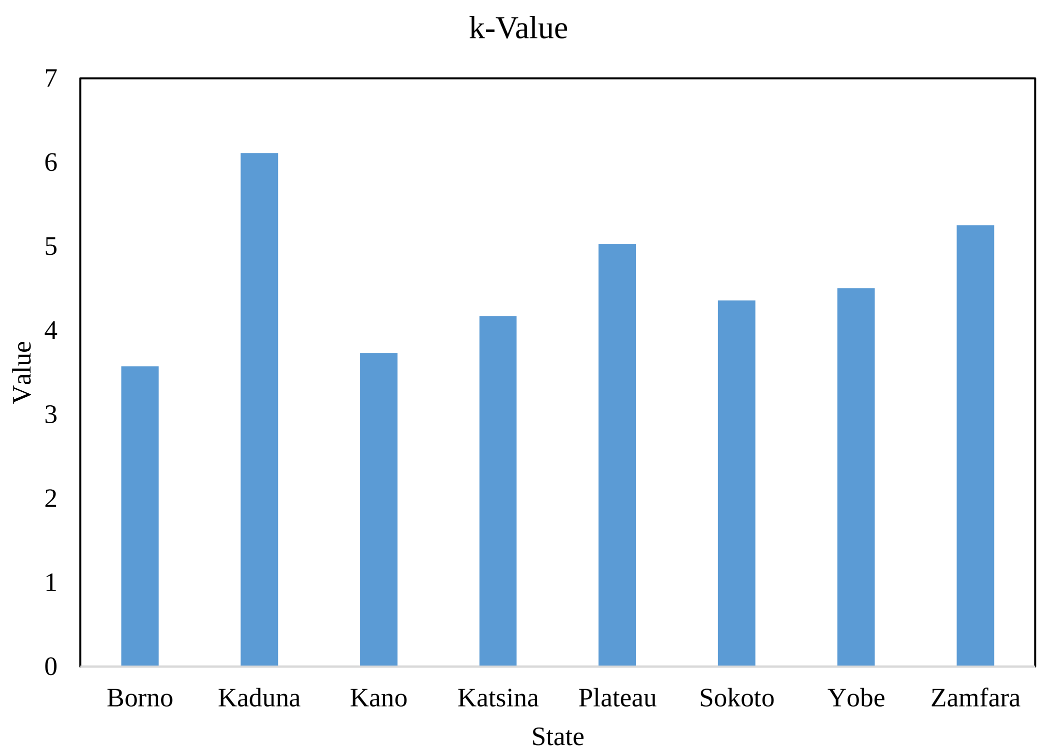
6
4
2
0
m/s
Borno
Kaduna
Kano
Katsina
Plateau
Sokoto
Yobe
Zamfara
State
Mean Weibul (m/s)
SD (m/s)
c (m/s)


k-Value
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Value
Borno
Kaduna
Kano
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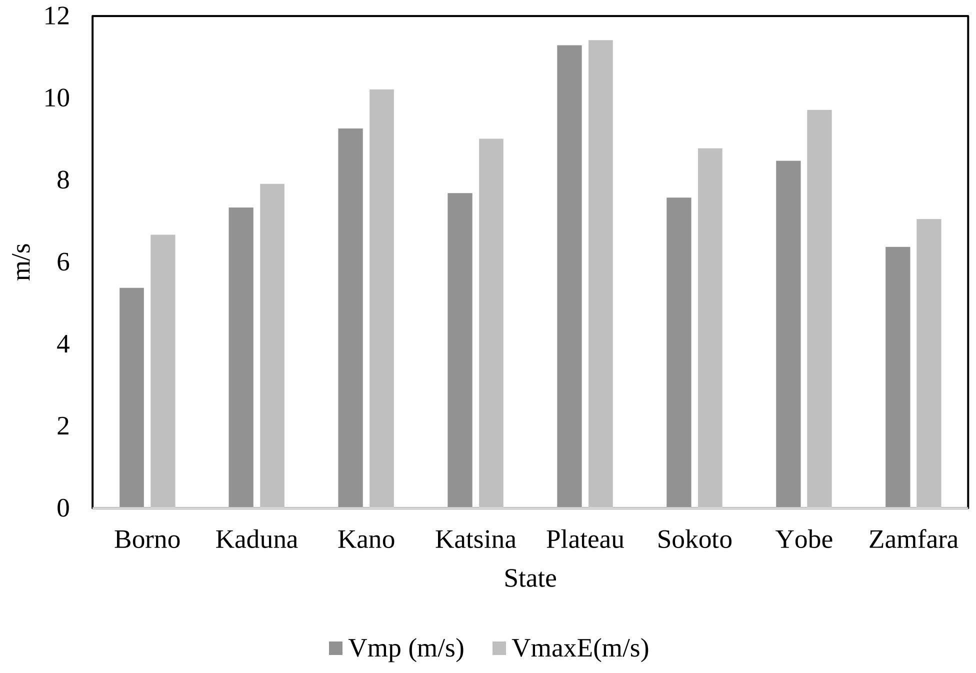
Plateau
Sokoto
Yobe
Zamfara
State



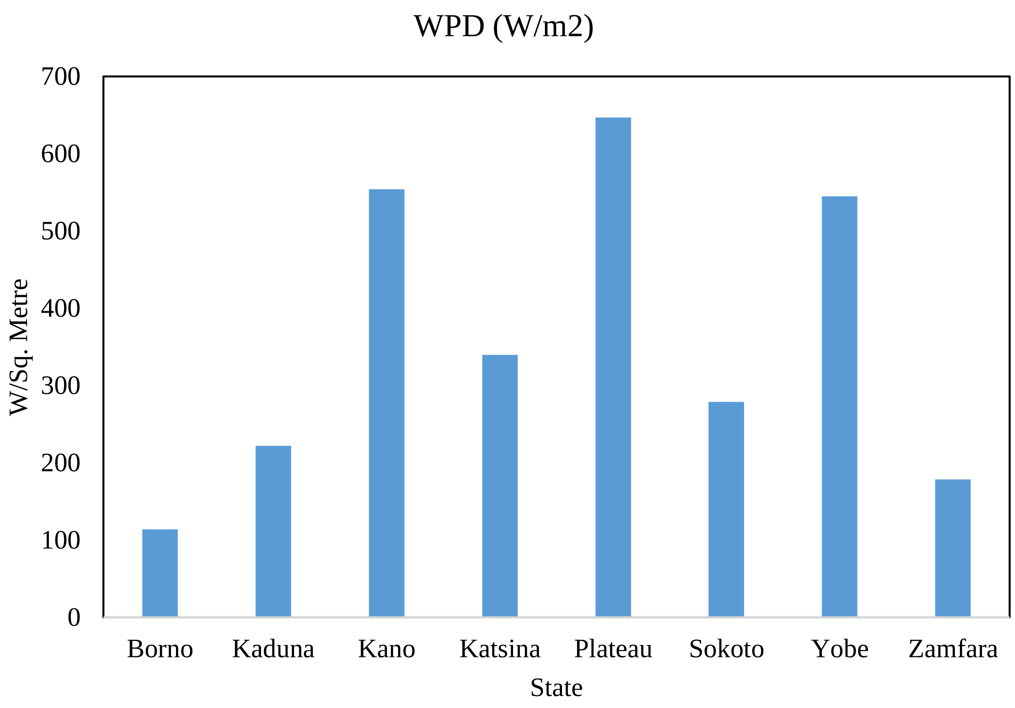



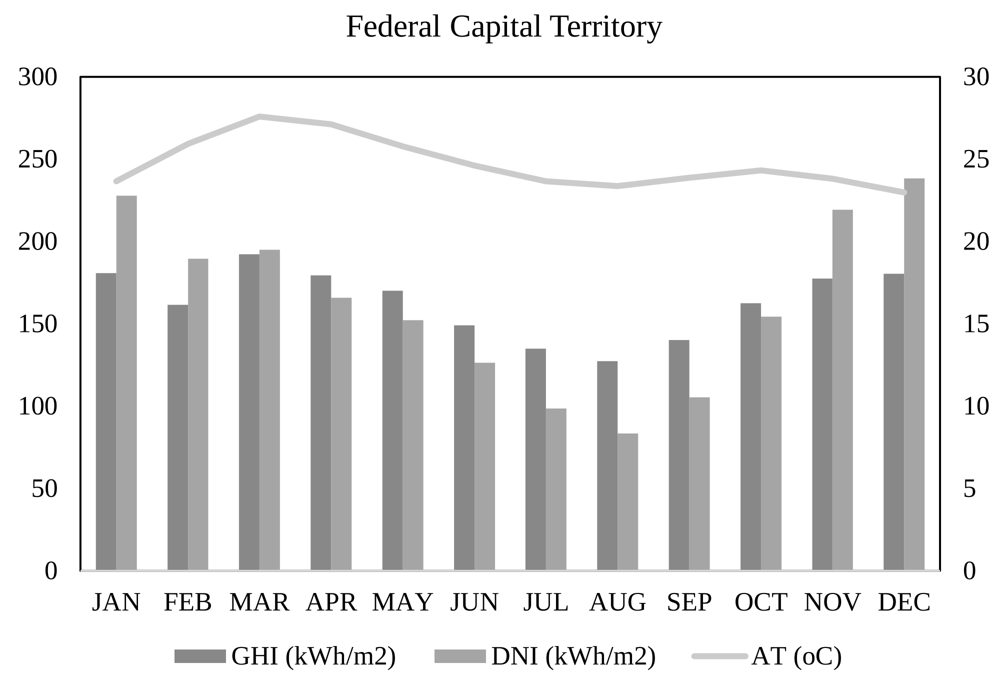

**Figure 4. 3:** Weibull Parametre

### 4.2. Potential of Solar Energy

In measuring the potential of solar energy for the selected study areas, the two Prăvălie et al., (2019) solar energy potential spatial assessment scale; GHI and DNI addition to air temperature (AT) which is essential for estimating the system performances (Kassem et al., 2020) are considered in this study.

#### 4.2.1. Global Solar Characteristics

Based on the monthly mean GHI, DNI, and AT of the selected study areas illustrated in Figure 4.4, the monthly mean GHI, DNI and AT received by all selected location are illustrated in Figure 6, Sokoto state and Kogi State identified highest and lowest GHI and DNI respectively (Figure 4.5). The highest and lowest GHI values recorded were 186.57 kWh/m$^2$ and 152.32 kWh/m$^2$ respectively. While the highest and lowest DNI values recorded were 211.69 kWh/m$^2$ and 140.41 kWh/m$^2$ respectively. In addition to solar irradiation, the maximum and minimum air temperatures value obtained identified Sokoto state with the highest average monthly AT of 27.92 $^o$C while Plateau state identified with the lowest average monthly AT of 22.96 $^o$C (Figure 4.5). Furthermore, the highest GHI event occurred between March and May, the mean maximum and minimum values; 197.3 kWh/m$^2$ and 146.42 kWh/m$^2$ recorded during May and August every year, while the highest DNI event occurred between November and May, the mean maximum and minimum values; 218.82 kWh/m$^2$ and 111.27 kWh/m$^2$ recorded during December and August every year (Figure 4.6). In addition to solar irradiation, the highest air temperature (AT) event occurred between February and October, the mean maximum and minimum AT value; 29.61 $^o$C and 22.73 $^o$C were recorded during March and December every year (Figure 4.6). Moreover, the total monthly GHI and DNI received in all selected location are illustrated in Figure 4.7, the highest and lowest GHI received during March and August with a total of 3156.73 kWh/m$^2$ and 2342.67 kWh/m$^2$ respectively. While the highest and lowest DNI received during December and August with a total of 3501.14 kWh/m$^2$ and 1780.33 kWh/m$^2$ respectively.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GHI (kWh/m2)
DNI (kWh/m2)
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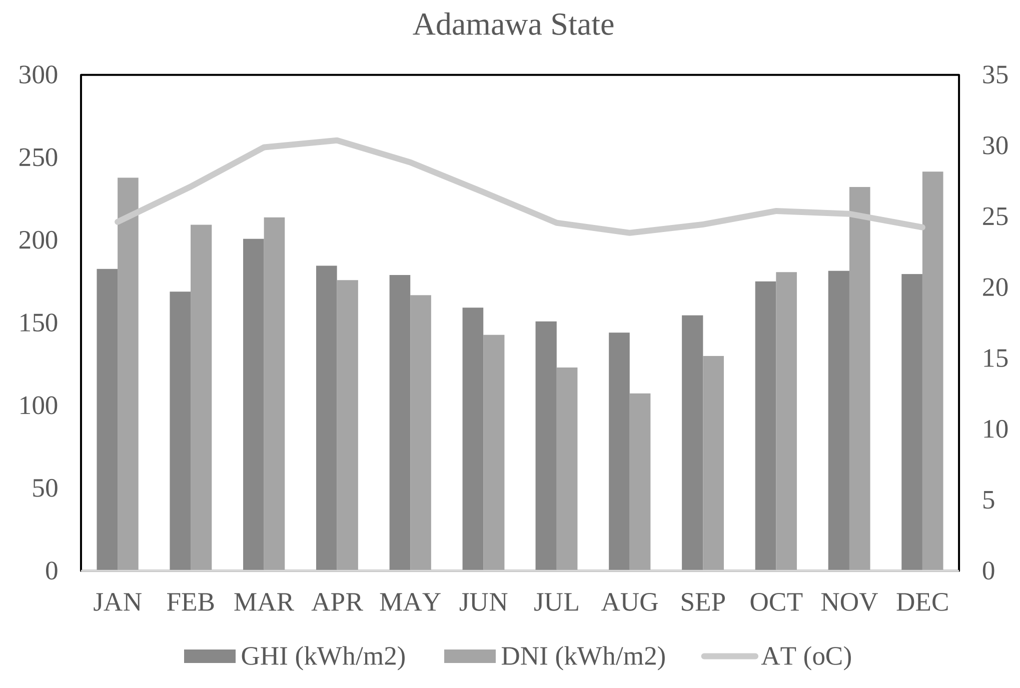
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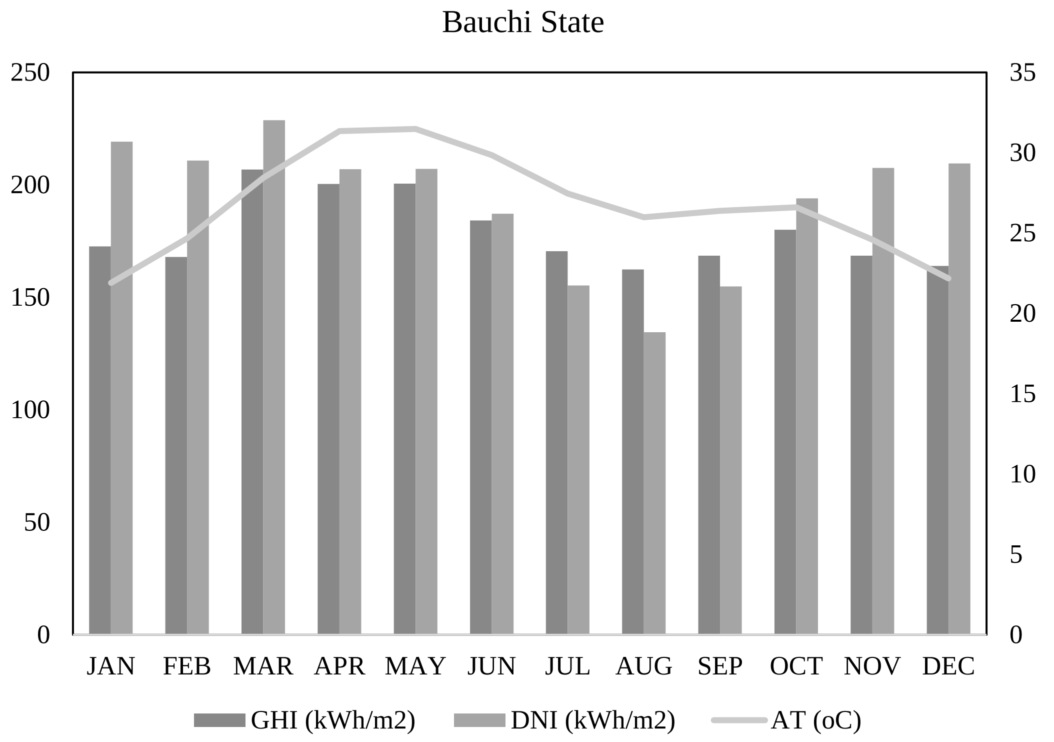
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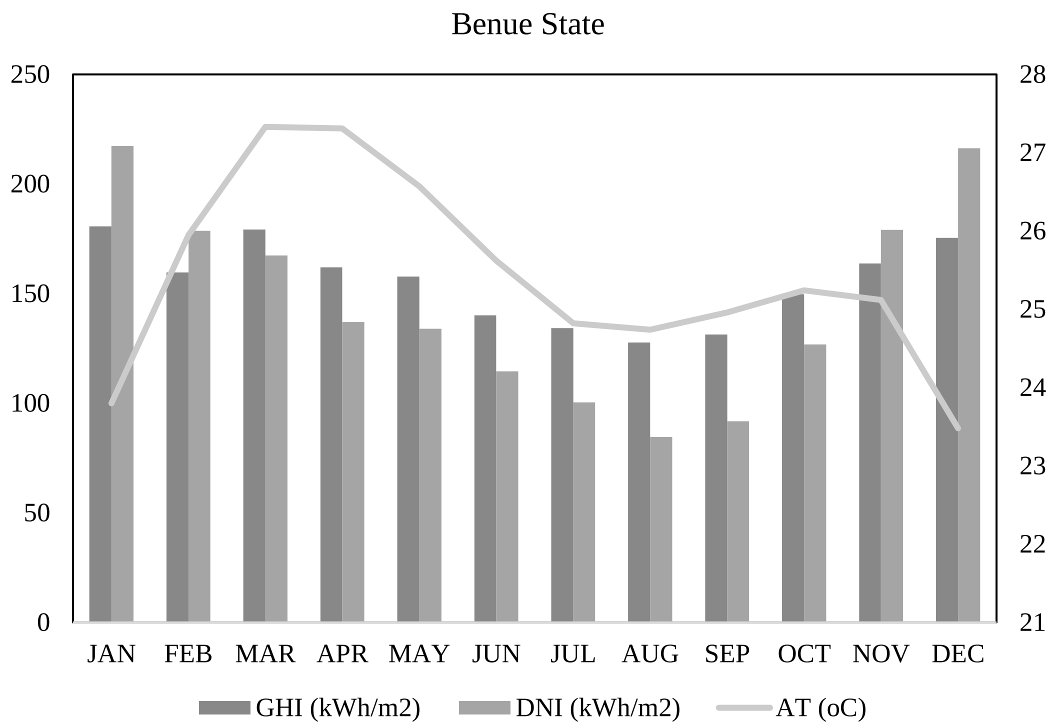
GHI (kWh/m2) DNI (kWh/m2) AT (oC)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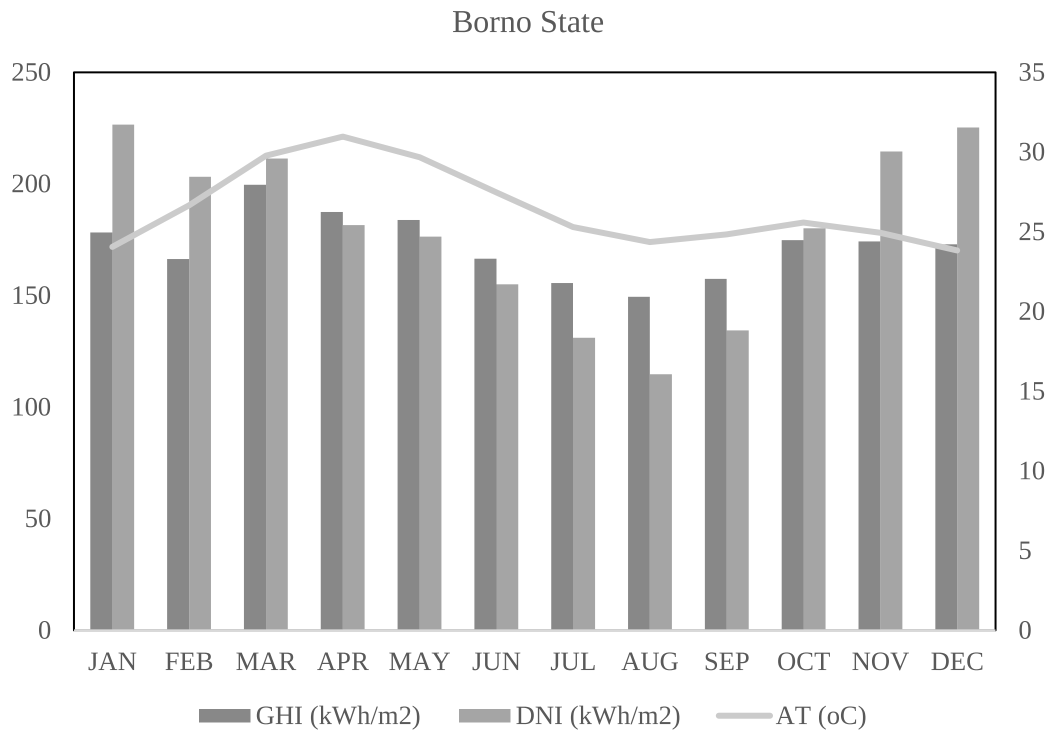
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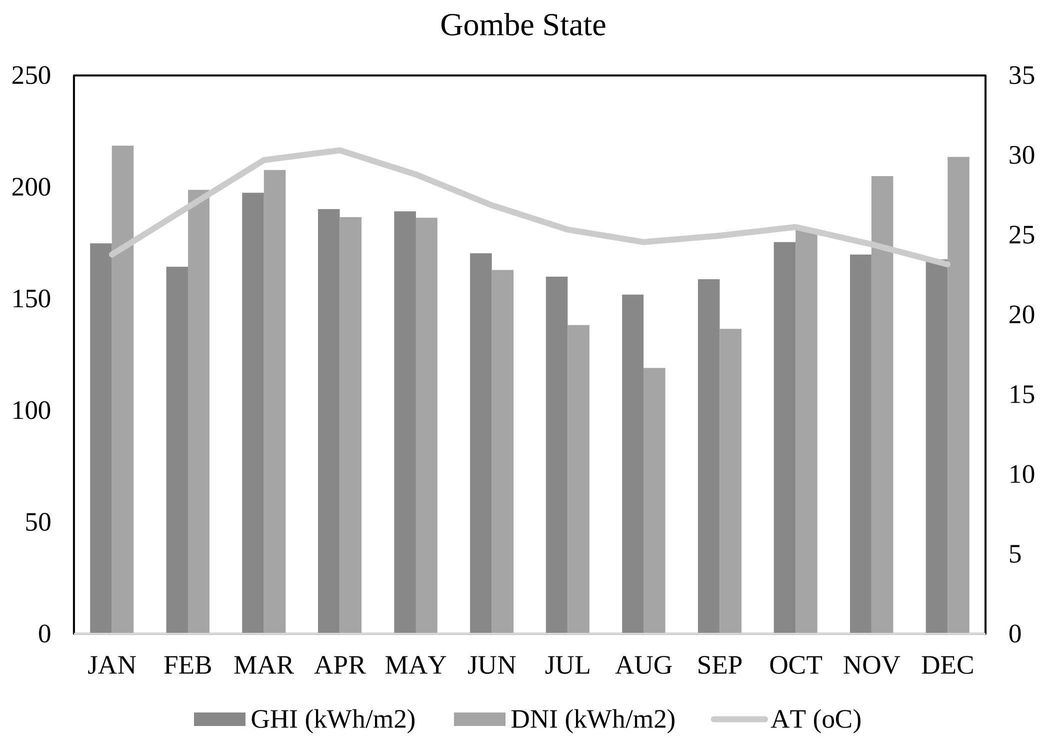
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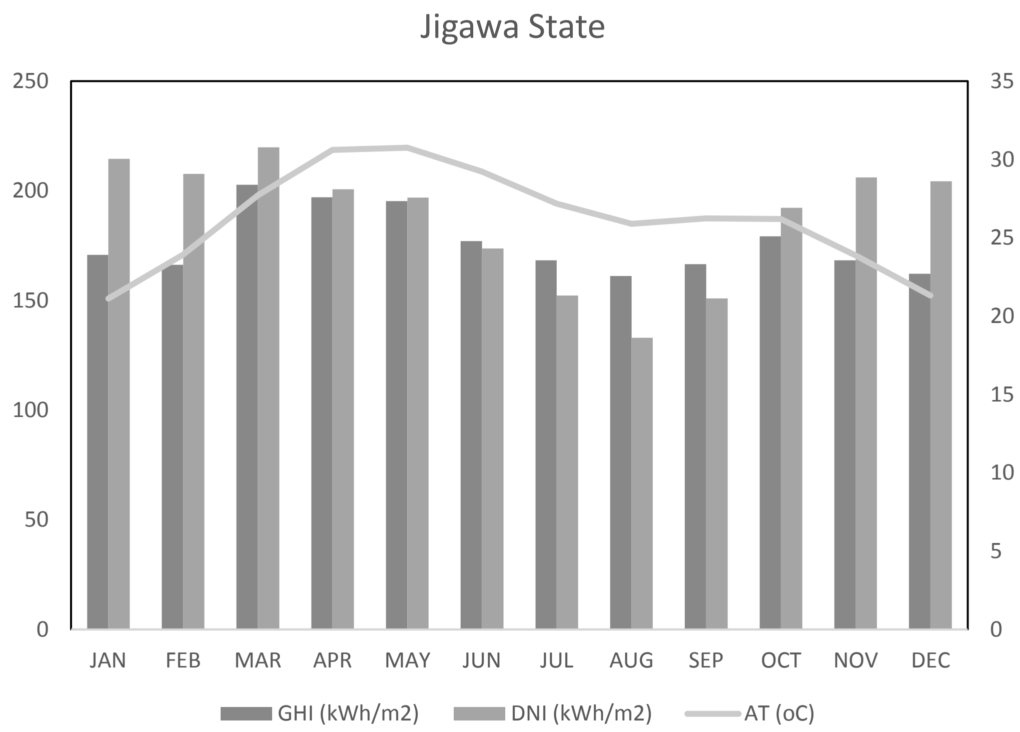
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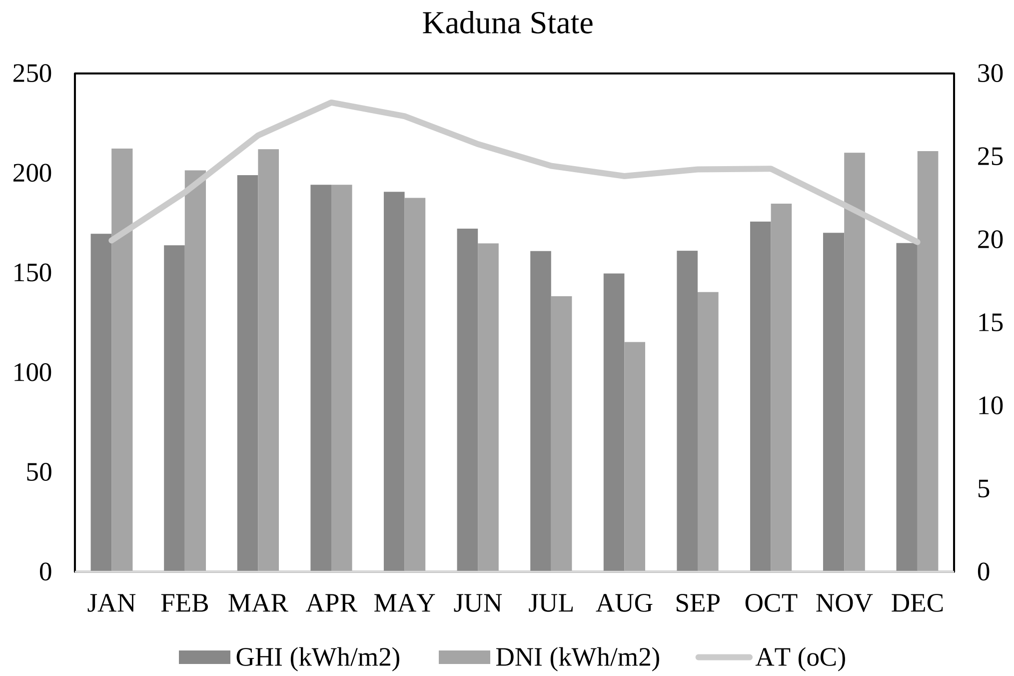
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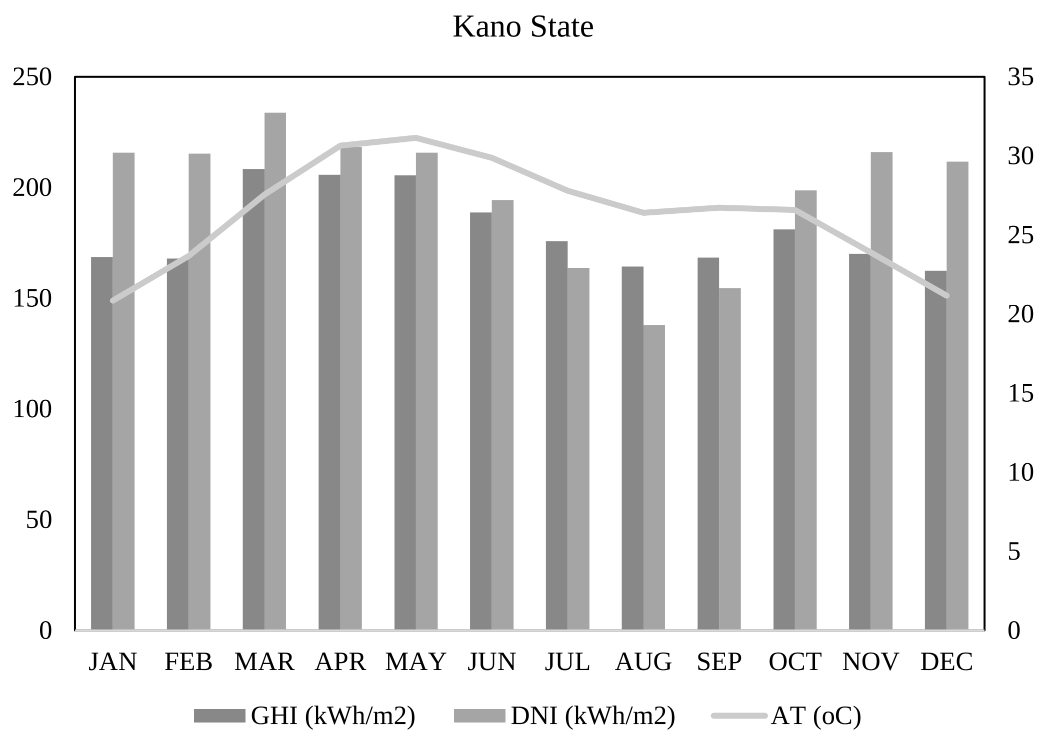
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DNI (kWh/m2)
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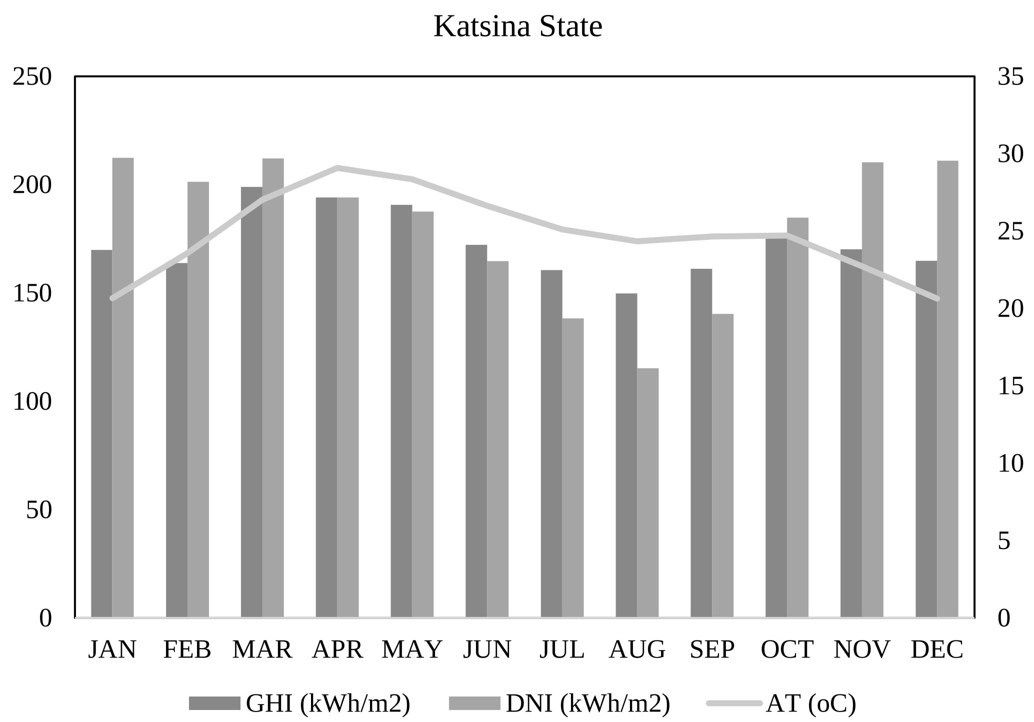
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DNI (kWh/m2)
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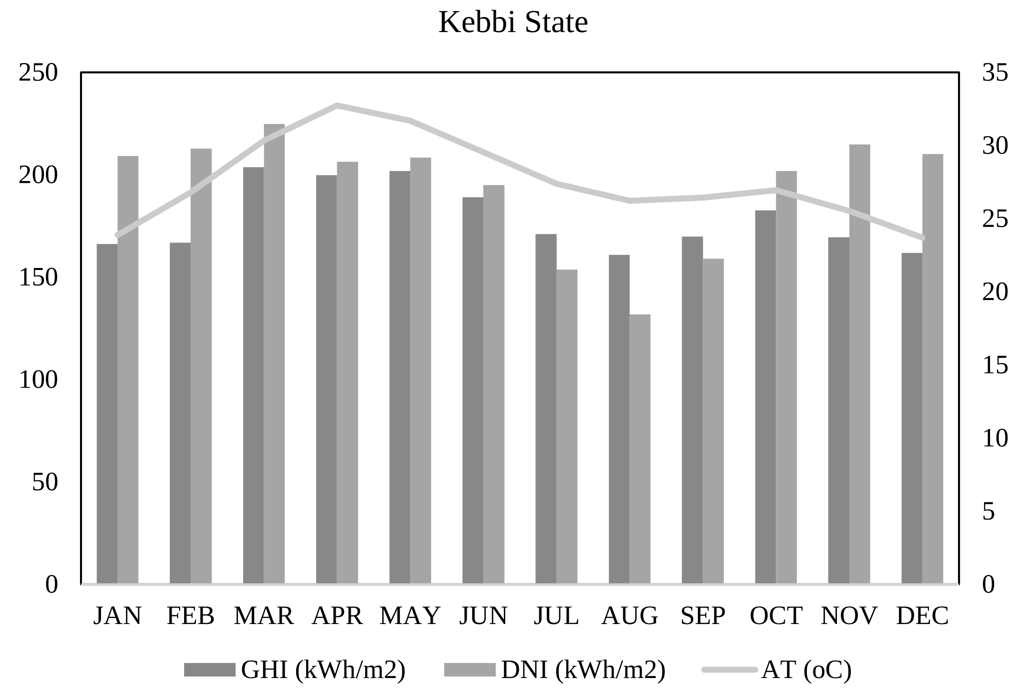
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DNI (kWh/m2)
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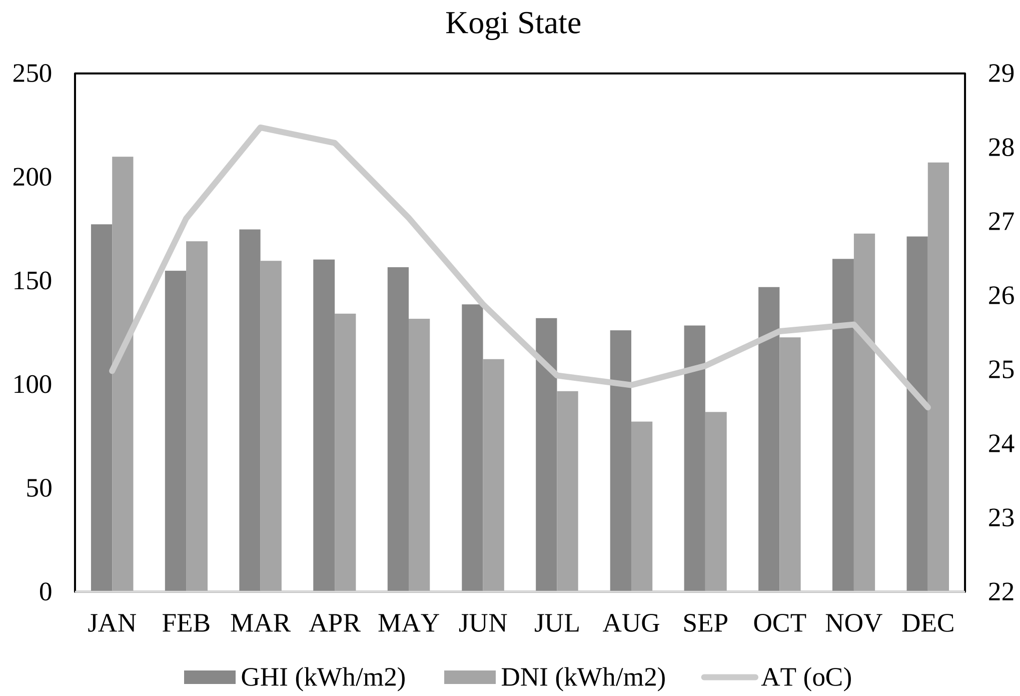
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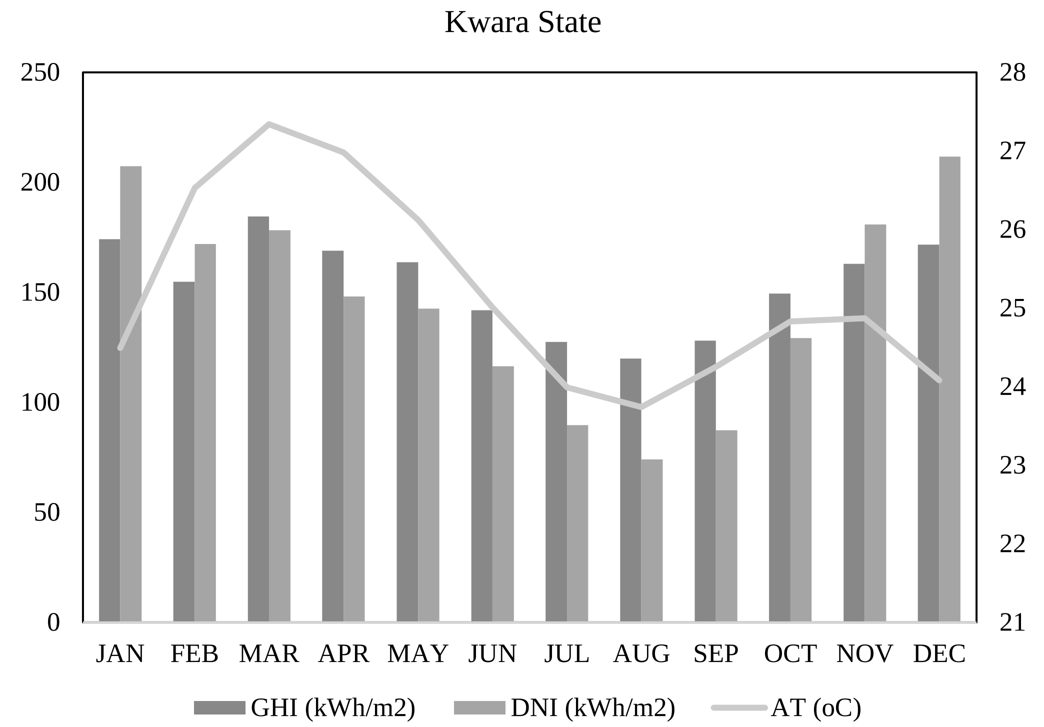
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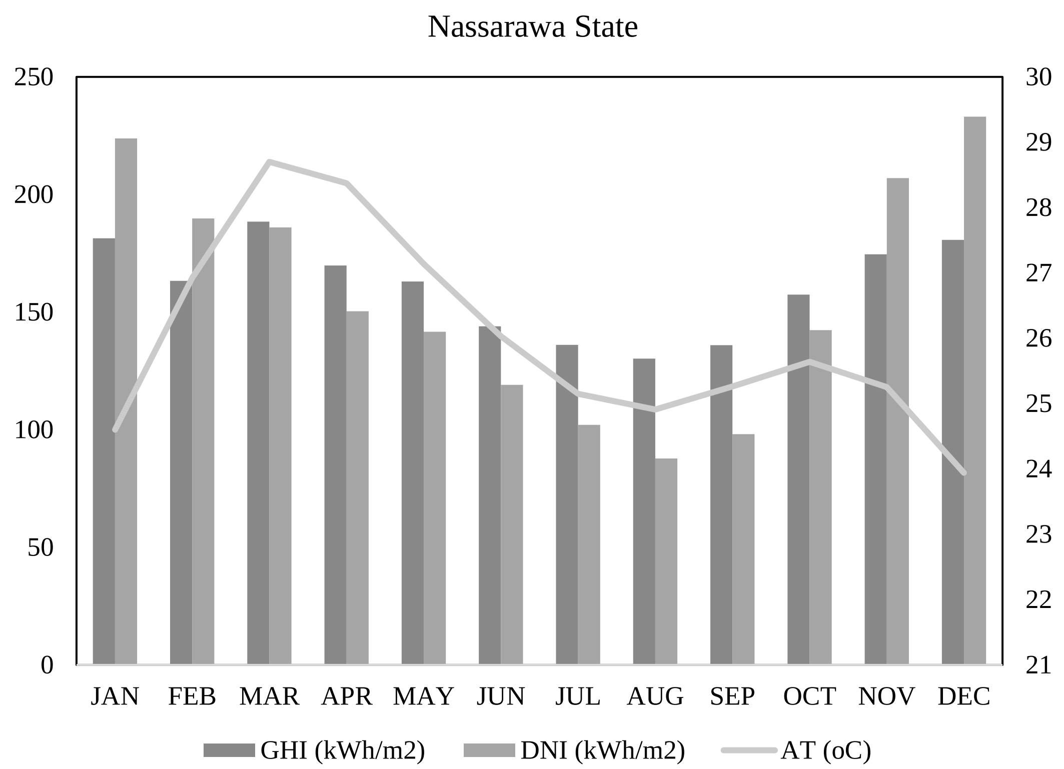
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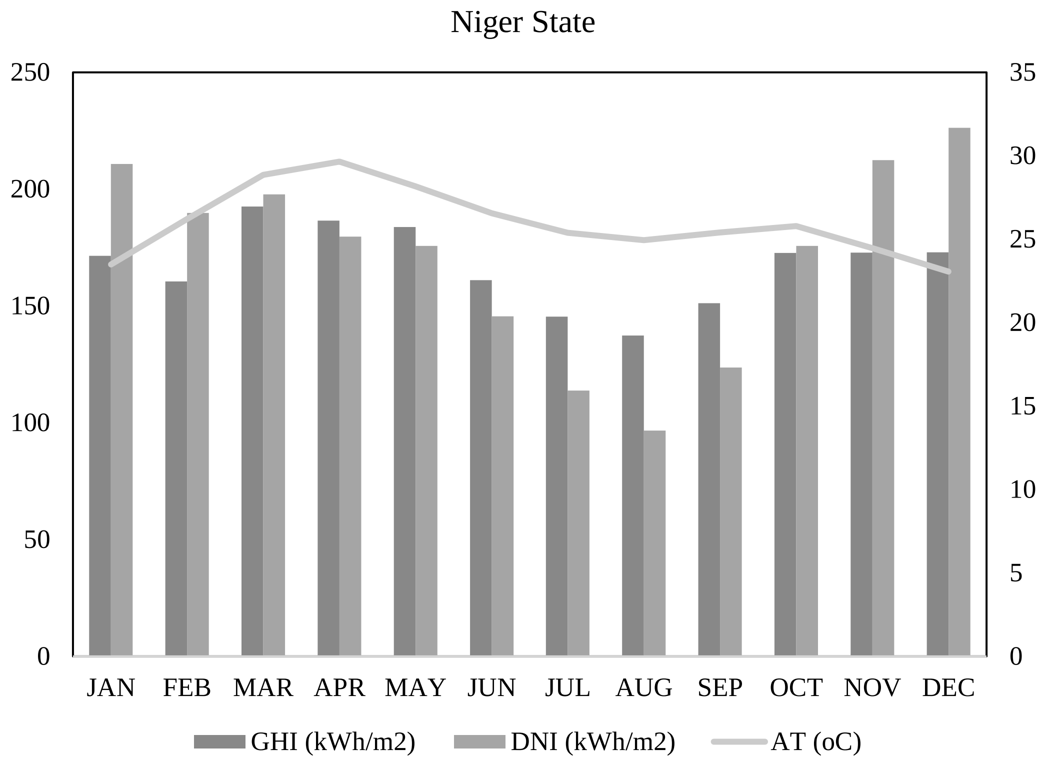
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GHI (kWh/m2)
DNI (kWh/m2)
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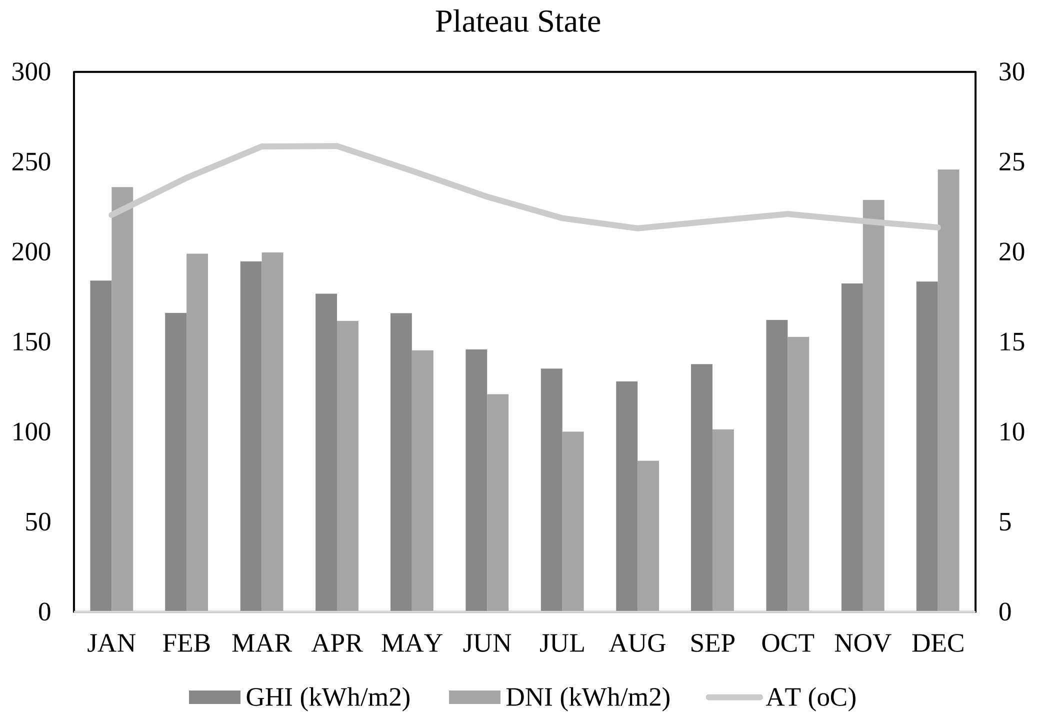
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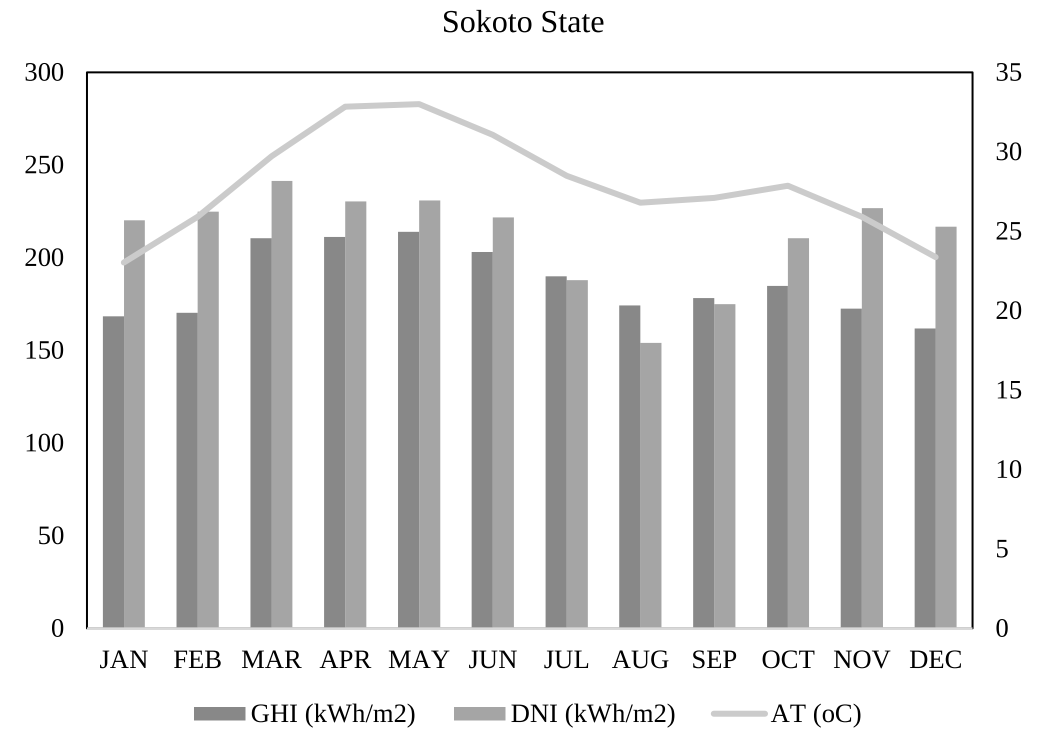
GHI (kWh/m2)
DNI (kWh/m2)
AT (oC)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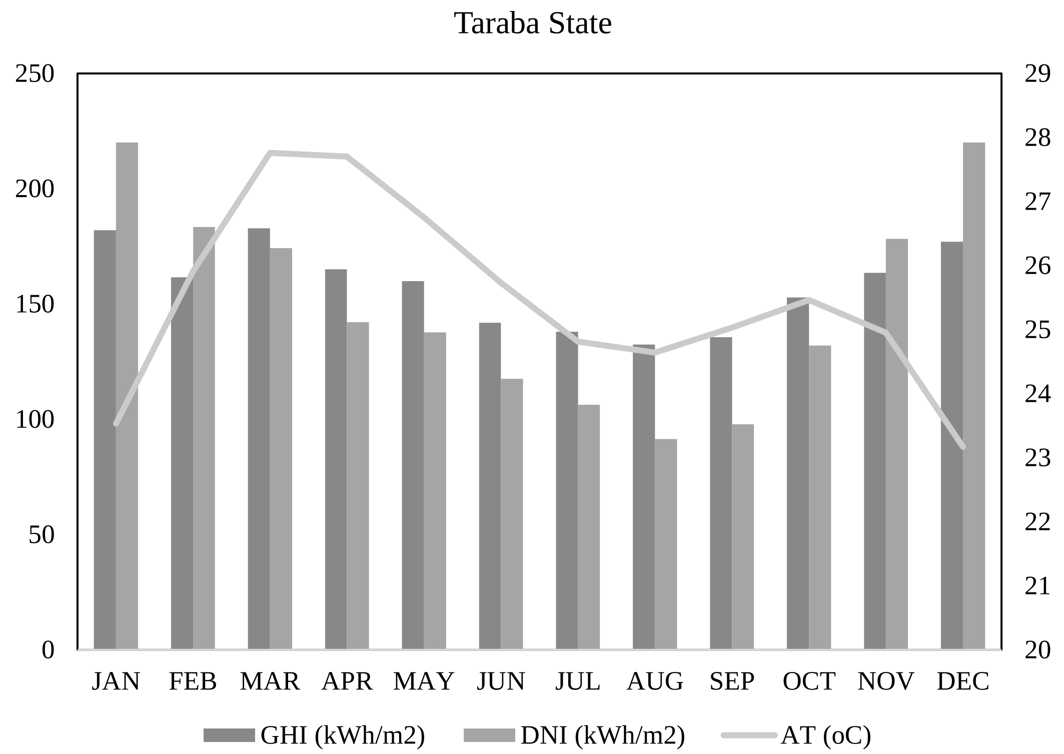
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
GHI (kWh/m2)
DNI (kWh/m2)
AT (oC)


Taraba State
250
200
150
100
50
0
29
28
27
26
25
24
23
22
21
20
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
GHI (kWh/m2)
DNI (kWh/m2)
AT (oC)

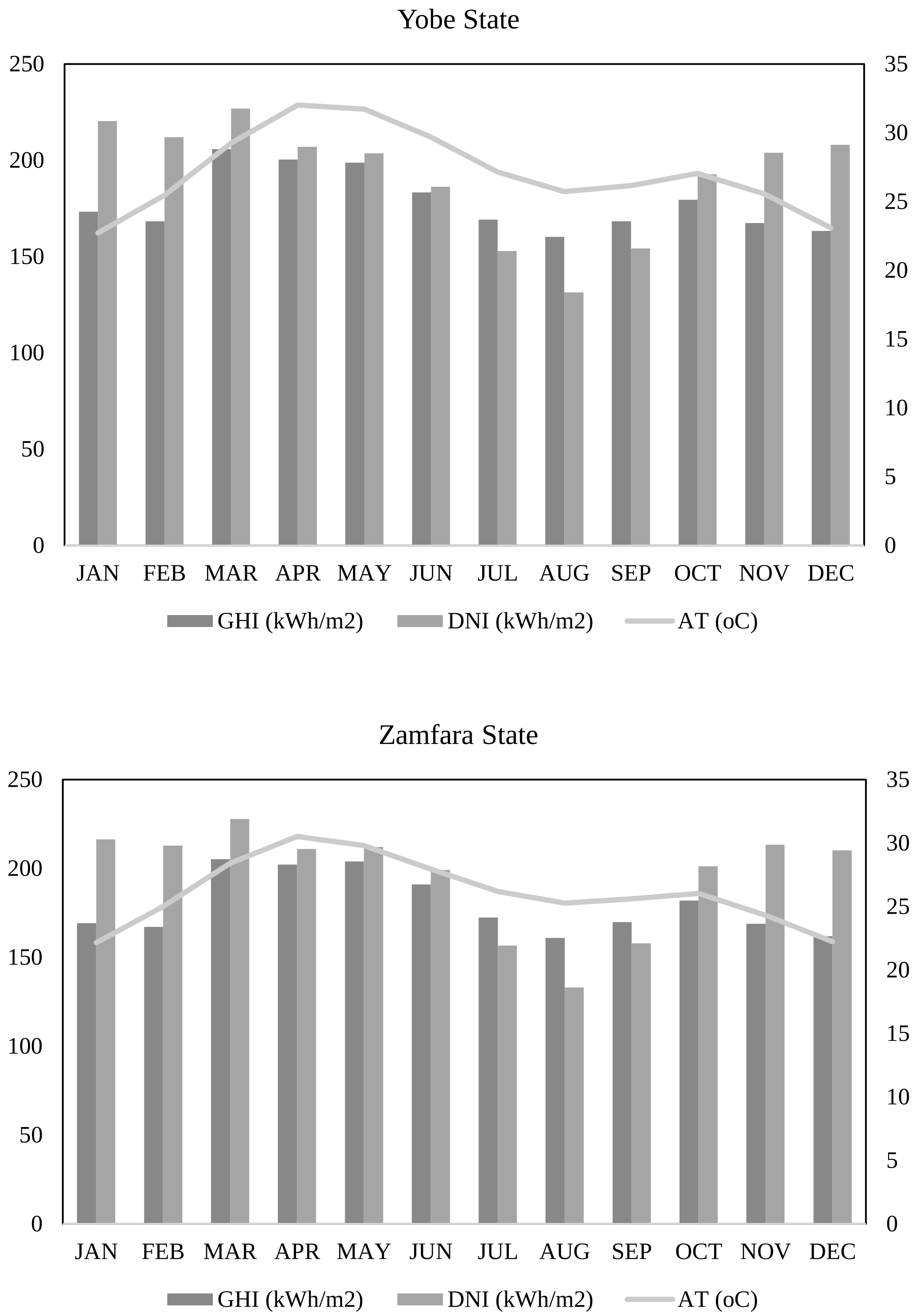
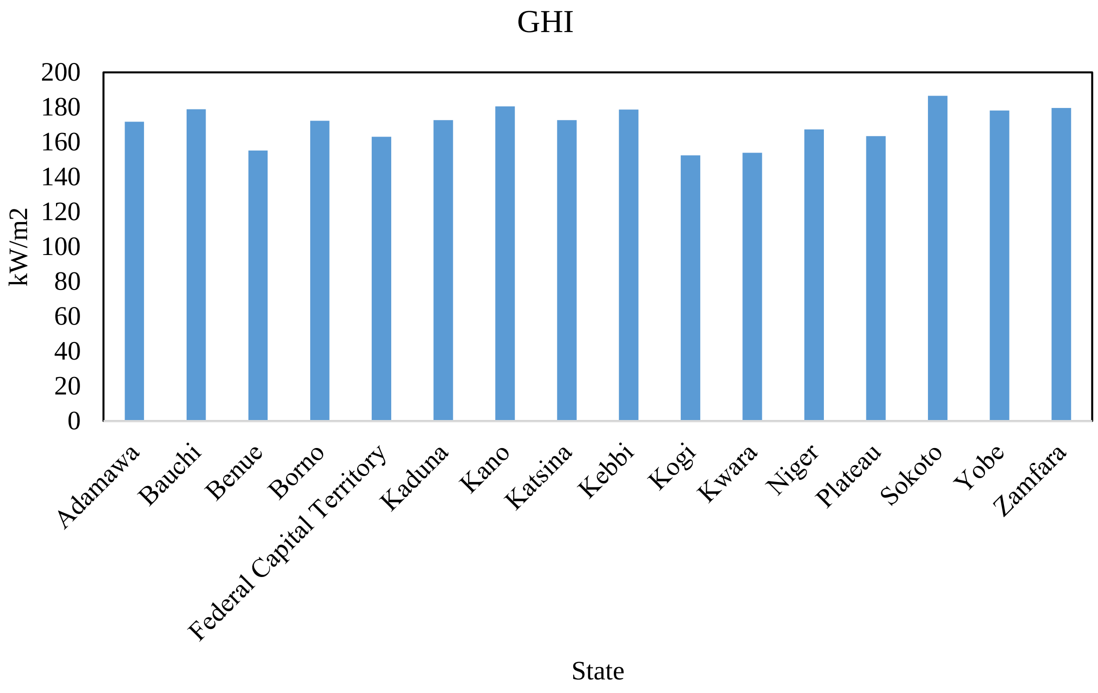
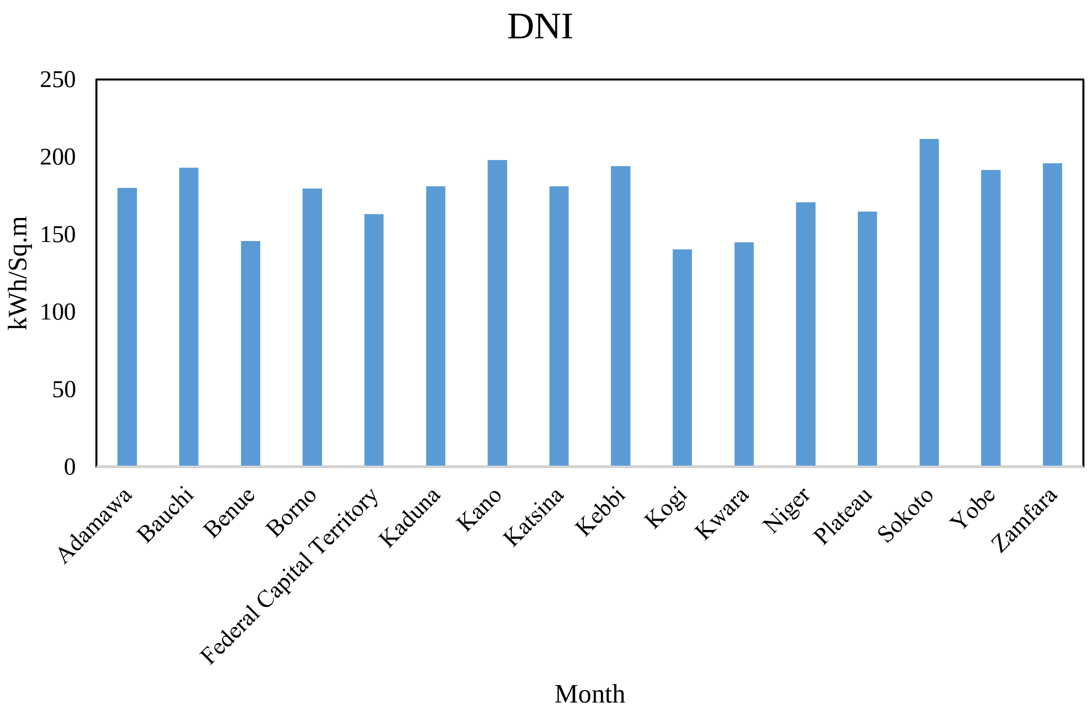



**Figure 4. 4**: GHI, DNI, and AT (°C) averaged monthly for all of Nigeria's studied regions.


GHI
kW/m2
200
180
160
140
120
100
80
60
40
20
0
Adamawa
Bauchi
Benue
Borno
Federal Capital Territory
Kaduna
Kano
Katsina
Kebbi
Kogi
Kwara
Niger
Plateau
Sokoto
Yobe
Zamfara
State


DNI
kWh/Sq.m
250
200
150
100
50
0
Adamawa
Bauchi
Benue
Borno
Federal Capital Territory
Kaduna
Kano
Katsina
Kebbi
Kogi
Kwara
Niger
Plateau
Sokoto
Yobe
Zamfara
Month

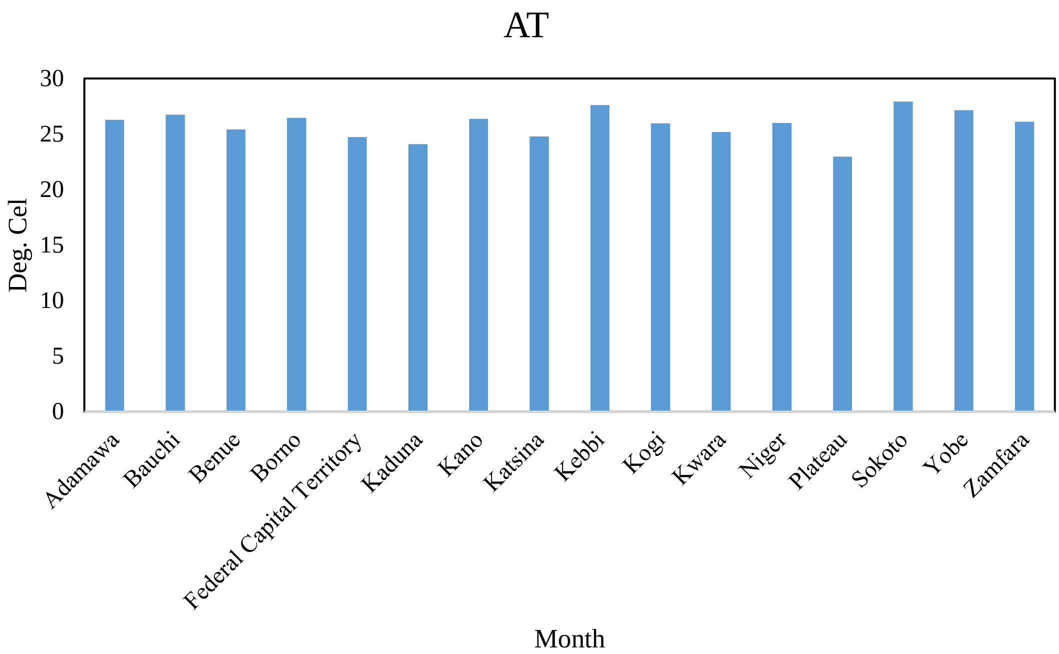
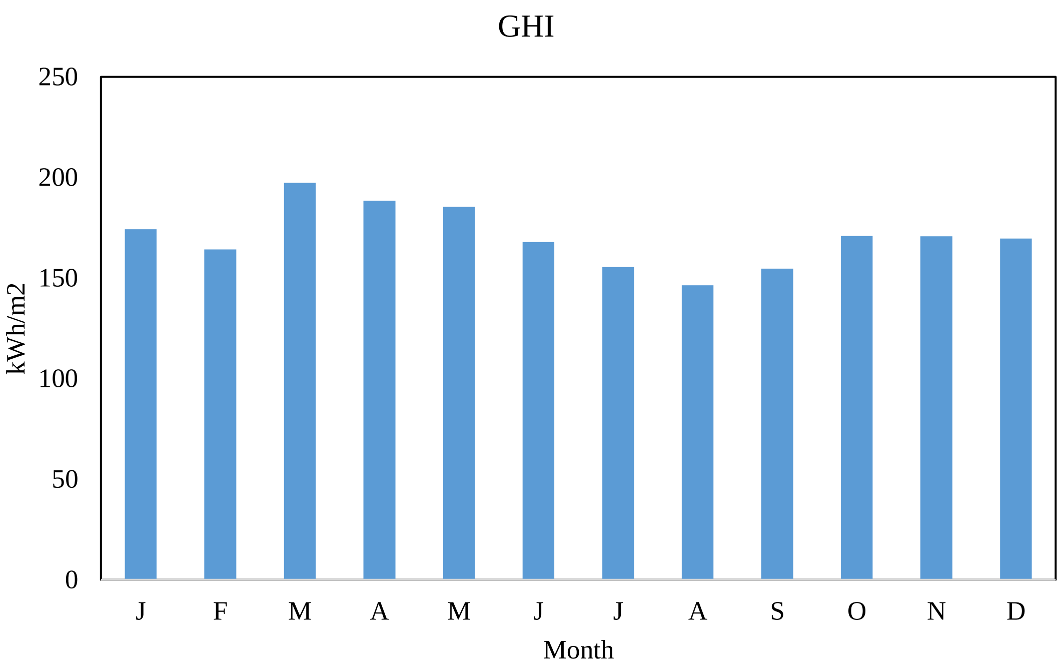
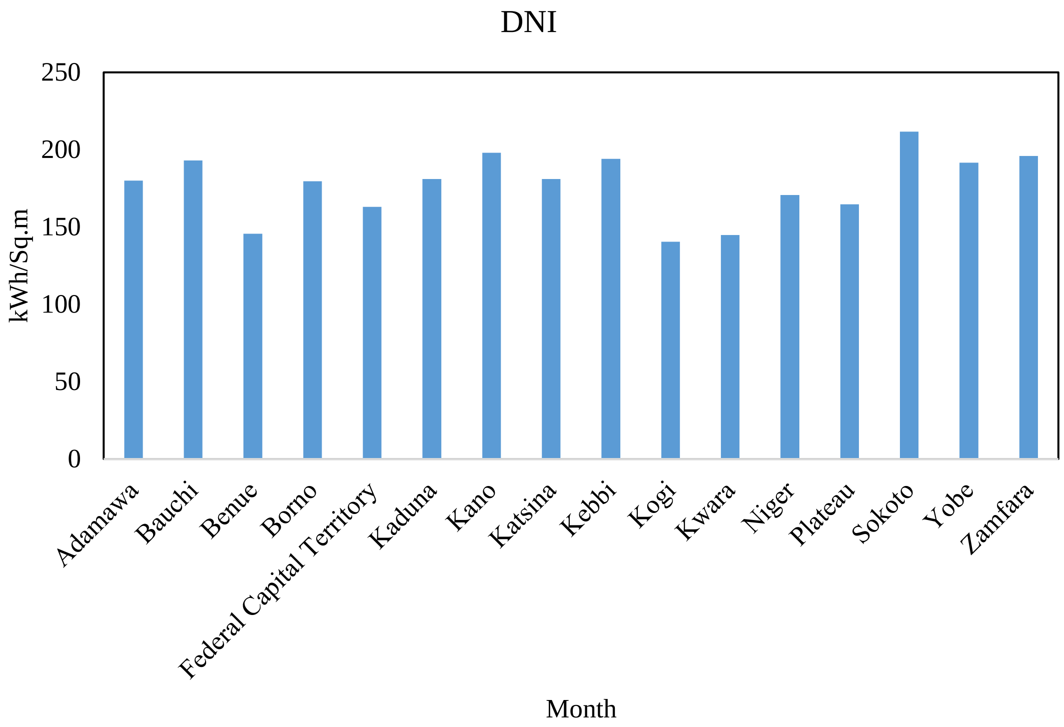



**Figure 4. 5**: Summary of GHI, DNI and AT (°C) averaged monthly for all of Nigeria's studied regions





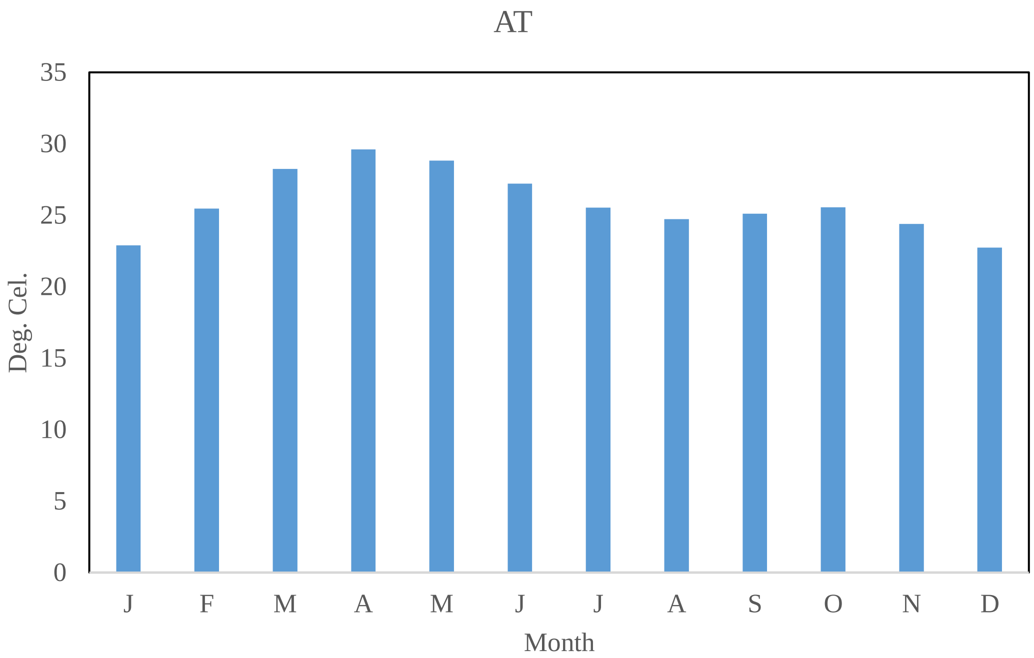
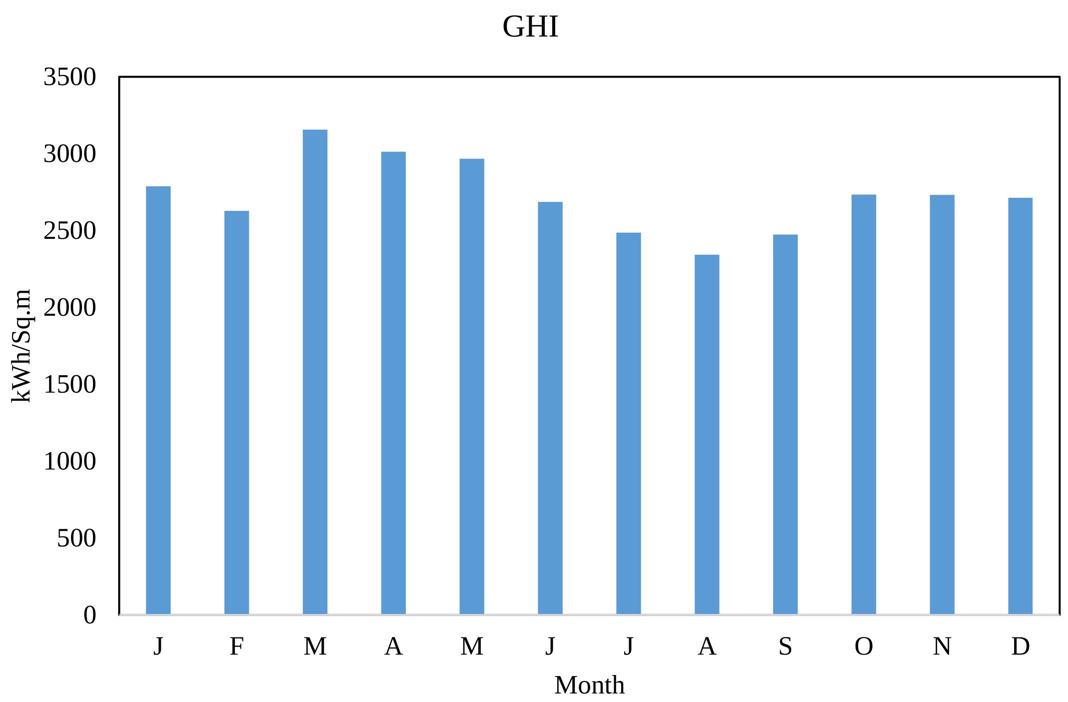




**Figure 4. 6**: Summary of Monthly GHI, DNI and AT for all Selected Locations.



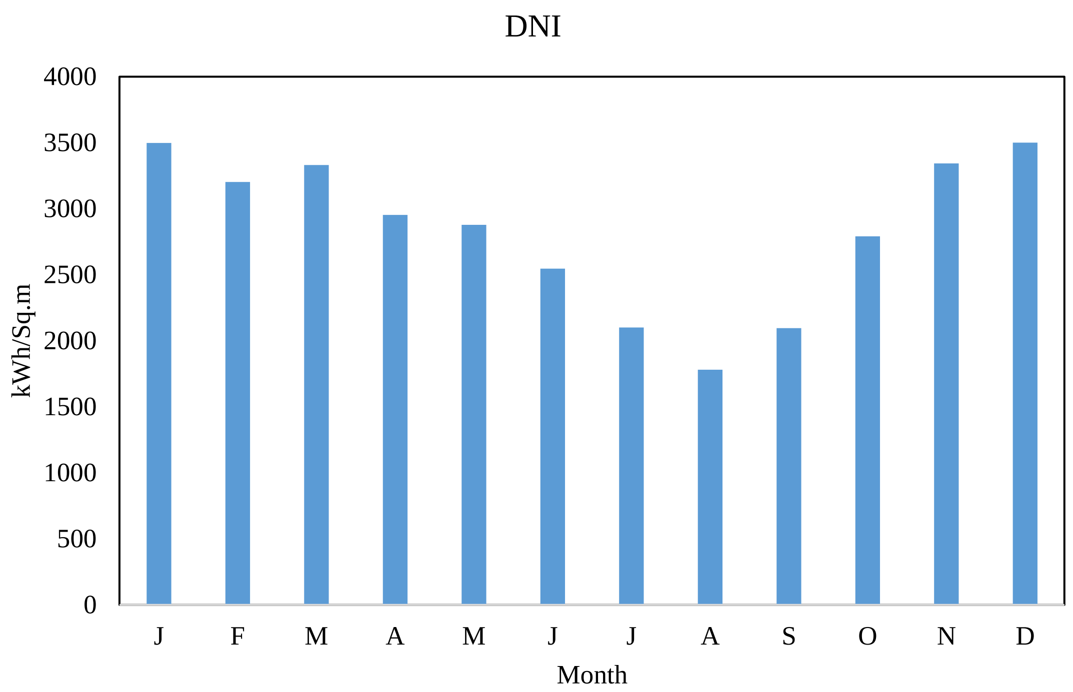




**Figure 4. 7:** Summary of Total GHI and DNI Received Monthly

The selected study areas' mean annual GHI, DNI, and AT are presented in Table 4.2, the study identified Sokoto state with annual maximum GHI and DNI values, and Kogi State with annual minimum GHI and DNI values. The maximum GHI and DNI values obtained are 2241.1 kWh/$m^2$ and 2540.4 kWh/$m^2$ while the minimum GHI and DNI values obtained are 1828.65 kWh/$m^2$ and 1686.3 kWh/$m^2$ (Table 4.2). In addition to solar irradiation, the maximum and minimum air temperatures value obtained identified Sokoto state with the mean highest annual temperature of 27.92 $^{o}$C while Plateau state identified with the lowest mean annual temperature of 22.96 $^{o}$C (Table 4.2).

**Table 4. 2**: GHI, DNI, and AT annual mean for all chosen areas.

| States/Characteristics | GHI (kWh/$m^2$) | DNI (kWh/$m^2$) | AT ($^{o}$C) |
|---|---|---|---|
| Adamawa | 2062.25 | 2160.8 | 26.27 |
| Bauchi | 2146.2 | 2317.75 | 26.74 |
| Benue | 1861.5 | 1748.35 | 25.41 |
| Borno | 2065.9 | 2153.5 | 26.45 |
| Federal Capital Territory | 1956.4 | 1956.4 | 24.73 |
| Kaduna | 2073.2 | 2171.75 | 24.1 |
| Kano | 2168.1 | 2376.15 | 26.36 |
| Katsina | 2073.2 | 2171.75 | 24.79 |
| Kebbi | 2142.55 | 2328.7 | 27.6 |
| Kogi | 1828.65 | 1686.3 | 25.97 |

**Table 4.2. continued**

| States/Characteristics | GHI (kWh/$m^2$) | DNI (kWh/$m^2$) | AT ($^{o}$C) |
|---|---|---|---|

| | | | |
|---|---|---|---|
| Kwara | 1850.55 | 1737.4 | 25.19 |
| Niger | 2011.15 | 2047.65 | 26 |
| Plateau | 1963.7 | 1974.65 | 22.96 |
| Sokoto | 2241.1 | 2540.4 | 27.92 |
| Yobe | 2138.9 | 2299.5 | 27.13 |
| Zamfara | 2157.15 | 2350.6 | 26.12 |

### 4.2.2. Solar Potential Classification

Based on the Prăvălie et al. (2019) solar energy potential spatial assessment scale, the annual mean GHI and DNI of all selected regions (Table 4.2) were classified and presented in Table 4.3. The classification shows that all study areas have abundant solar resources which belong to potential classes of good, excellent, outstanding, or superb. From all the classification, Sokoto state classified class 7 (superb) of GHI and DNI, thus, the state considered the most suitable place to install large-scale PV systems because of the state abundant solar irradiation potential. The analysis further classified nine states of the study area as the class (outstanding) for both GHI and DNI, six state classified as class 6 (excellence) for GHI and three state DNI, while three states classified as 5 class (good) for DNI only. Therefore, based on Table 4.3 all study area suitable for PV/flat-plate and concentrated power system (CSP) systems installation.

**Table 4. 3**: Classification of GHI and DNI.

| | **NASA Classification** | |
|---|---|---|
| **States** | **GHI** | **DNI** |
| Adamawa | Outstanding | Outstanding |

| | | |
|---|---|---|
| Bauchi | Outstanding | Outstanding |
| Benue | Excellence | Good |
| Borno | Outstanding | Outstanding |
| Federal Capital Territory | Excellence | Excellence |
| Kaduna | Outstanding | Outstanding |
| Kano | Outstanding | Outstanding |
| Katsina | Outstanding | Outstanding |
| Kebbi | Outstanding | Outstanding |
| Kogi | Excellence | Good |
| Kwara | Excellence | Good |
| Niger | Excellence | Excellence |
| Plateau | Excellence | Excellence |
| Sokoto | Superb | Superb |
| Yobe | Outstanding | Outstanding |
| Zamfara | Outstanding | Outstanding |

### 4.2.3. Wind/PV Plant Suitable Locations in Nigeria

In the comparison between solar and wind potential, solar energy appeared to be better than wind in all selected locations based on WPC (Table 4.1) and GHI and DNI classification (Table 4.3). The suitability comparison between wind energy and solar energy power plant is presented in Table 4.4. The suitability comparison (Table 4.4) shows that all 15 selected study locations are suitable for future solar plant installation, while only eight out of fifteen selected locations are suitable for future wind plant installation.

**Table 4. 4:** Suitability Comparison Between Wind Energy and Solar Energy Power Plant

| | **Suitability Comparison** | |
|---|---|---|
| **States** | **Solar** | **Wind** |
| Adamawa | Suitable | Not Suitable |
| Bauchi | Suitable | Not Suitable |
| Benue | Suitable | Not Suitable |
| Borno | Suitable | Suitable |
| Federal Capital Territory | Suitable | Not Suitable |
| Kaduna | Suitable | Suitable |
| Kano | Suitable | Suitable |
| Katsina | Suitable | Suitable |
| Kebbi | Suitable | Not Suitable |

**Table 4.4. continued**

| **States** | **Solar** | **Wind** |
|---|---|---|
| Kogi | Suitable | Not Suitable |
| Kwara | Suitable | Not Suitable |

| | | |
|---|---|---|
| Niger | Suitable | Not Suitable |
| Plateau | Suitable | Suitable |
| Sokoto | Suitable | Suitable |
| Yobe | Suitable | Suitable |
| Zamfara | Suitable | Suitable |

### 4.3. A 50 MW Grid-Connected PV/Wind System Economic Analysis and Feasibility Study

On the basis of the suitability comparisons (Table 4.5), solar atlas map and current researches, Nigeria's solar energy potential is fairly high, although the solar energy potential is much more variable than the wind potential, solar with potential energy output estimates ranging from 1828.65 kWh/kWp to 2241.1 kWh/kWp (Table 4.2), PV power plants could be economically feasible in all selected locations than that of the wind with the mean WPD of between 114 W/m$^2$ and 647 W/m$^2$ (Figure 4.3). To find out, the RETScreen program was used to undertake a techno-economic feasibility and viability study for a 50MW grid-connected PV and wind facility in the appropriate areas (Table 4.5). In addition to the PV analysis, the PVGIS online simulation tool was utilized to determine the best angles for the slope angle and azimuth angle in Table 4.6.

**Table 4. 5**: Optimal PV system angles for all chosen areas.

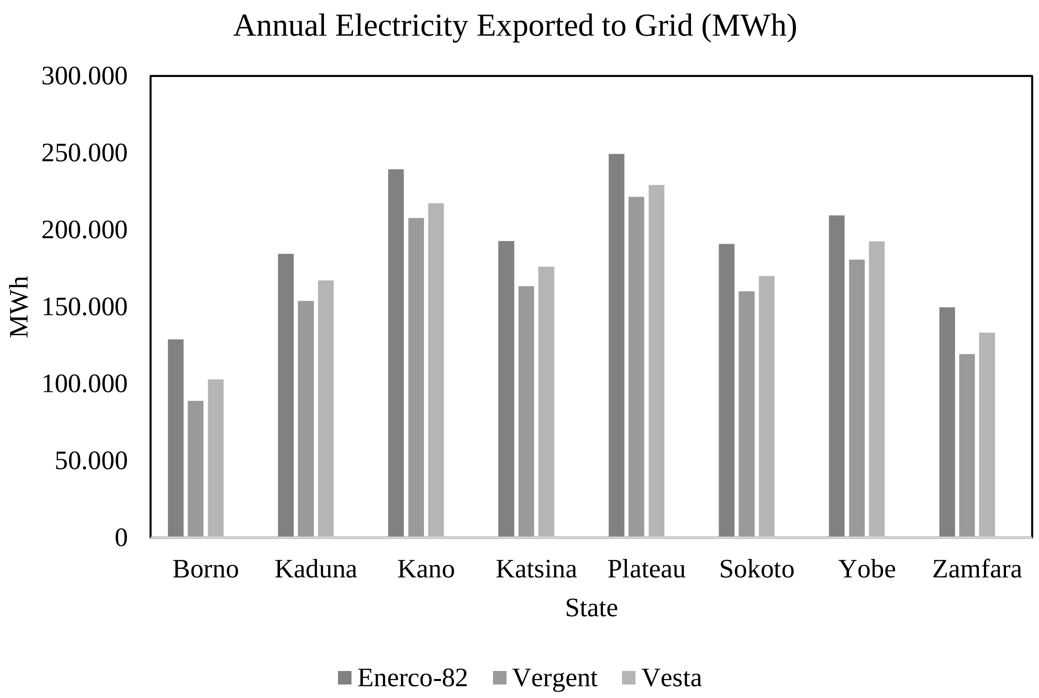
| States | Slope Angle (º) | Azimuth Angle (º) |
|---|---|---|
| Adamawa | 11 | 0 |
| Bauchi | 11 | 0 |
| Benue | 11 | 0 |

| | | |
|---|---|---|
| Borno | 11 | 0 |
| Federal Capital Territory | 9 | 0 |
| Kaduna | 11 | 0 |
| Kano | 11 | 0 |
| Katsina | 11 | 0 |
| Kebbi | 11 | 0 |
| Kogi | 11 | 0 |
| Kwara | 11 | 0 |
| Niger | 11 | 0 |
| Plateau | 10 | 0 |
| Sokoto | 13 | 0 |
| Yobe | 12 | 0 |
| Zamfara | 13 | 0 |

#### 4.3.1. Assessment of Systems Performance

**A. Wind System Performance**

A wind turbine, in general, is a device that converts wind kinetic energy into mechanical energy, which is subsequently captured to generate electricity. It is divided into two categories: horizontal and vertical axis, with Kassem, 2020 focusing on the horizontal axis wind turbine in their research. As stated in the previous chapter, the wind power density (WPD) is the expected wind availability at the location, hence the wind turbine selection is based on the WPD class (Kassem, 2020). Furthermore, the quantity of energy produced by a wind turbine is determined by the wind speed. The annual production of electricity and the capacity factor of the proposed system using Enerco-82-E2 turbine technologies are illustrated in Figure 4.8. Kano and Plateau States has the highest yearly power generation, while Borno State had the lowest annual power output (Figure 4.8). The performance result showed that the turbine systems would export between 88,884 and 249,291 MWh per year to the grid, respectively. The enercon turbine found to have the highest power export rate. Moreover, the maximum capacity factor was found to be 56.9% for the climatic conditions of Plateau for the enercon systems, as shown in Figure 4.8. Besides, the capacity factor (CF) values are in the 29.4-56.9% range, implying that the selected locations are suitable for the manufacturing of wind plant projects. The outcome also demonstrates that constructing a grid-connected wind power facility in Nigeria is technically viable.



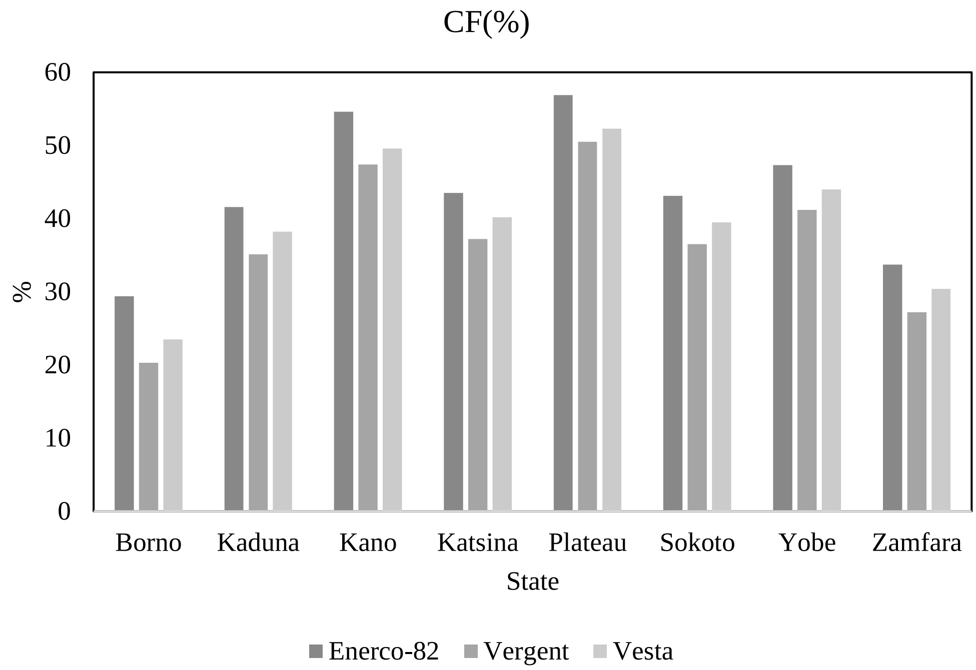
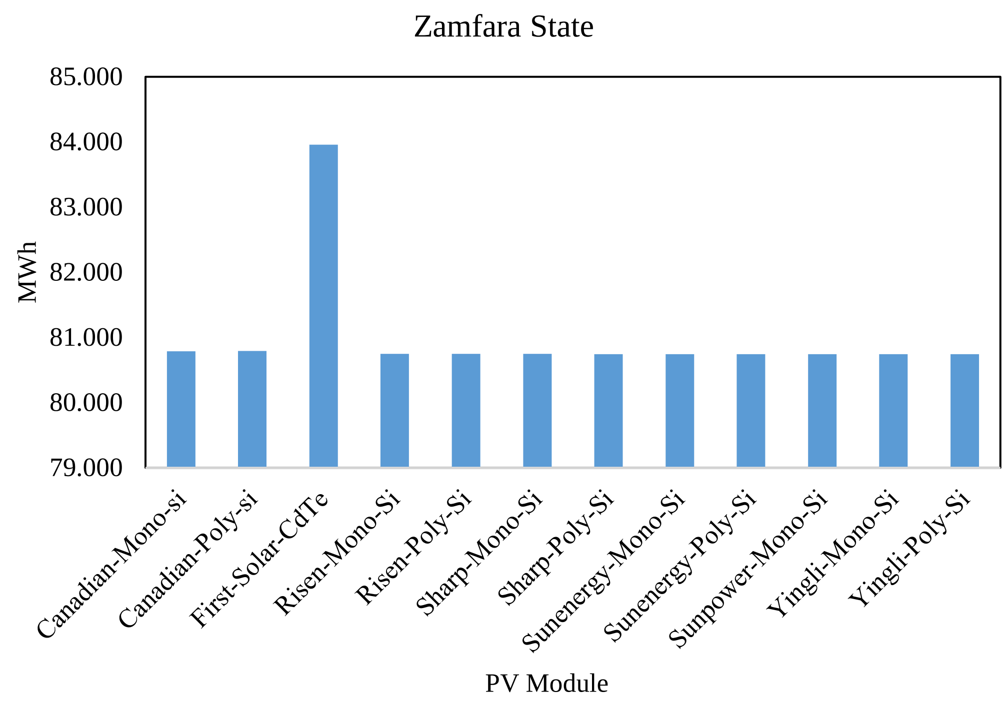
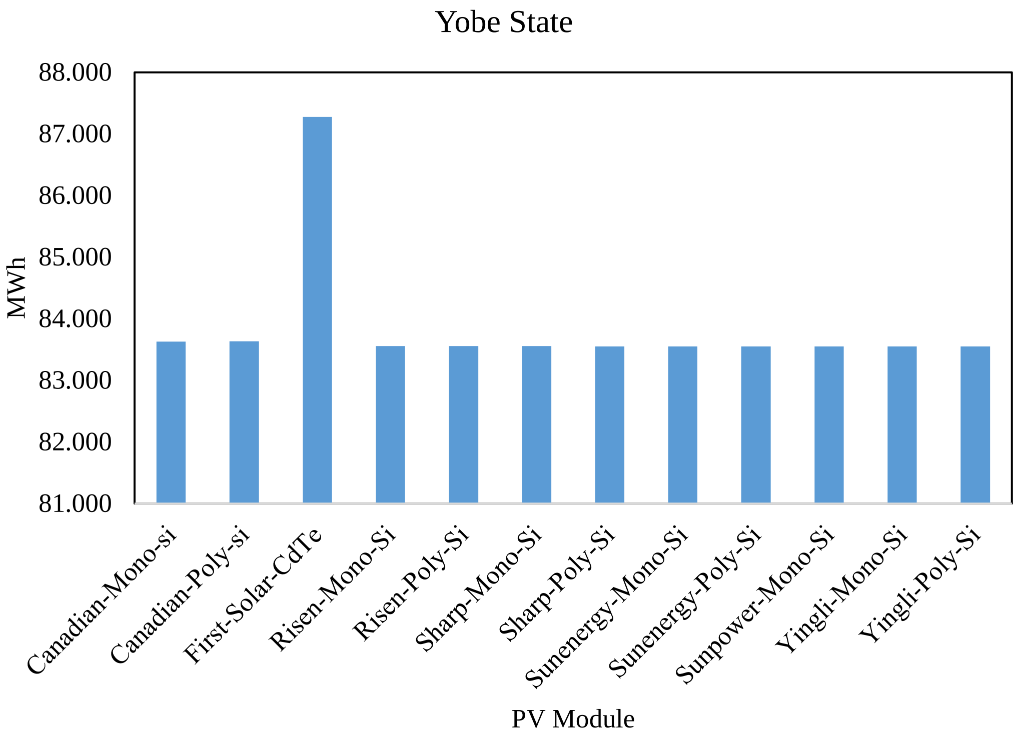


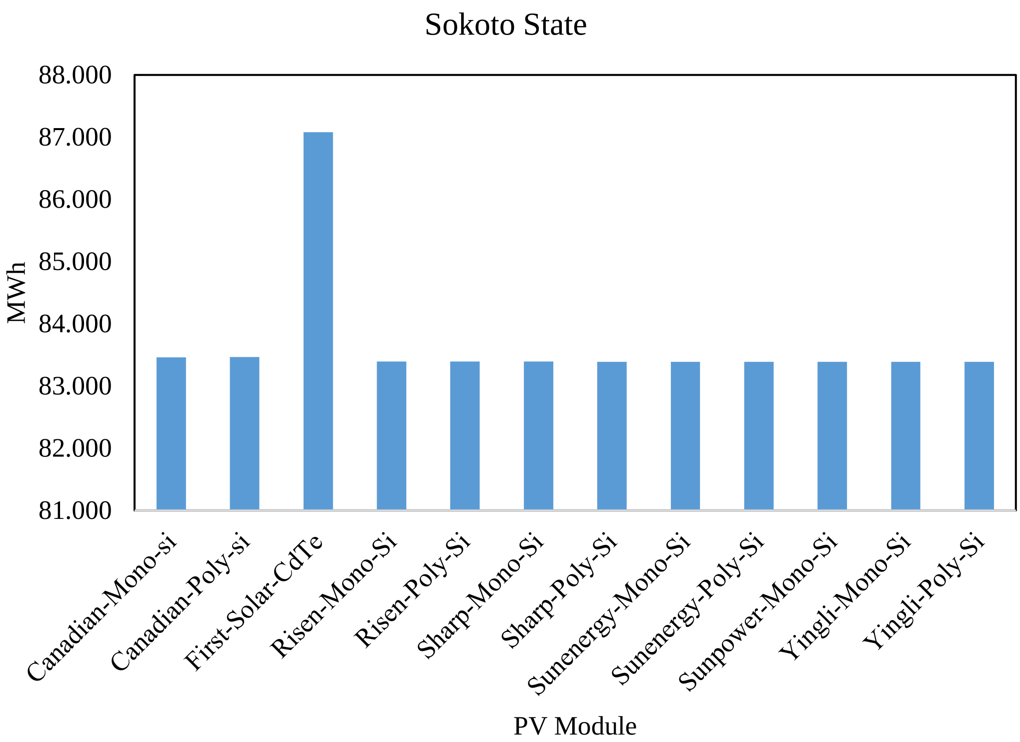

**Figure 4. 8**: The Proposed Wind systems' annual power output and capacity factor.

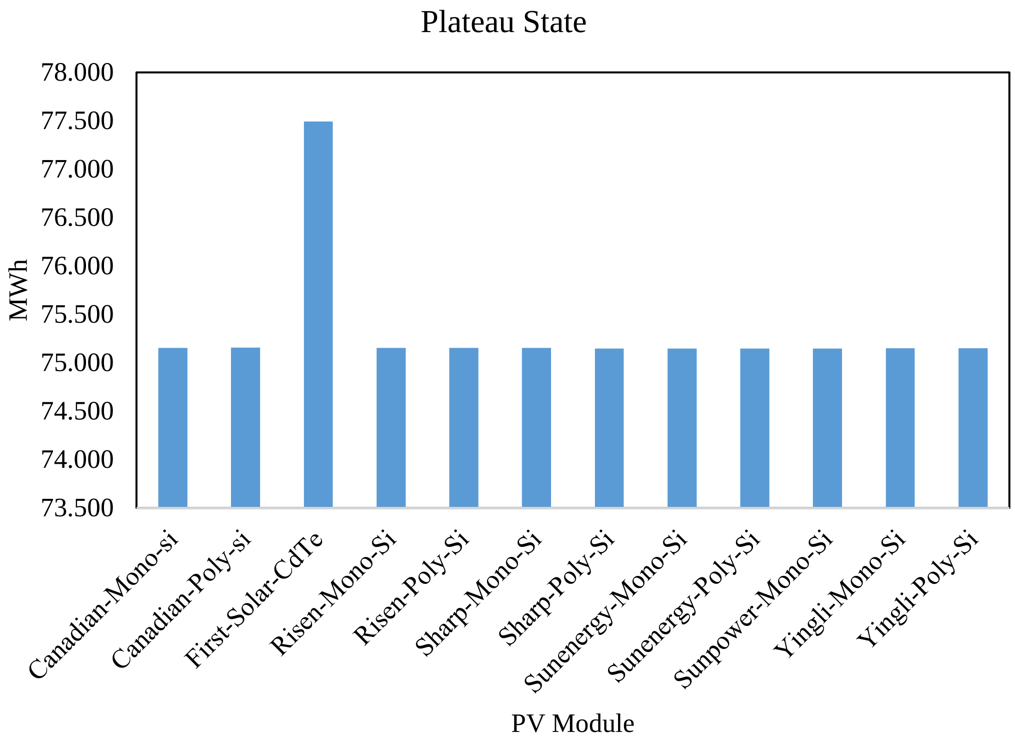
**B. Photovoltaic Systems Performance**

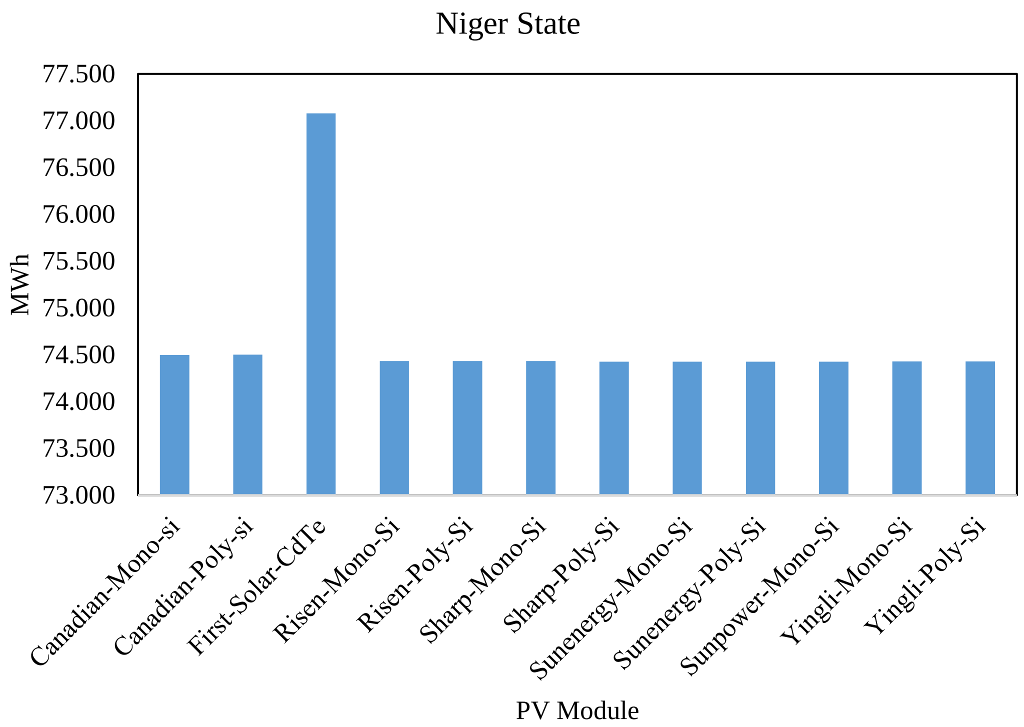
For the proposed solar power plant, a fixed-tilt PV system is being investigated. Figure 4.9 shows the yearly power output and capacity factor of the proposed system employing three PV technologies. Yobe State in Nigeria's north-eastern area had the greatest annual power output, while Kogi State in the country's north-central area had the lowest annual power output (Figure 4.9). The performance analysis revealed that in the Yobe State of North Eastern Nigeria, MWh per year to the grid (Figure 4.9A), respectively. Also, it was observed that the CdTe system provided the highest amount of electricity exported to the grid compared to other systems (Figure 4.9A). Moreover, the maximum capacity factor was found to be 19.1% for the climatic conditions of the Yobe State in the North-Eastern region of Nigeria, as shown in Figure 4.9B. Besides, the capacity factor (CF) values are in the 18.20-19.1 percent range (Figure 4.9B), implying that the selected locations are suitable for the development of PV projects. Based on the findings, it appears that the installing of grid-connected PV power plants in Nigeria is technically feasible (Rehman et al., 2017; Owolabi et al., 2019).

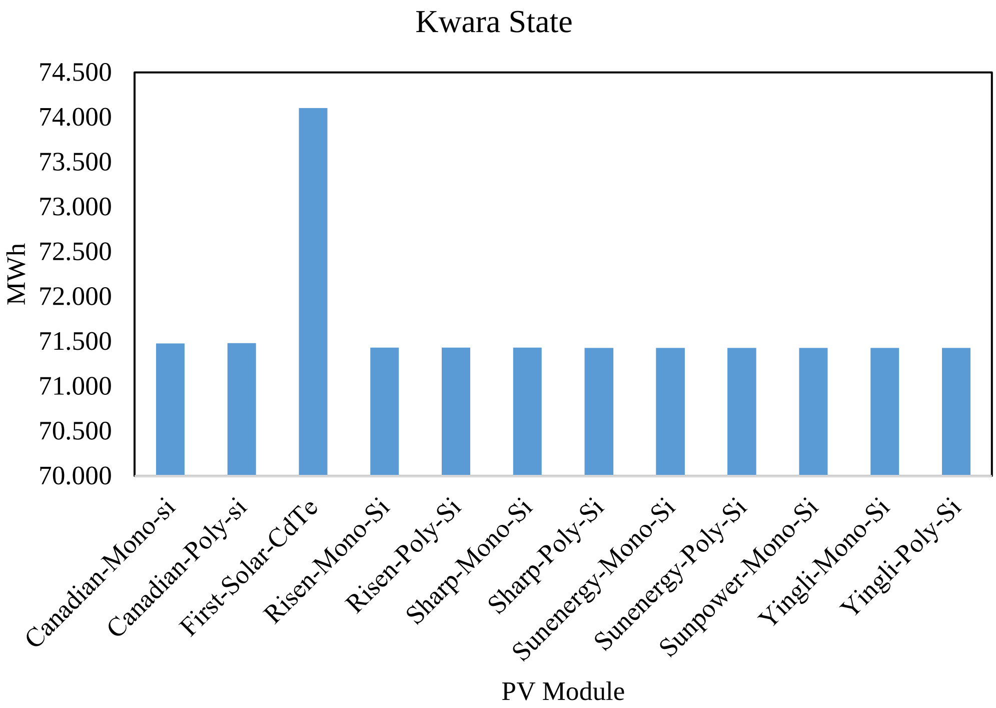

Zamfara State
85.000
84.000
83.000
82.000
81.000
80.000
79.000
MWh
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

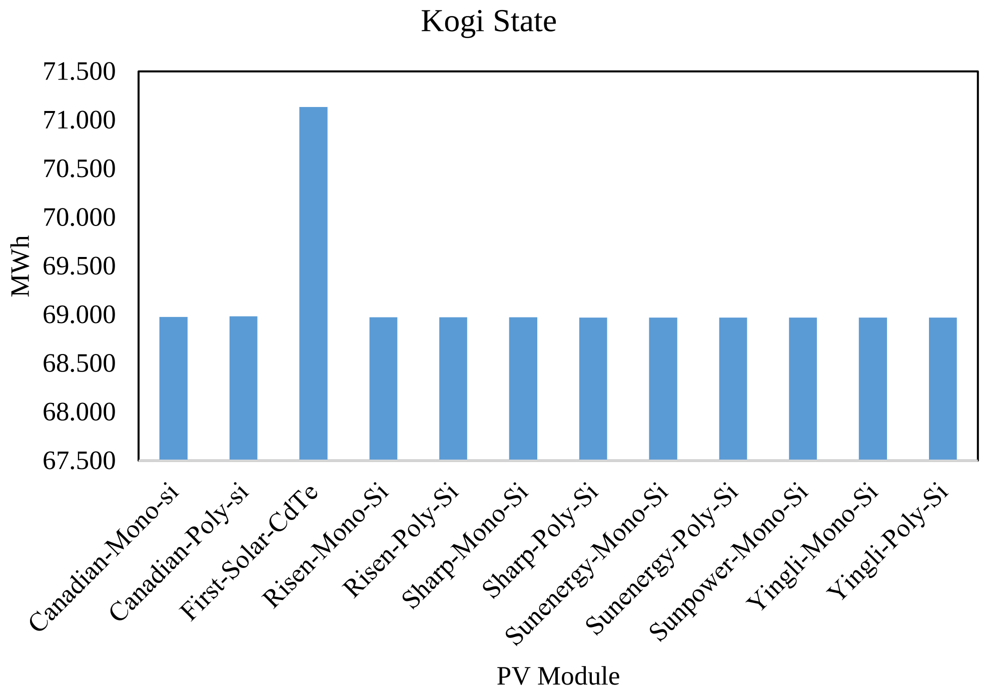

Yobe State
88.000
87.000
86.000
85.000
84.000
83.000
82.000
81.000
MWh
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

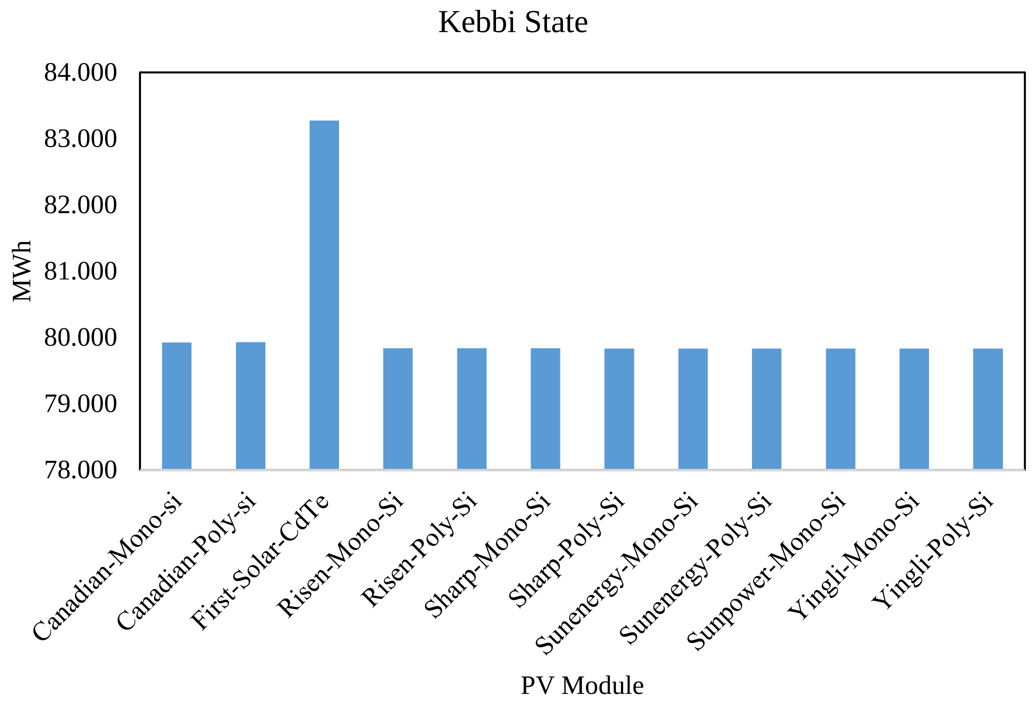

Sokoto State
88.000
87.000
86.000
85.000
84.000
83.000
82.000
81.000
MWh
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module


Plateau State
78.000
77.500
77.000
76.500
76.000
75.500
75.000
74.500
74.000
73.500
MWh
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module


Niger State
77.500
77.000
76.500
76.000
75.500
75.000
74.500
74.000
73.500
73.000
MWh
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module


Kwara State
MWh
74.500
74.000
73.500
73.000
72.500
72.000
71.500
71.000
70.500
70.000
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module


Kogi State
MWh
71.500
71.000
70.500
70.000
69.500
69.000
68.500
68.000
67.500
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module


Kebbi State
84.000
83.000
82.000
81.000
80.000
79.000
78.000
MWh
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
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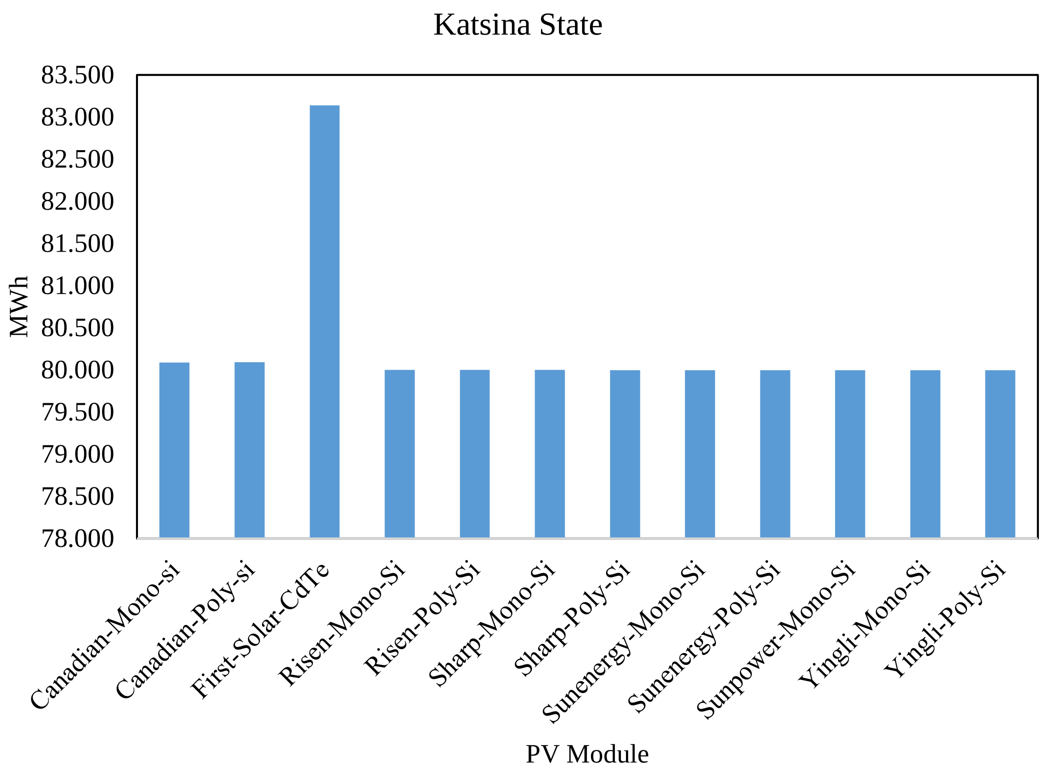
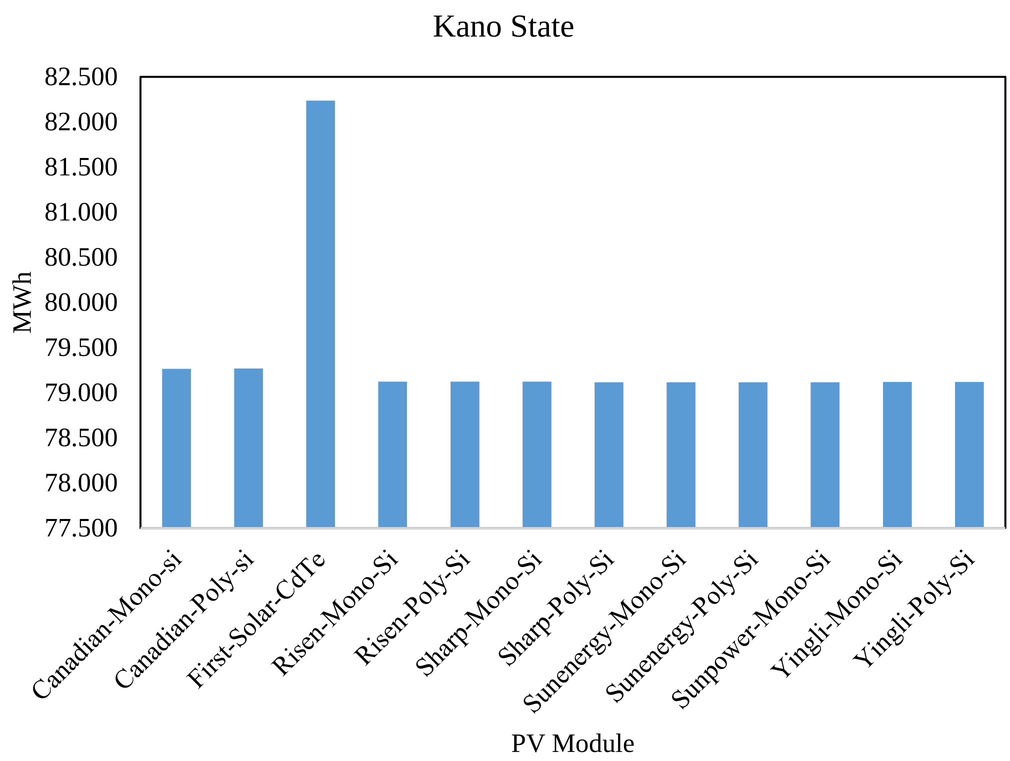
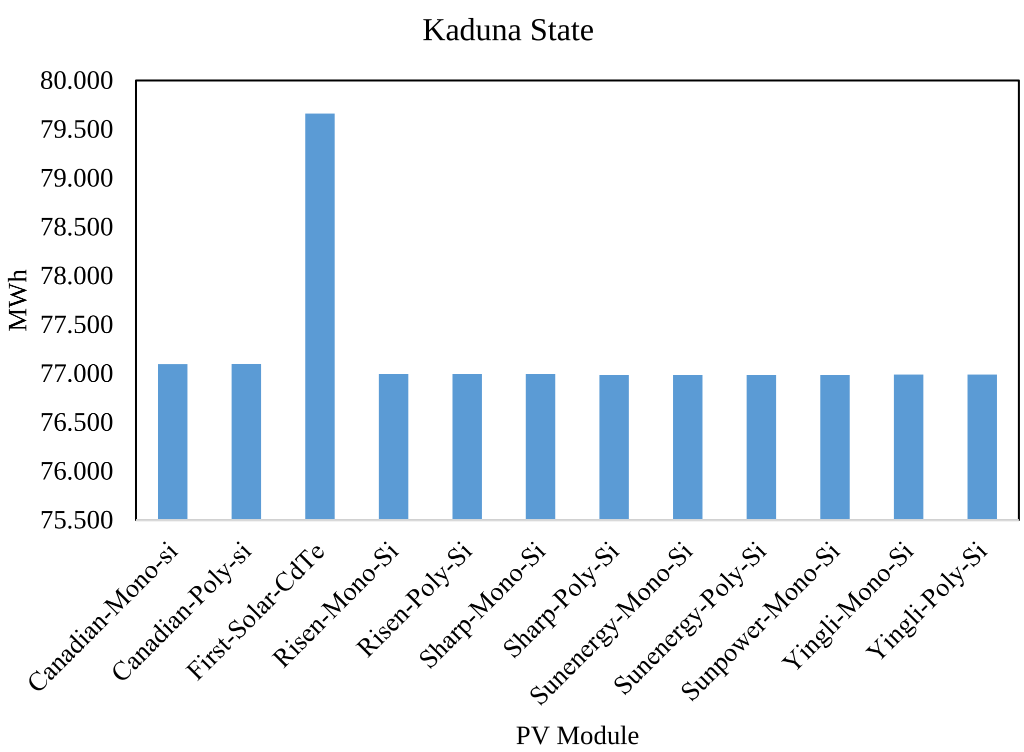
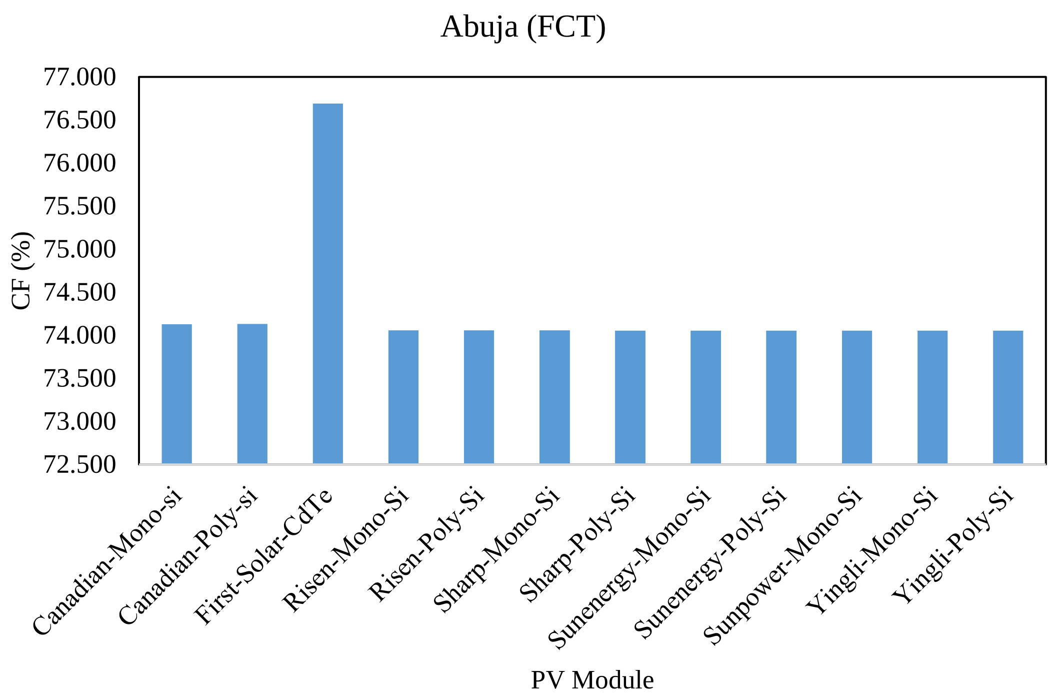
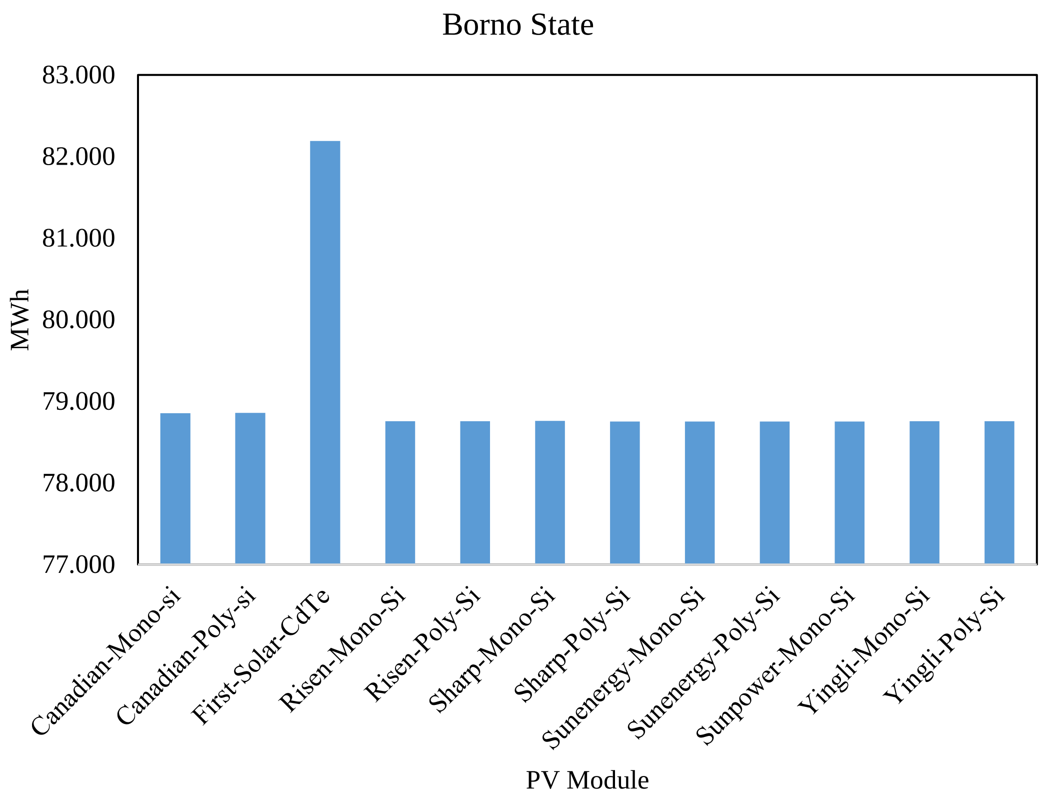
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

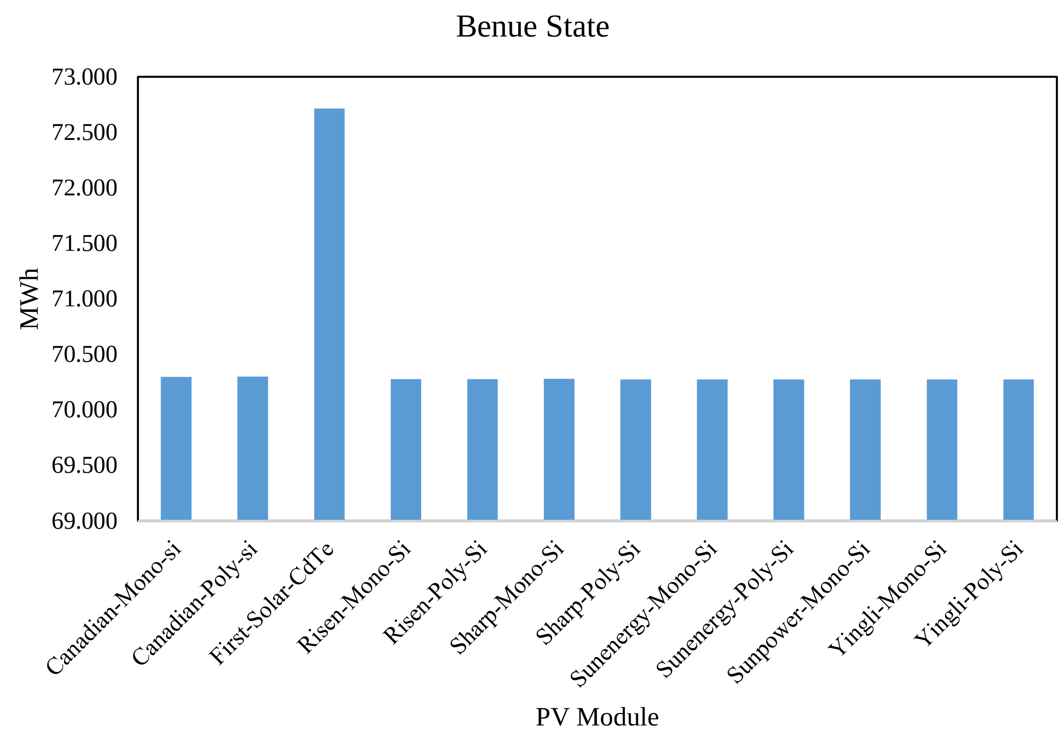

Katsina State
83.500
83.000
82.500
82.000
81.500
81.000
80.500
80.000
79.500
79.000
78.500
78.000
MWh
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

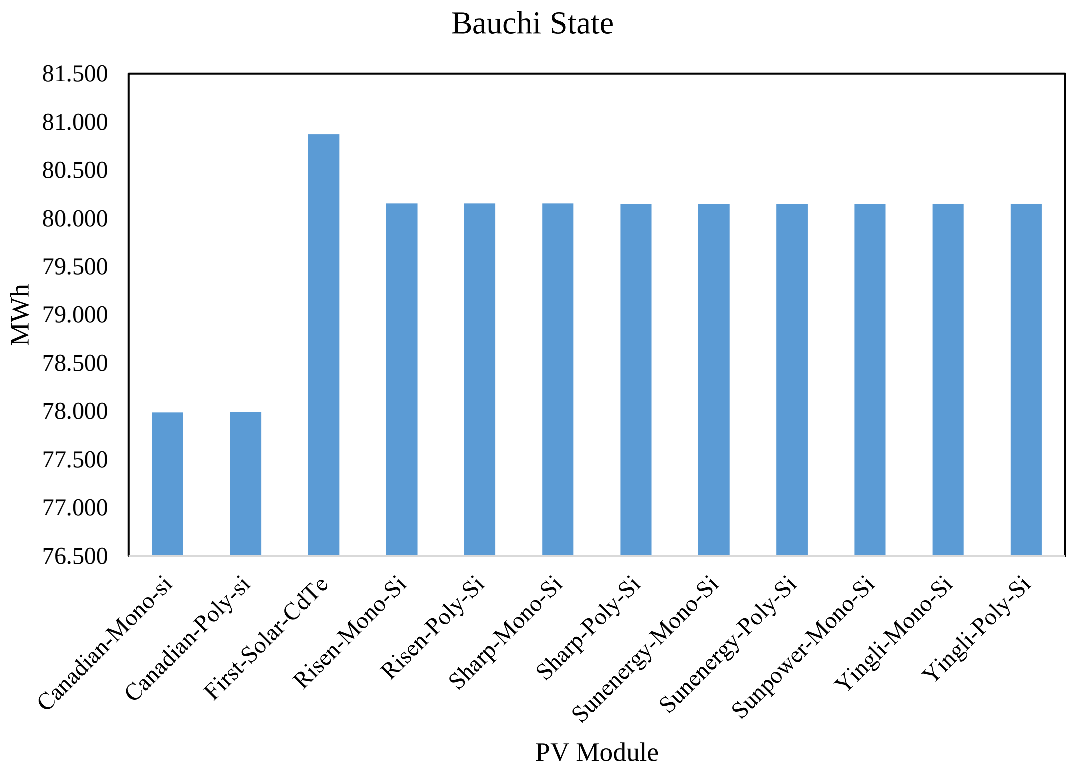

Kano State
82.500
82.000
81.500
81.000
80.500
80.000
79.500
79.000
78.500
78.000
77.500
MWh
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

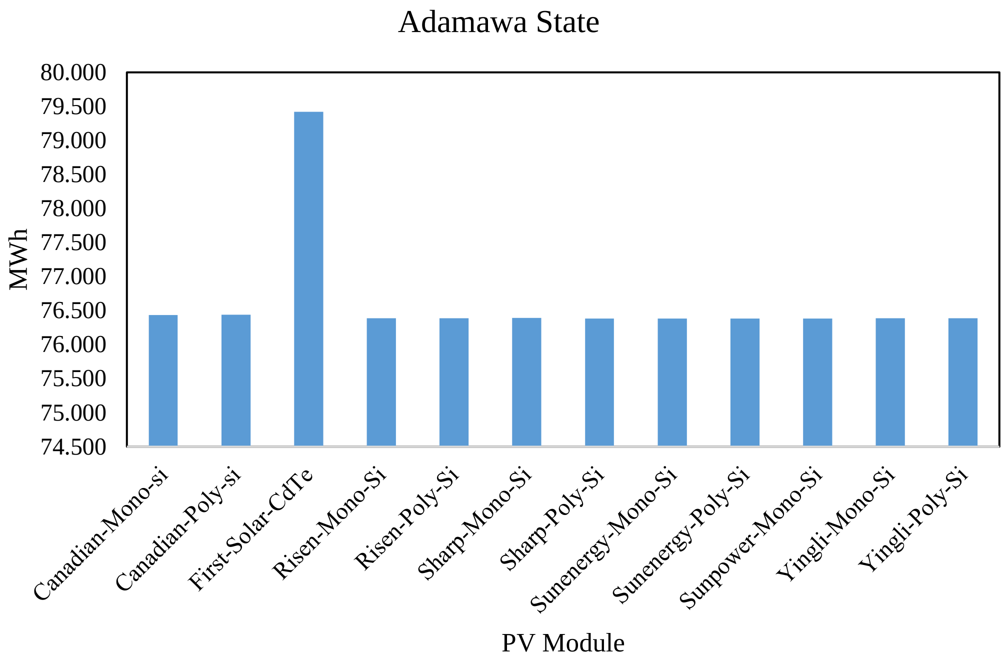

Kaduna State
80.000
79.500
79.000
78.500
78.000
77.500
77.000
76.500
76.000
75.500
MWh
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module


Abuja (FCT)
CF (%)
77.000
76.500
76.000
75.500
75.000
74.500
74.000
73.500
73.000
72.500
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

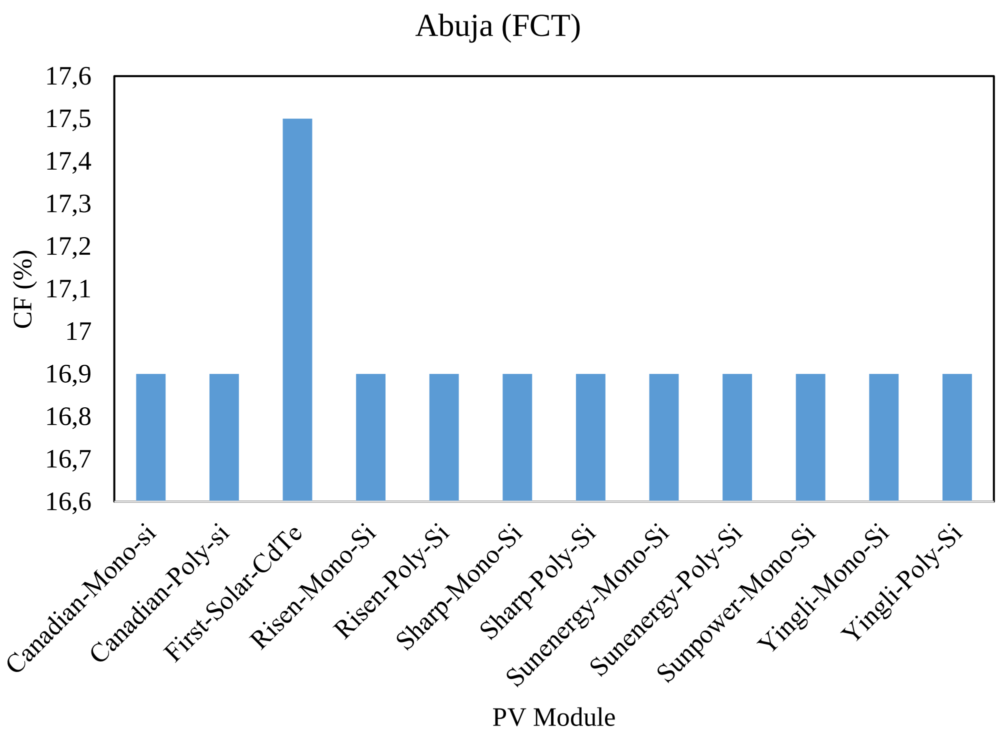

Borno State
MWh
83.000
82.000
81.000
80.000
79.000
78.000
77.000
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

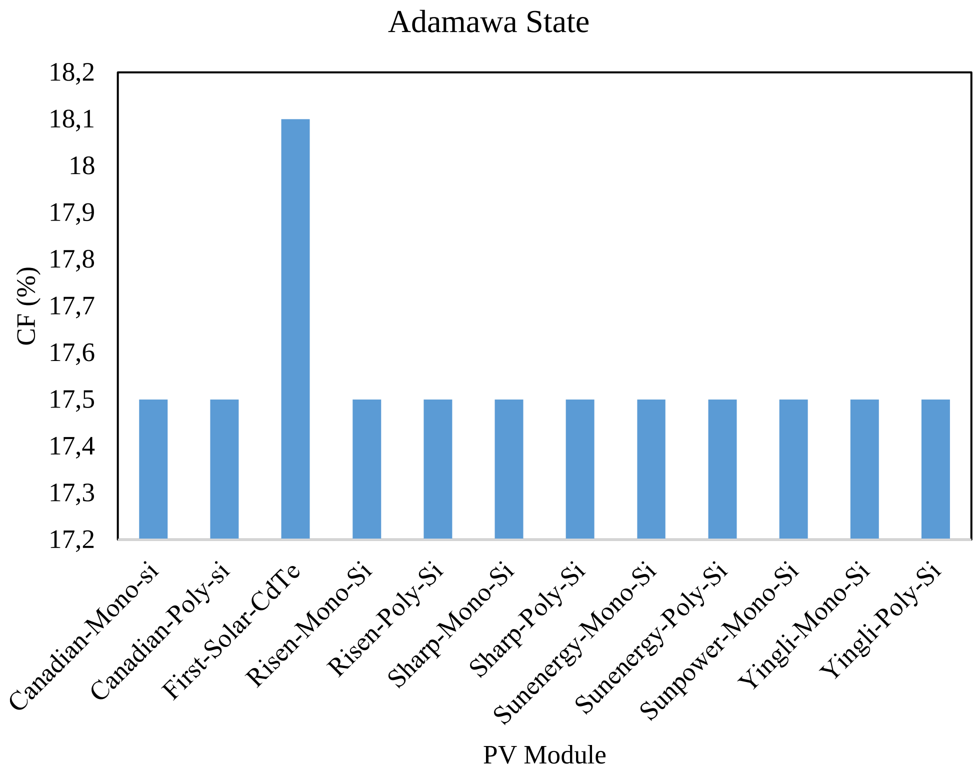

Benue State
73.000
72.500
72.000
71.500
71.000
70.500
70.000
69.500
69.000
MWh
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

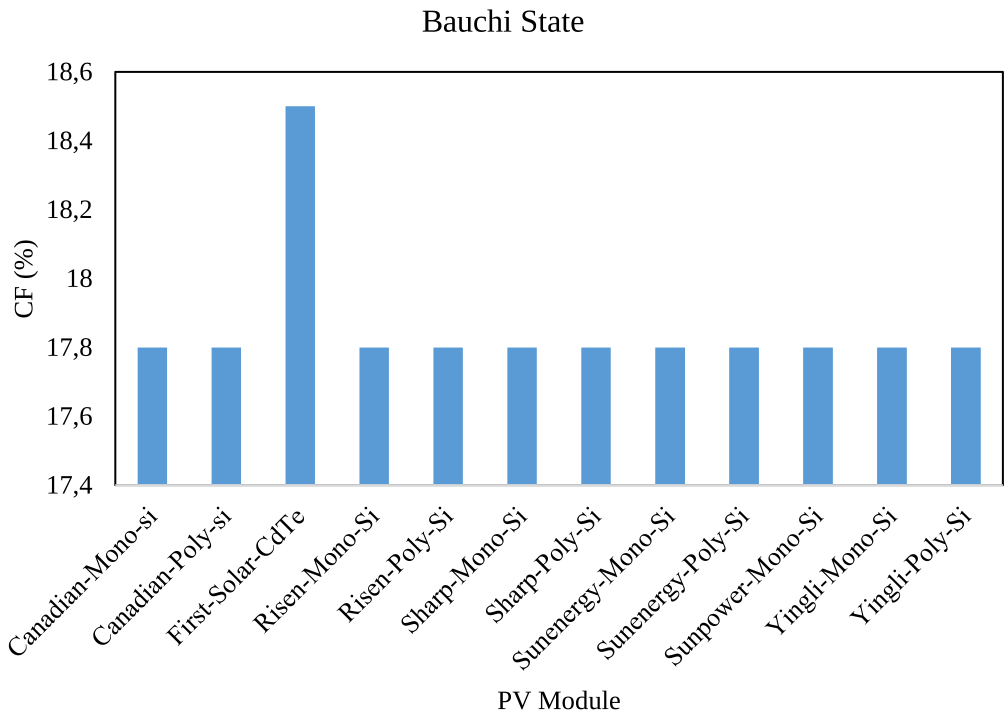

Bauchi State
81.500
81.000
80.500
80.000
79.500
79.000
78.500
78.000
77.500
77.000
76.500
MWh
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

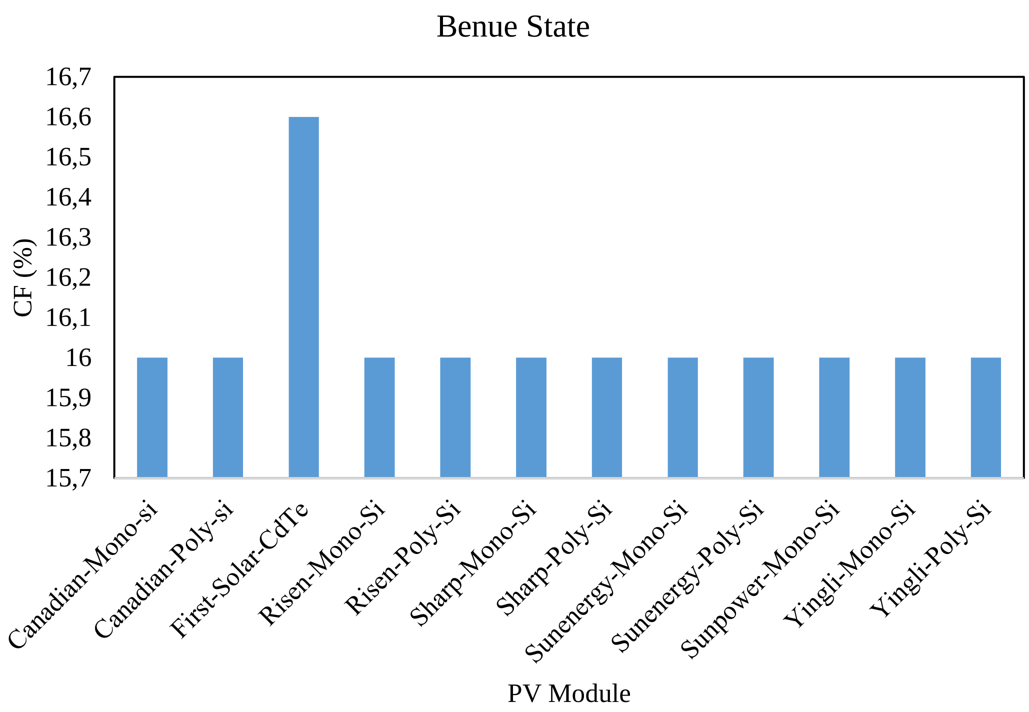


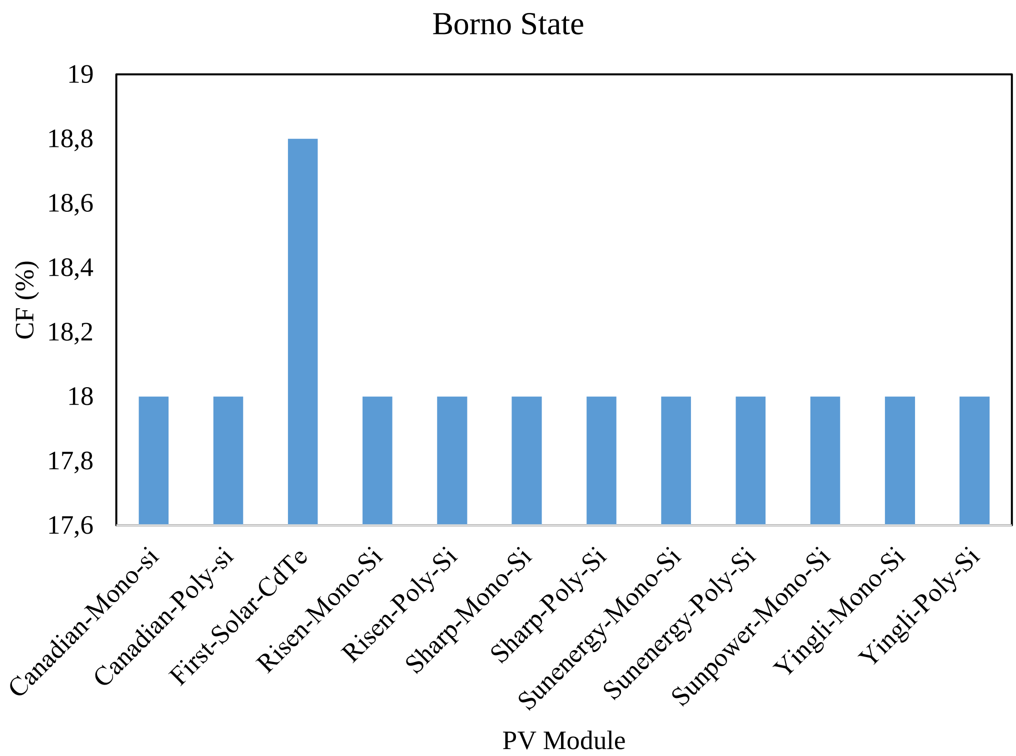

**A. Energy Exported Rate (MWh)**

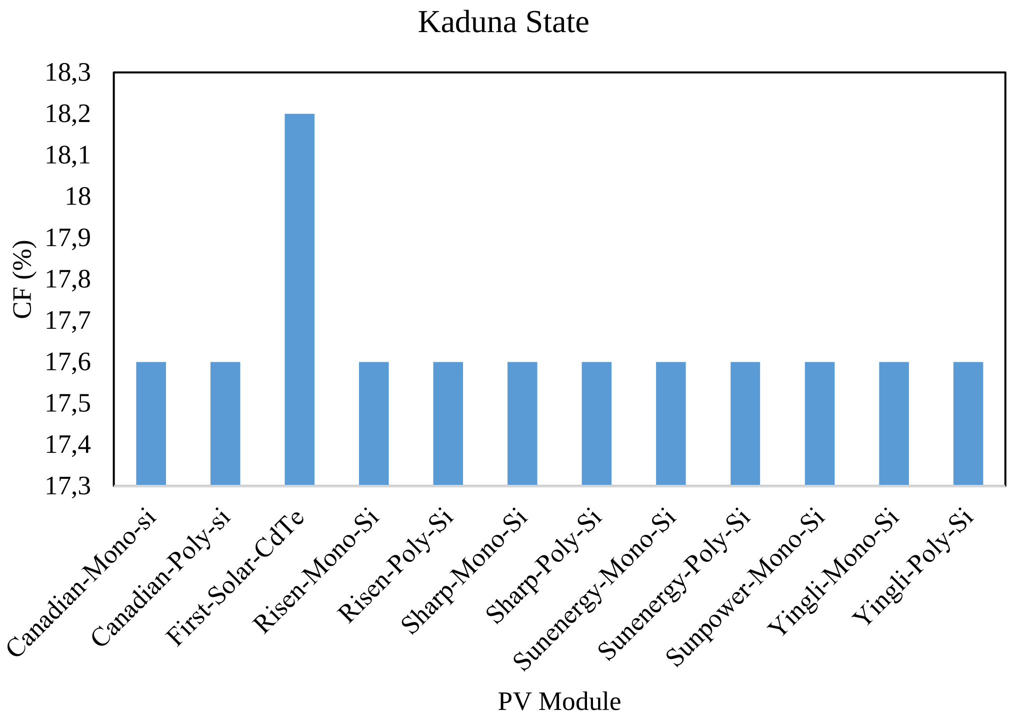


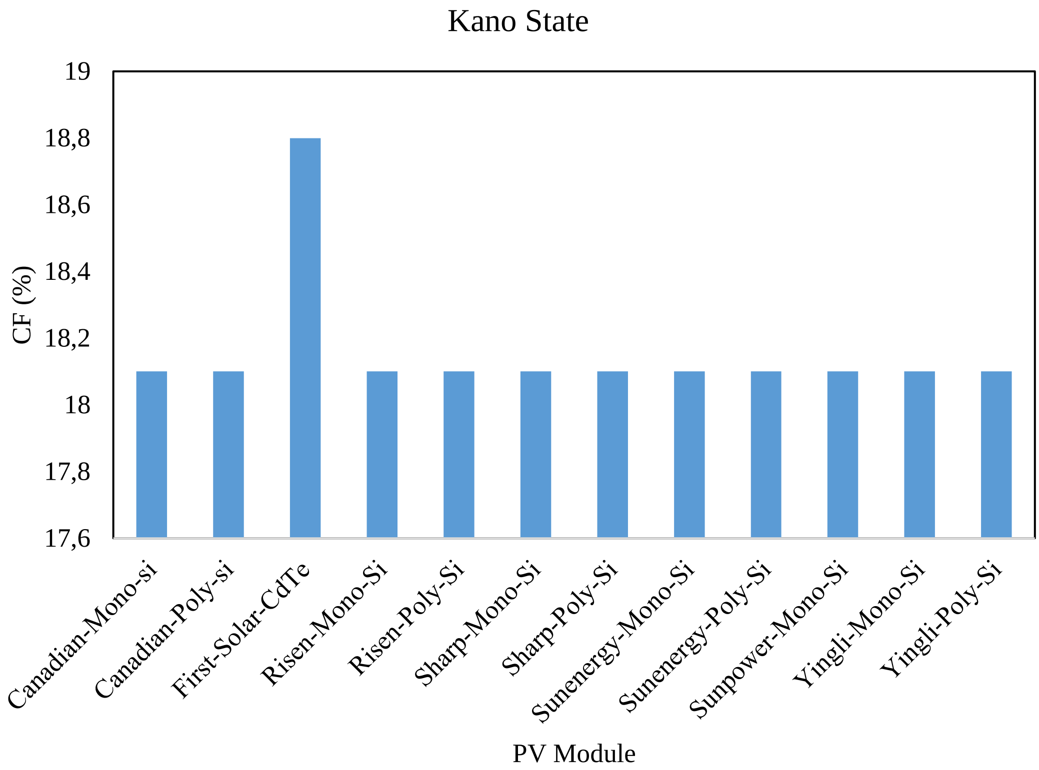

Adamawa State
18,2
18,1
18
17,9
17,8
17,7
17,6
17,5
17,4
17,3
17,2
CF (%)
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

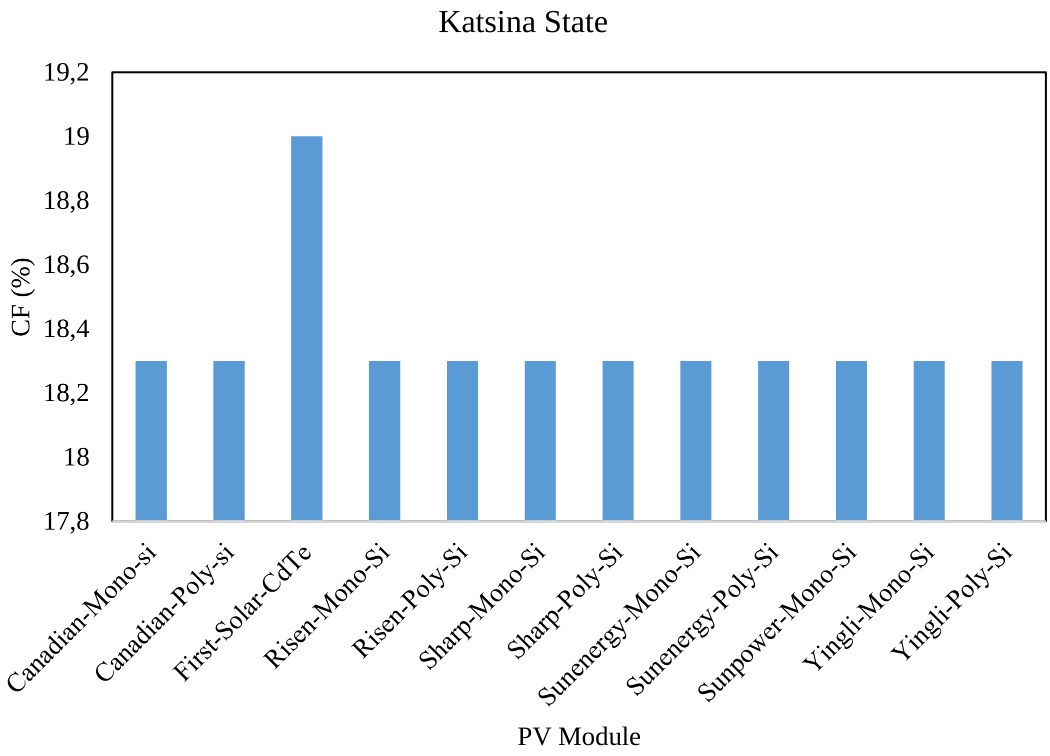

Bauchi State
18,6
18,4
18,2
18
17,8
17,6
17,4
CF (%)
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

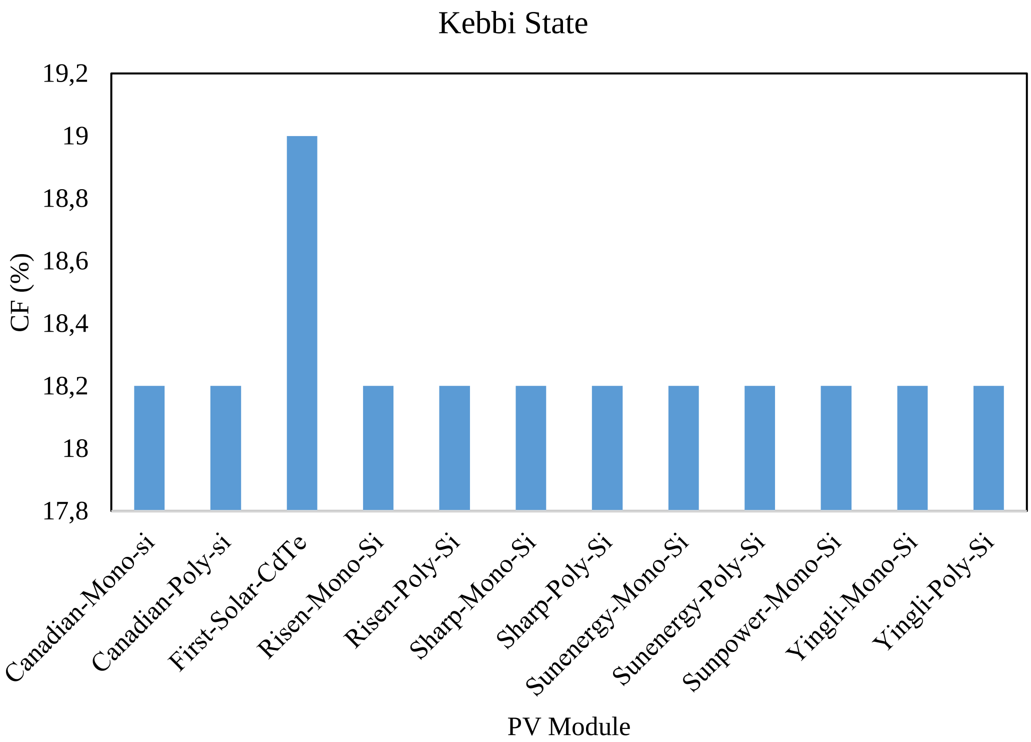

Benue State
CF (%)
16,7
16,6
16,5
16,4
16,3
16,2
16,1
16
15,9
15,8
15,7
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

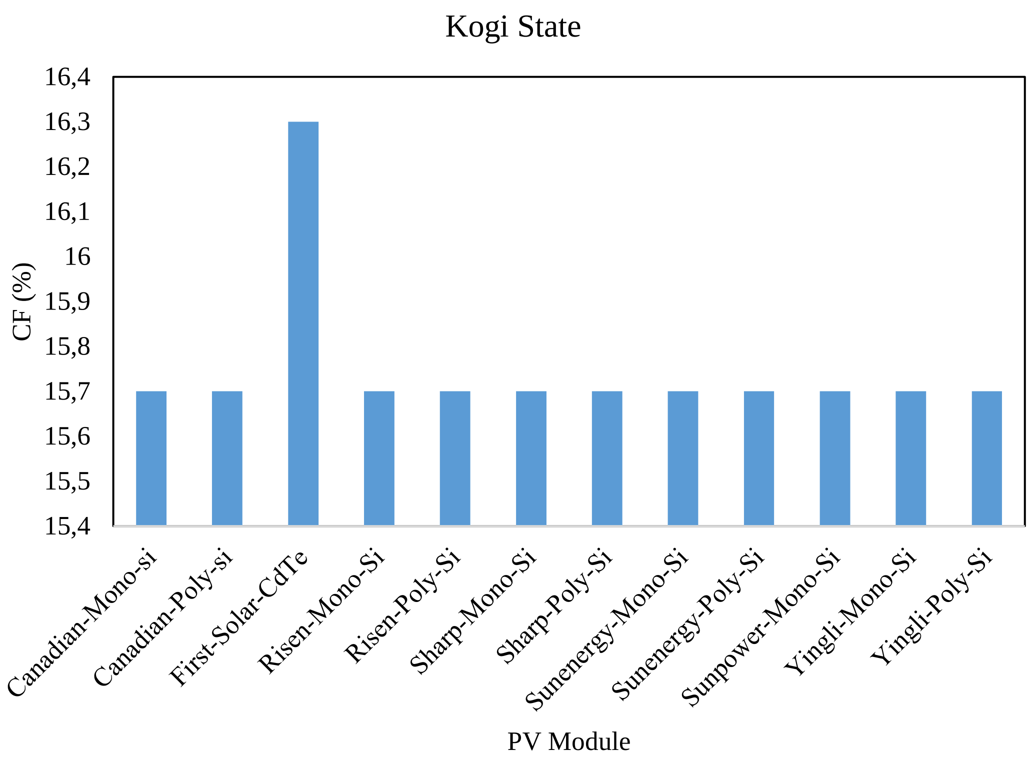

Borno State
CF (%)
19
18,8
18,6
18,4
18,2
18
17,8
17,6
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

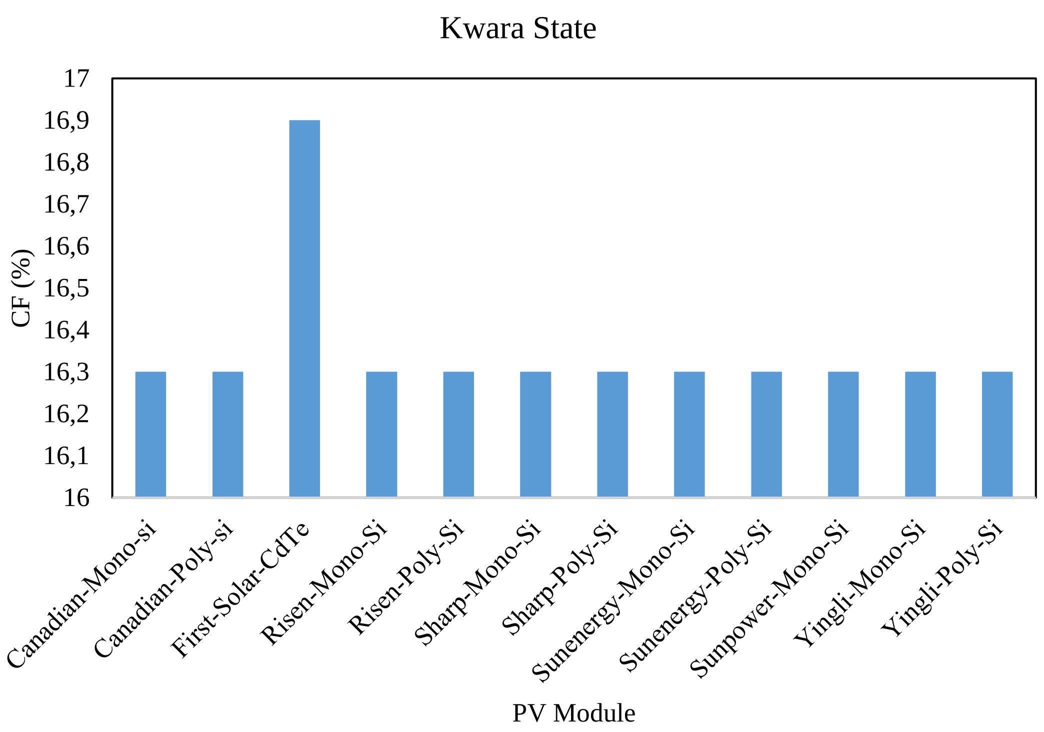

Kaduna State
CF (%)
18,3
18,2
18,1
18
17,9
17,8
17,7
17,6
17,5
17,4
17,3
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

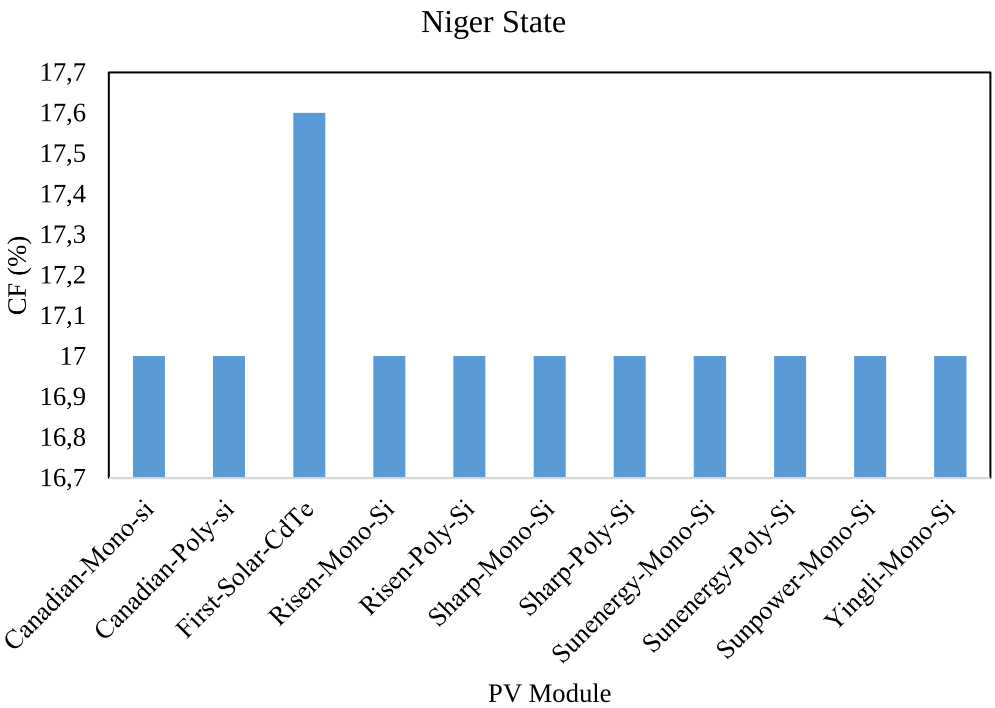

Kano State
CF (%)
19
18,8
18,6
18,4
18,2
18
17,8
17,6
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module


Katsina State
19,2
19
18,8
18,6
18,4
18,2
18
17,8
CF (%)
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

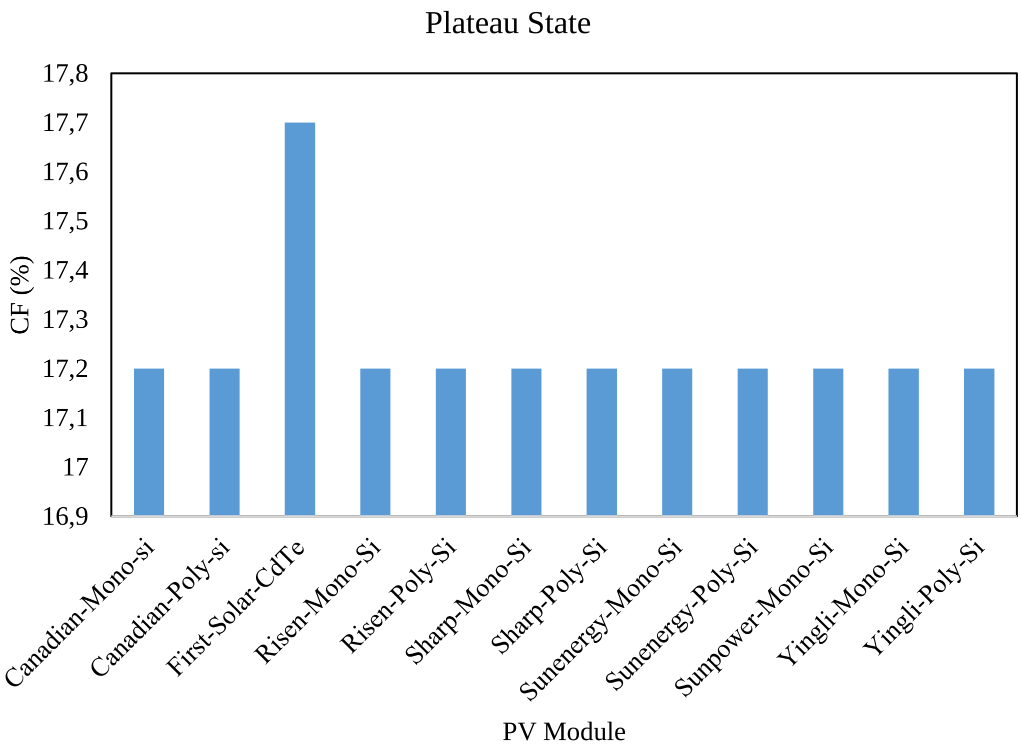

Kebbi State
19,2
19
18,8
18,6
18,4
18,2
18
17,8
CF (%)
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module


Kogi State
CF (%)
16,4
16,3
16,2
16,1
16
15,9
15,8
15,7
15,6
15,5
15,4
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

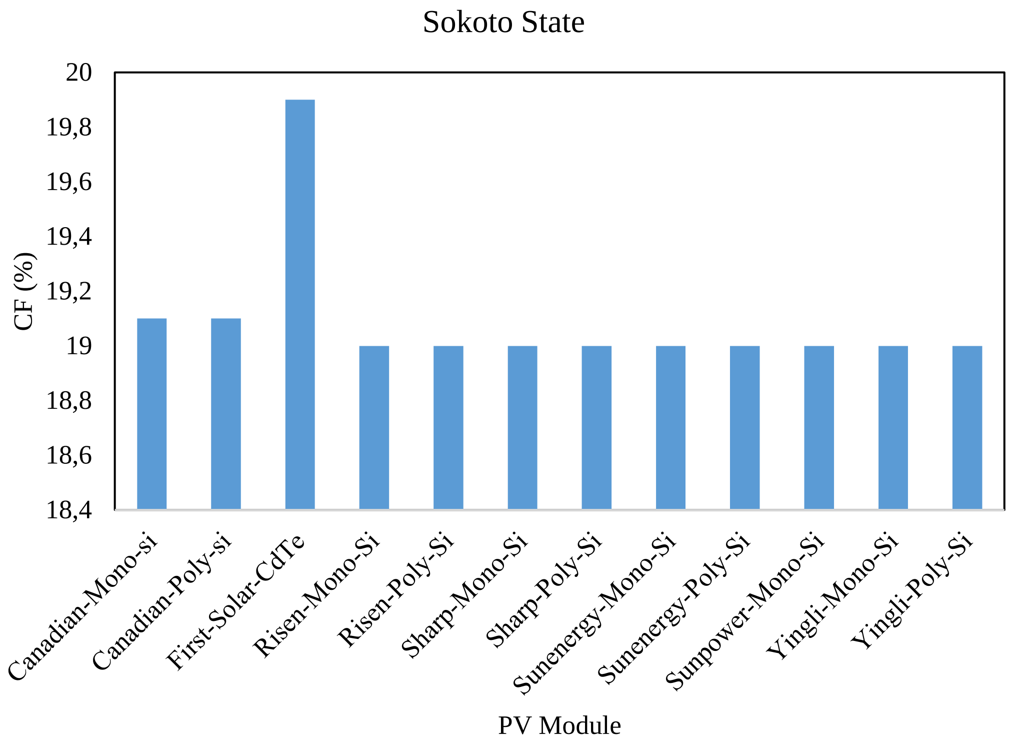

Kwara State
CF (%)
17
16,9
16,8
16,7
16,6
16,5
16,4
16,3
16,2
16,1
16
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module



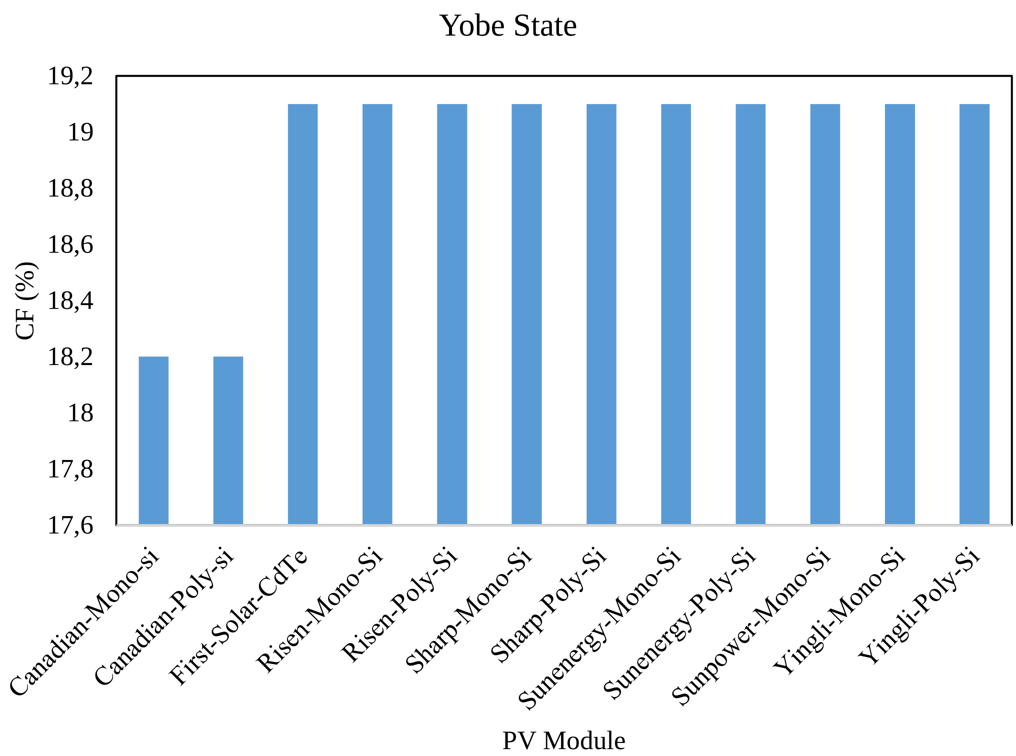
Niger State
CF (%)
17,7
17,6
17,5
17,4
17,3
17,2
17,1
17
16,9
16,8
16,7
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
PV Module

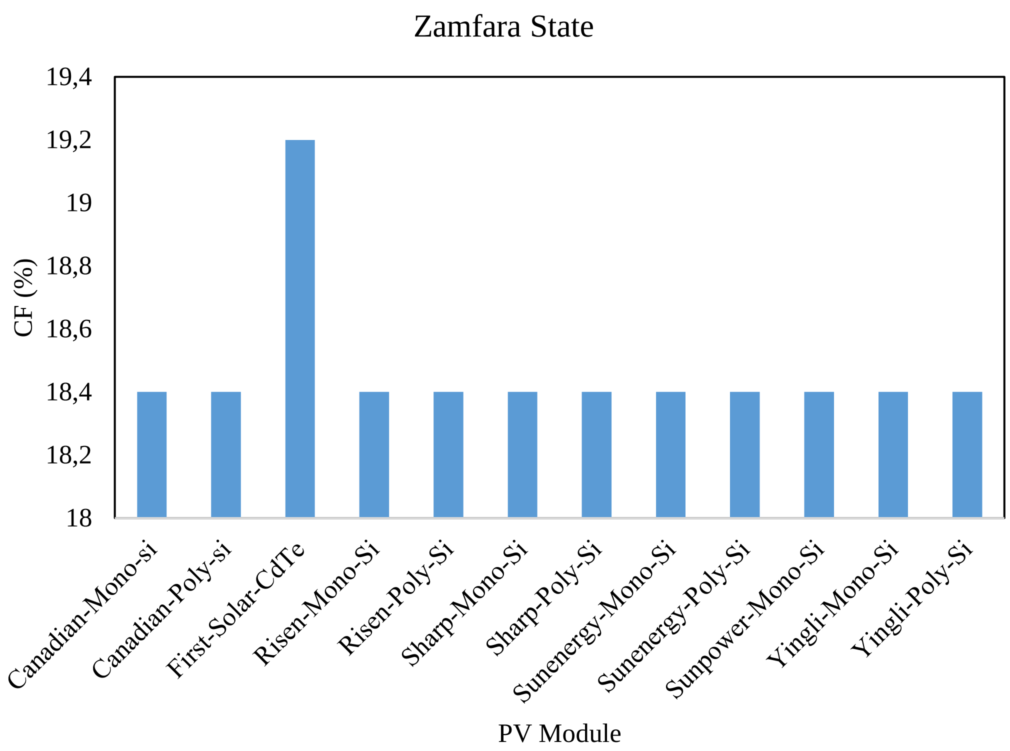
Plateau State
CF (%)
17,8
17,7
17,6
17,5
17,4
17,3
17,2
17,1
17
16,9
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module



Sokoto State
CF (%)
20
19,8
19,6
19,4
19,2
19
18,8
18,6
18,4
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

Yobe State
CF (%)
19,2
19
18,8
18,6
18,4
18,2
18
17,8
17,6
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module




**B. Capacity Factor**

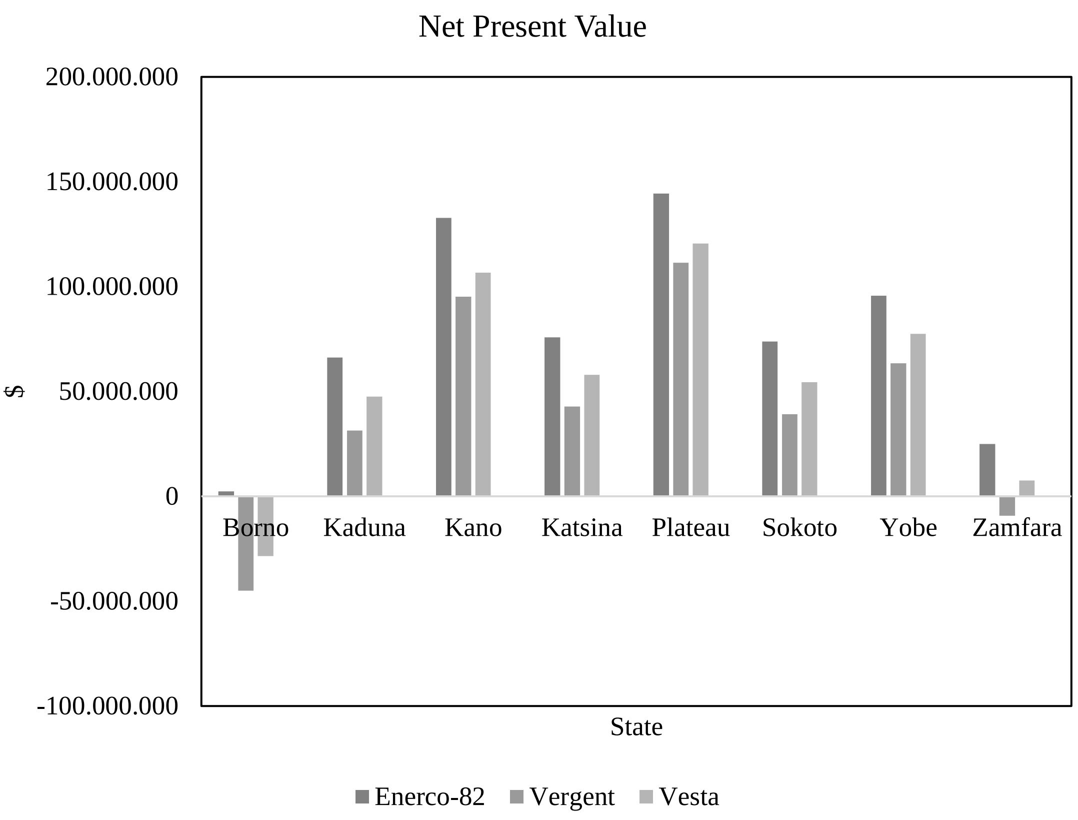
**Figure 4. 9**: The proposed PV systems' annual power generation and capacity factor.

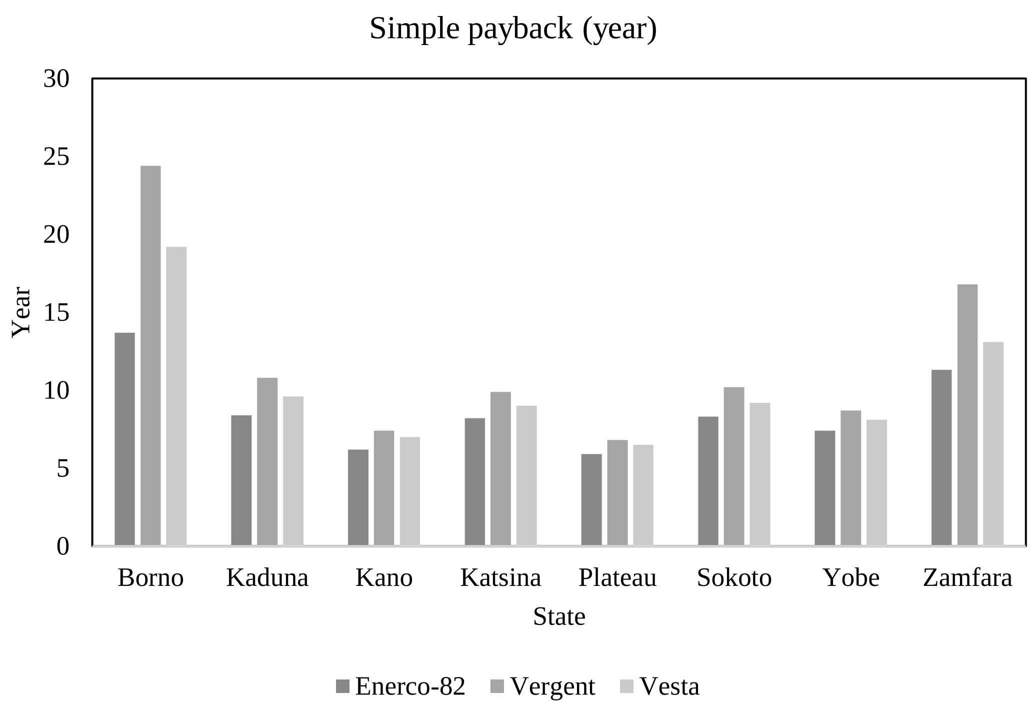
### 4.3.2. Financial and Emission Reduction Analysis Simulation Results

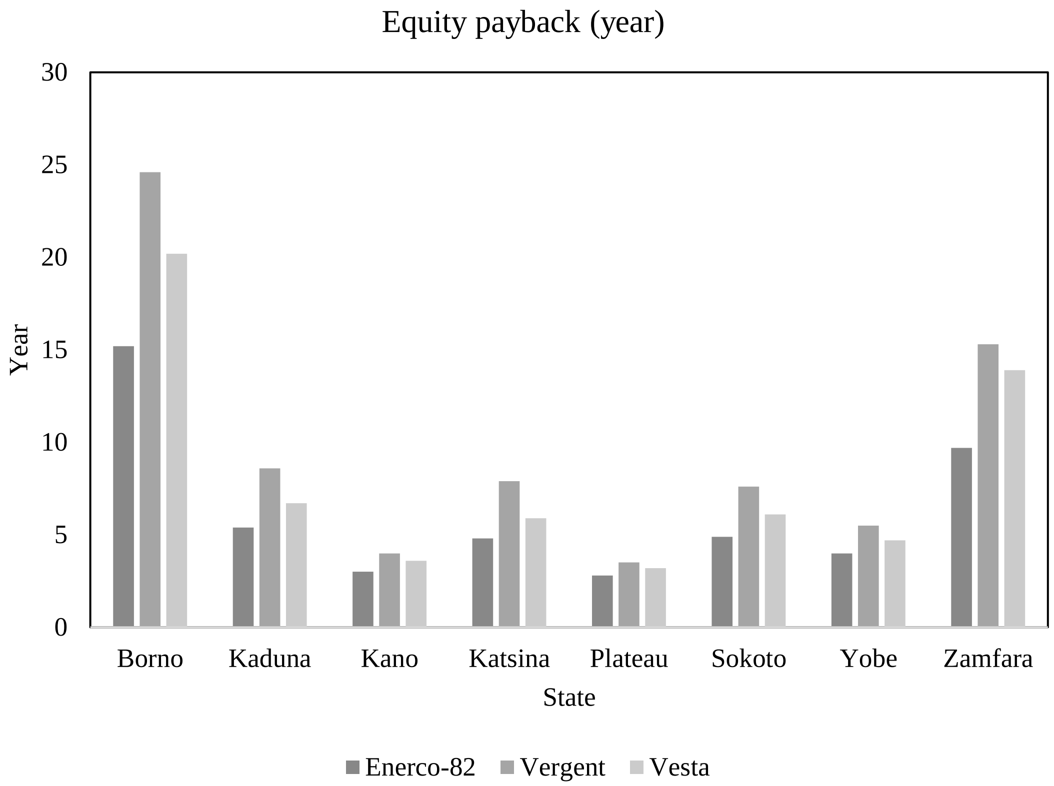
Economic analysis is critical for determining the project's economic feasibility and informing investors and politicians. The RETScreen software calculated the financial metrics NPV, ALCS, LCOE, SP, and EP based on the provided values.

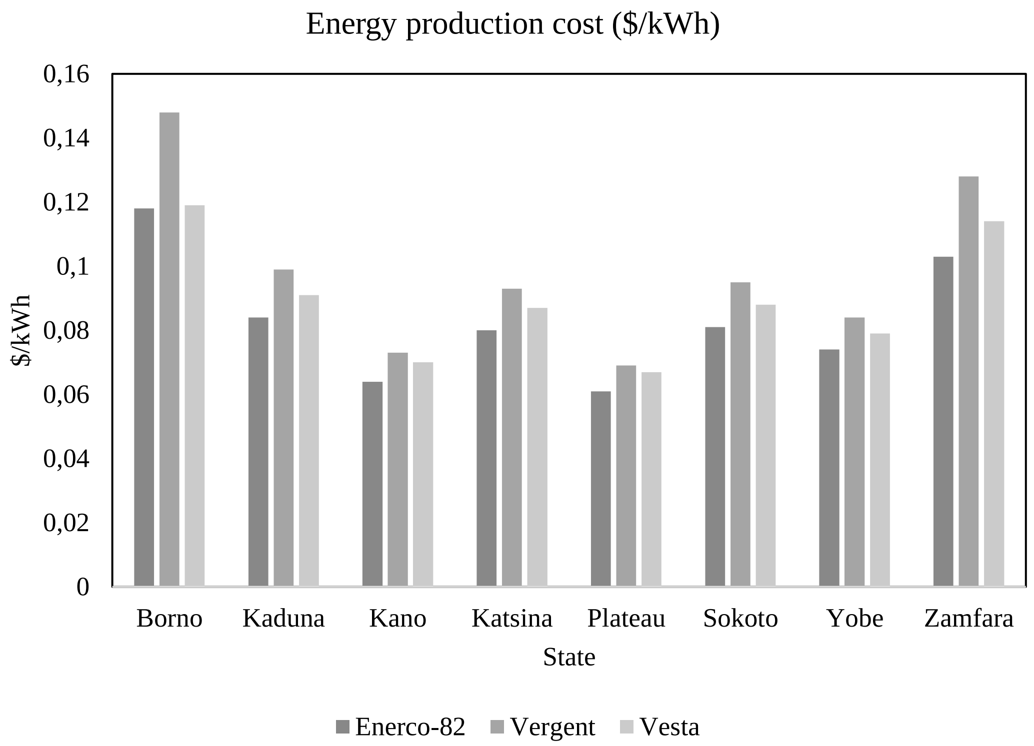
#### A. Wind Financial and Emission Reduction Analysis

Based on (Owolabi et al., 2019), the primary determinants of economic viability to considered in measuring the sustainability of wind project are NPV and the payback period. As result, the NPV values of all selected locations (Figure 4.10) are positive based on the performed analysis result, thus, qualified the proposed estimated project to be financially and economically viable based on (Rehman et al., 2017; Owolabi et al., 2019).


Net Present Value
200.000.000
150.000.000
100.000.000
50.000.000
0
-50.000.000
-100.000.000
$
Borno
Kaduna
Kano
Katsina
Plateau
Sokoto
Yobe
Zamfara
State
Enerco-82
Vergent
Vesta


Simple payback (year)
30
25
20
15
10
5
0
Year
Borno
Kaduna
Kano
Katsina
Plateau
Sokoto
Yobe
Zamfara
State
Enerco-82
Vergent
Vesta


Equity payback (year)
30
25
20
15
10
5
0
Year
Borno
Kaduna
Kano
Katsina
Plateau
Sokoto
Yobe
Zamfara
State
Enerco-82
Vergent
Vesta


Energy production cost ($/kWh)
0,16
0,14
0,12
0,1
0,08
0,06
0,04
0,02
0
$/kWh
Borno
Kaduna
Kano
Katsina
Plateau
Sokoto
Yobe
Zamfara
State
Enerco-82
Vergent
Vesta

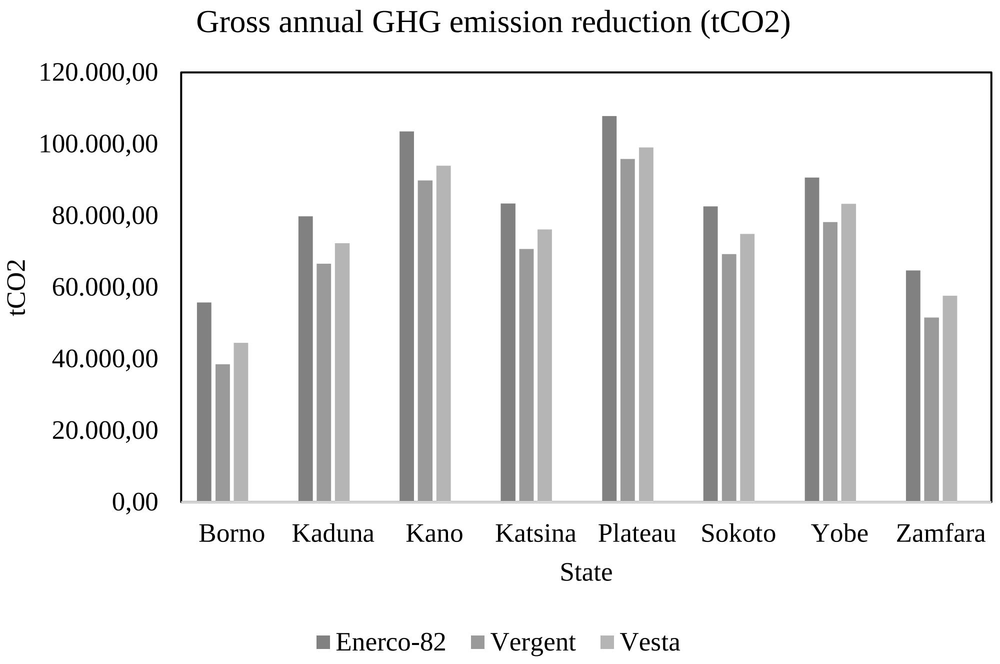



**Figure 4. 10**: Sensitivity study for the grid-connected wind system with a capacity of 50 MW.

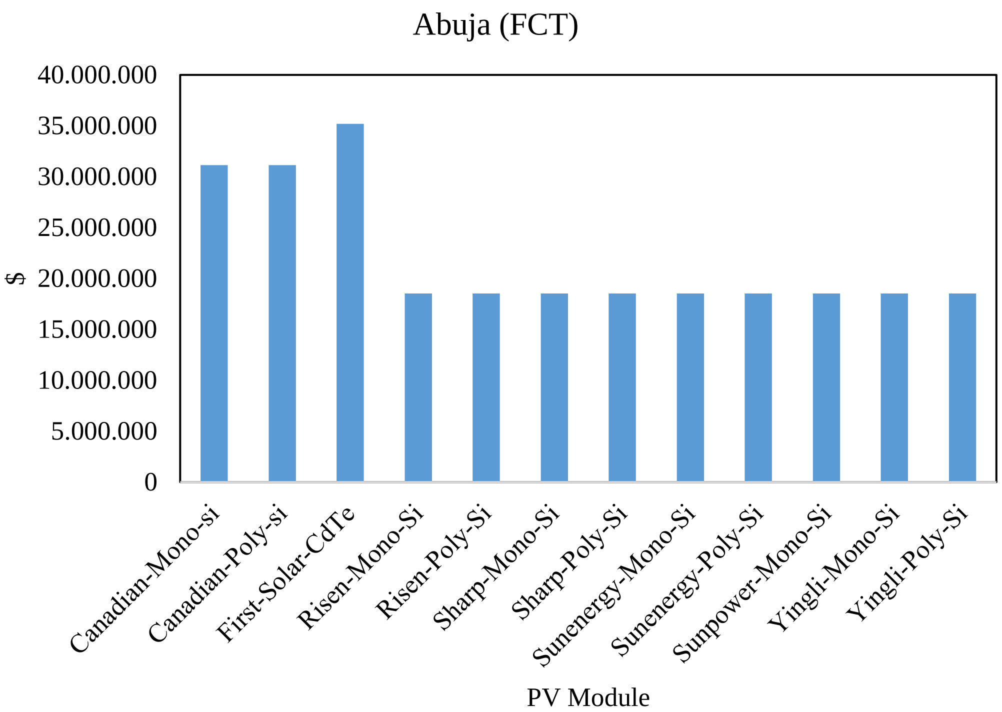
In addition, the proposed wind project has the longest payback period in the Benue State with 13.7 years' payback period, followed by Zamfara State with 11.7 years' period, while Plateau State and Kano State have the shortest payback period 5.9 and 6.2 years respectively. Moreover, Borno and Zamfara States have the highest equity payback, while Plateau and the Kano States have the lowest equity payback of 2.8 and 3 years' period, respectively, as shown in Figure 4.10.

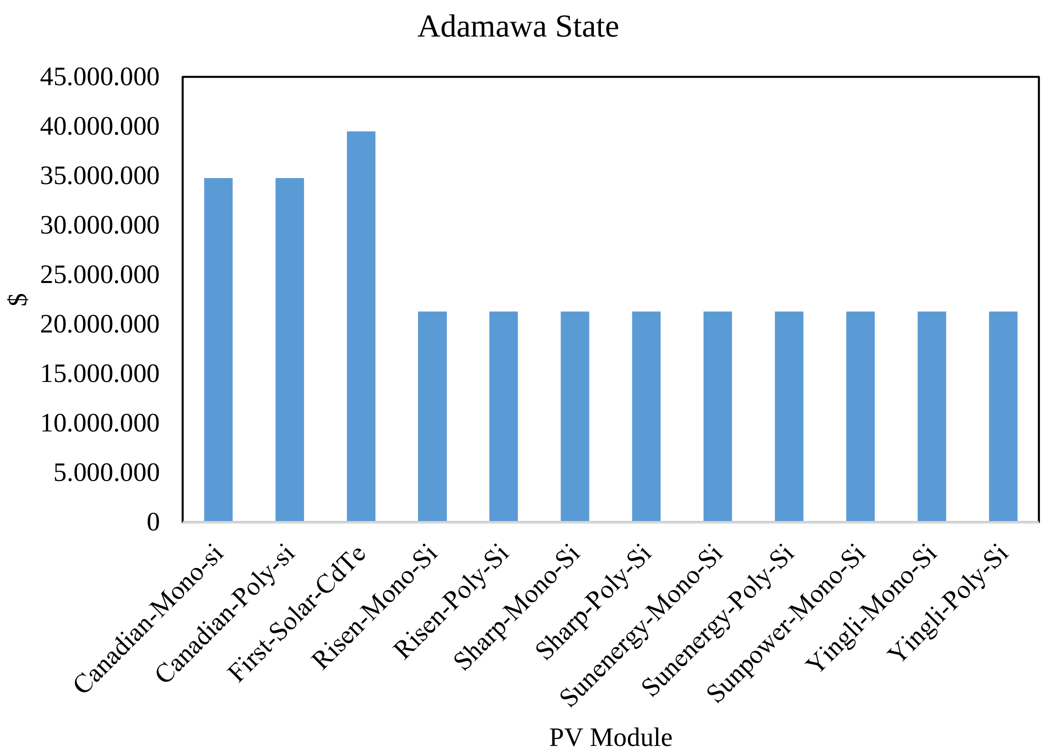
In addition, the Plateau and Kano States were found to have the lowest electricity cost of 0.061 $/kWh and 0.064 $/kWh respectively, followed by Yobe States with an average value of 0.074 $/kWh in the North-Eastern region of Nigeria, while the Borno and Zamfara States have the highest average electricity cost of 0.0118 $/kWh and 0.0103 $/kWh, as shown in Figure 4.10.

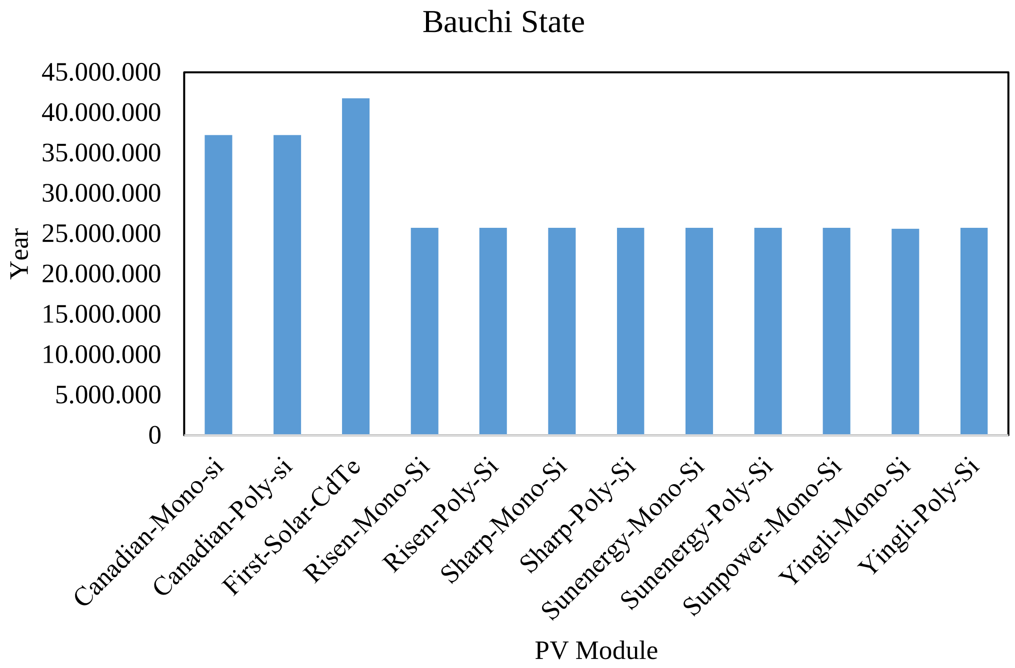
RETScreen program calculated the total yearly GHG emission reductions for each state illustrated in Figure 4.10. The project in Plateau State has the biggest GHG emission reduction of 107,839.60 tCO2, followed by the project in Kano State with a reduction of 103,537.90, and the project in Borno State with the smallest emission reduction.

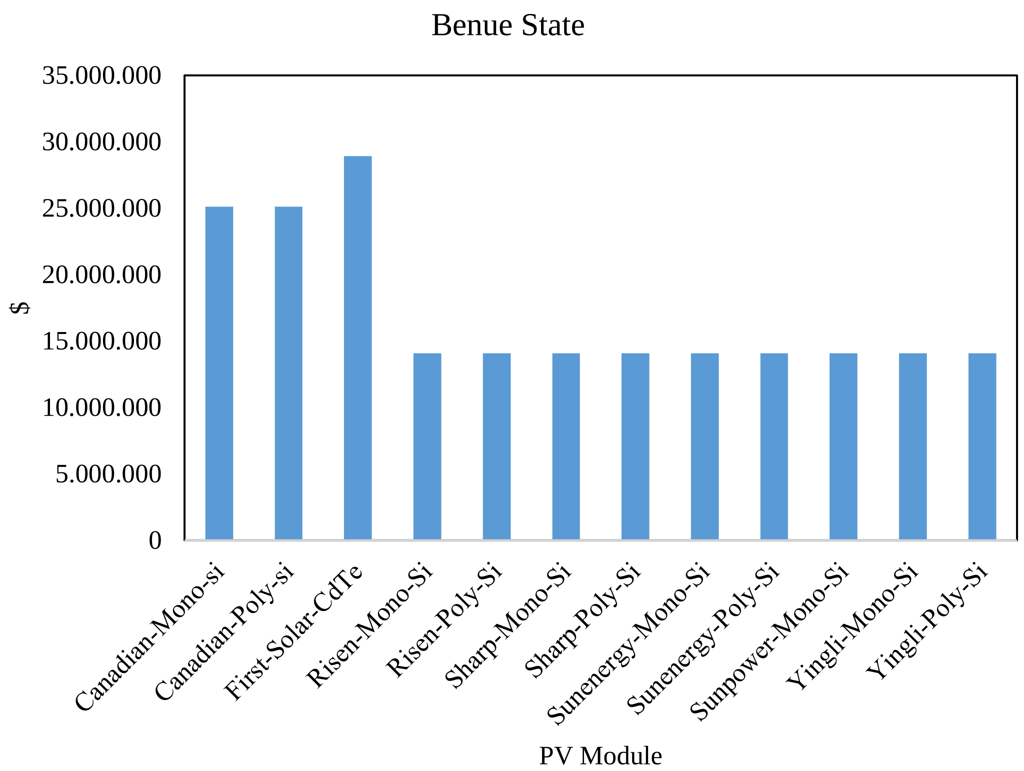
**B. PV Financial and Emission Reduction Analysis**

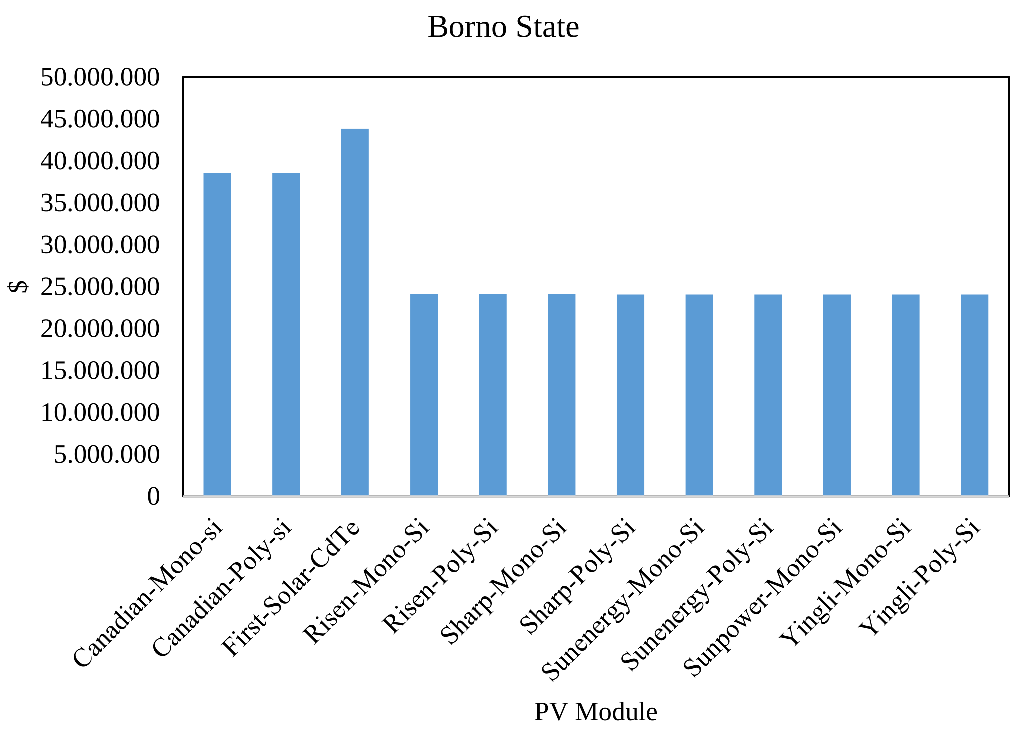
Based on Owolabi et al. (2019), the main economic factors to considered in measuring the sustainability of photovoltaic project are NPV and the payback period. As result, the NPV values of all selected locations (Figure 4.11) are positive based on the performed analysis result, thus, qualified the proposed estimated project to be financially and economically viable based on (Rehman et al., 2017; Owolabi et al., 2019).



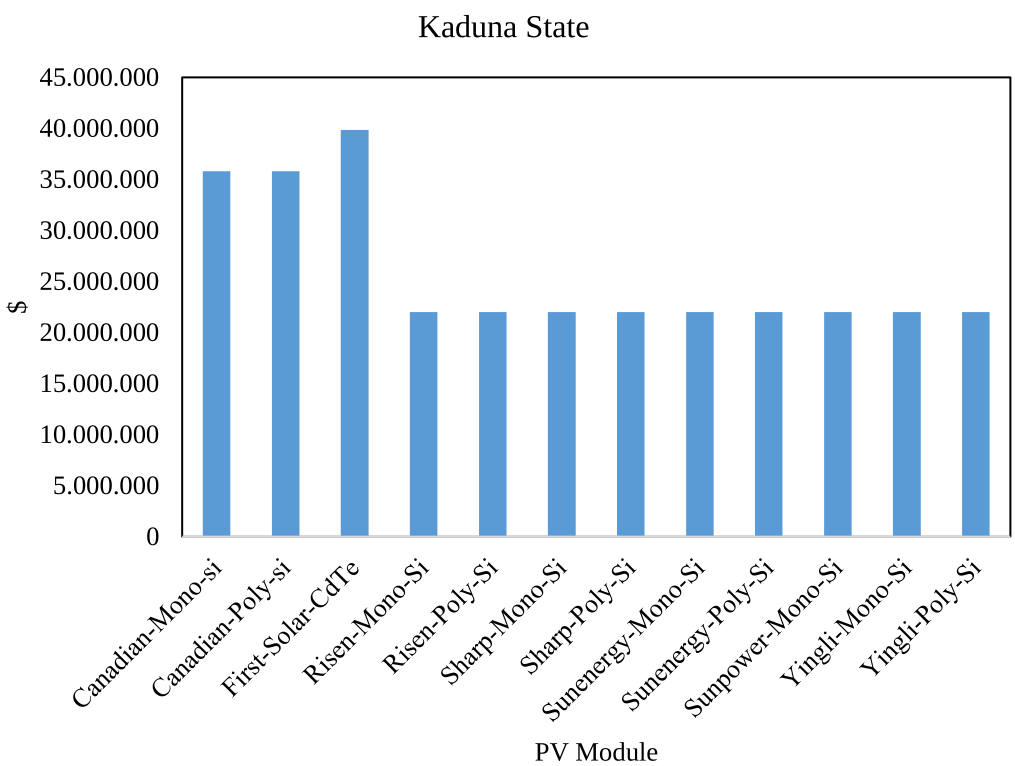

Adamawa State
45.000.000
40.000.000
35.000.000
30.000.000
25.000.000
20.000.000
15.000.000
10.000.000
5.000.000
0
$
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module


Bauchi State
45.000.000
40.000.000
35.000.000
30.000.000
25.000.000
20.000.000
15.000.000
10.000.000
5.000.000
0
Year
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

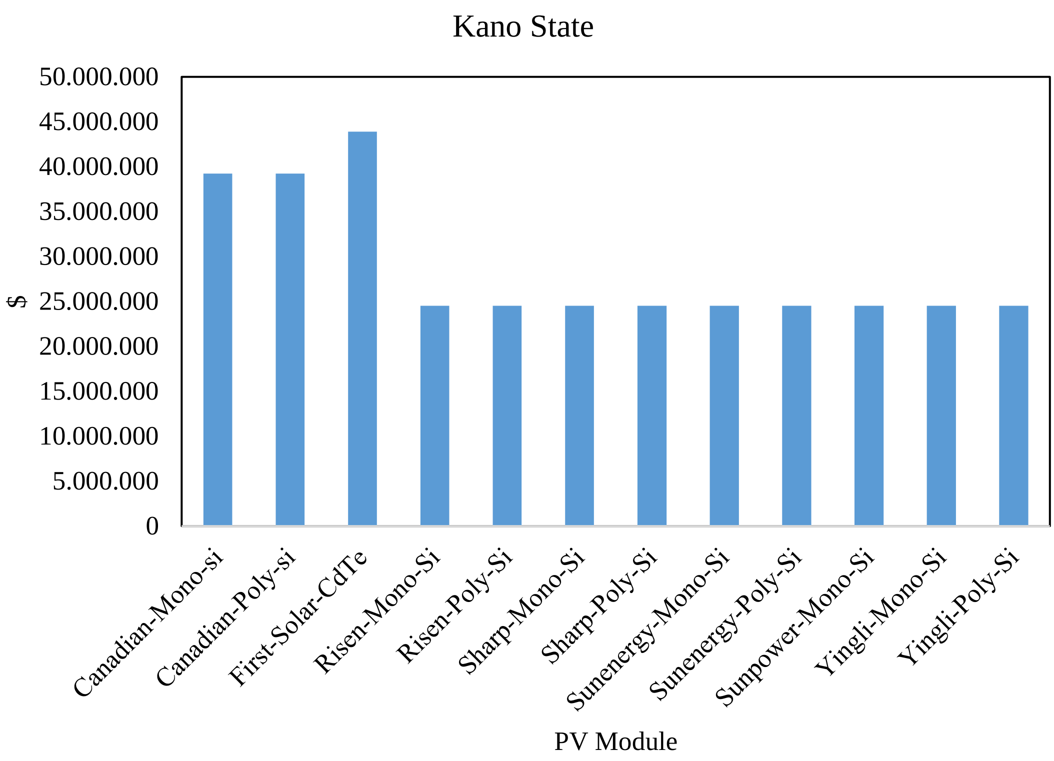

Benue State
35.000.000
30.000.000
25.000.000
20.000.000
15.000.000
10.000.000
5.000.000
0
$
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

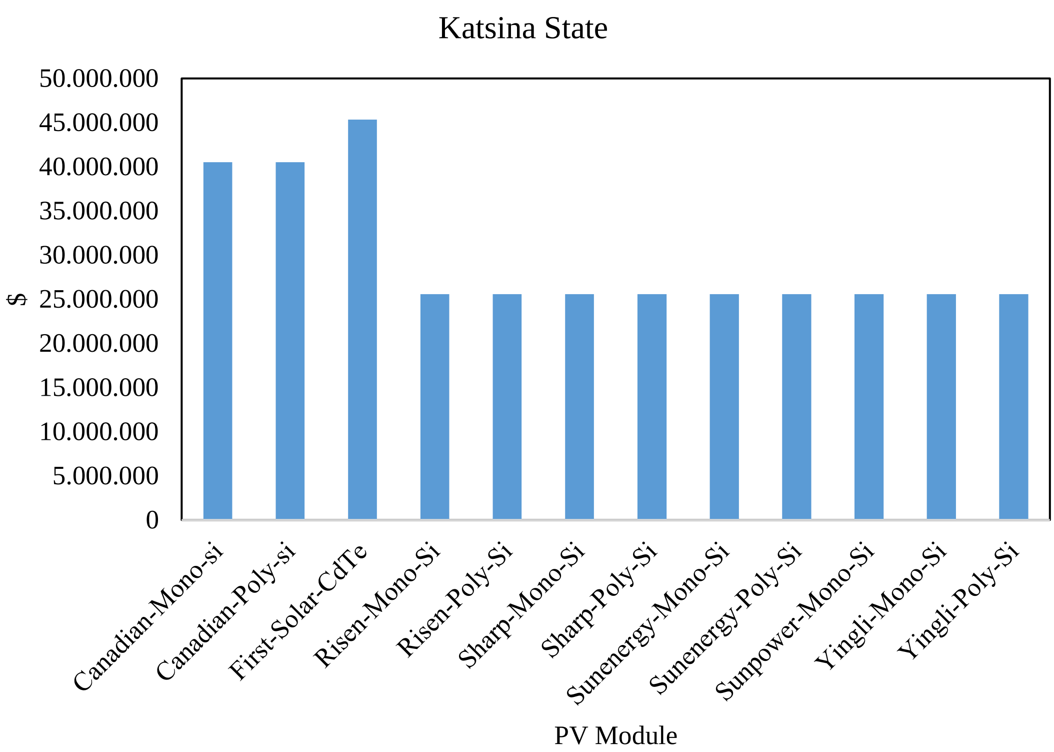


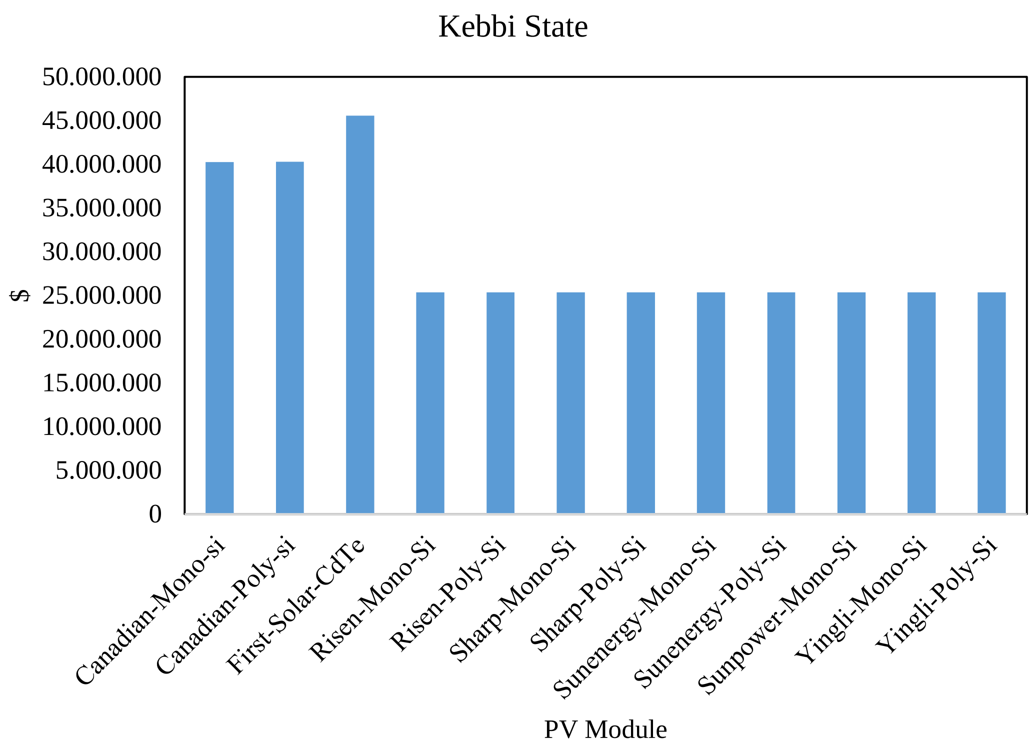
Borno State
50.000.000
45.000.000
40.000.000
35.000.000
30.000.000
25.000.000
20.000.000
15.000.000
10.000.000
5.000.000
0
$
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

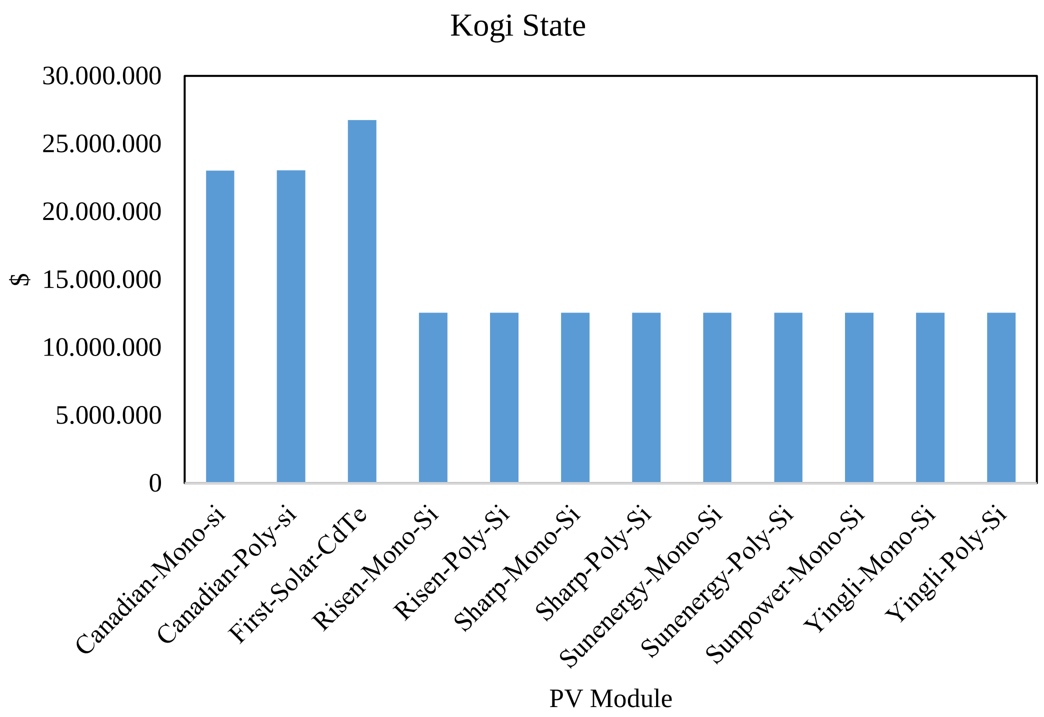
Kaduna State
45.000.000
40.000.000
35.000.000
30.000.000
25.000.000
20.000.000
15.000.000
10.000.000
5.000.000
0
$
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module


Kano State
$
50.000.000
45.000.000
40.000.000
35.000.000
30.000.000
25.000.000
20.000.000
15.000.000
10.000.000
5.000.000
0
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

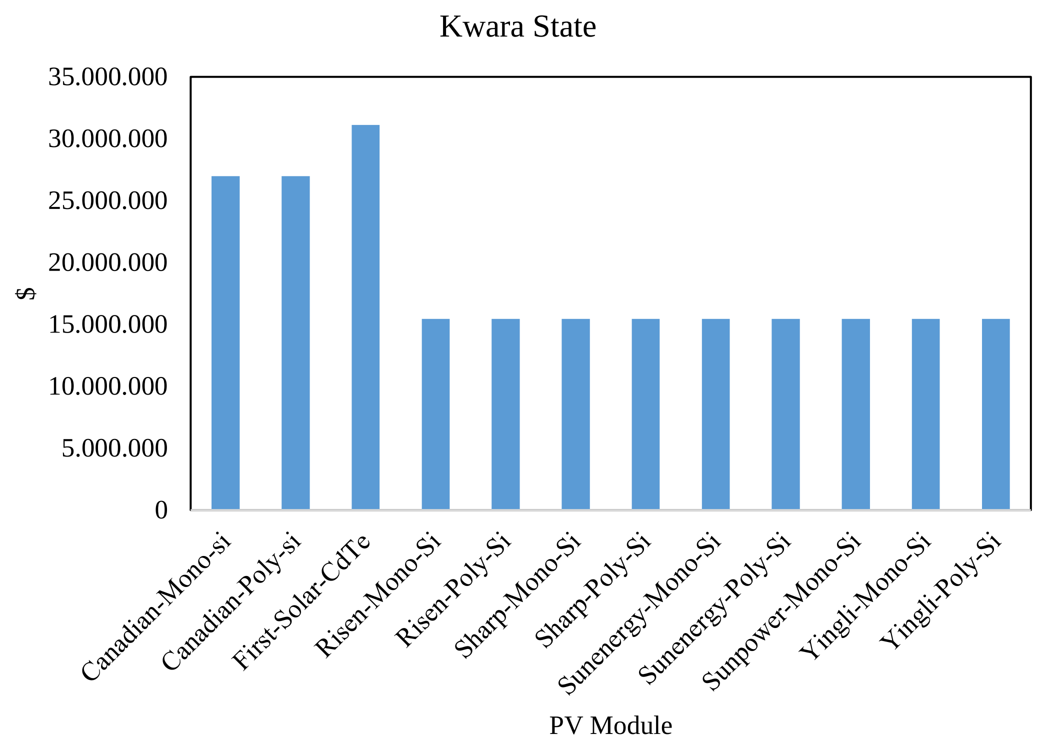

Katsina State
$
50.000.000
45.000.000
40.000.000
35.000.000
30.000.000
25.000.000
20.000.000
15.000.000
10.000.000
5.000.000
0
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

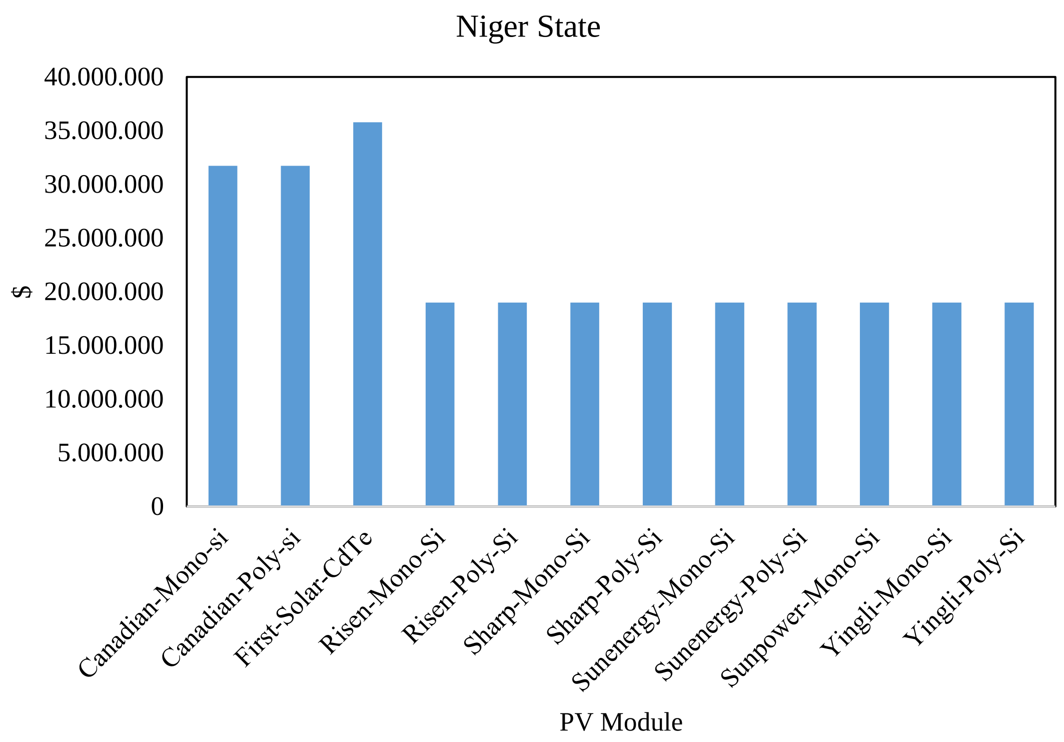


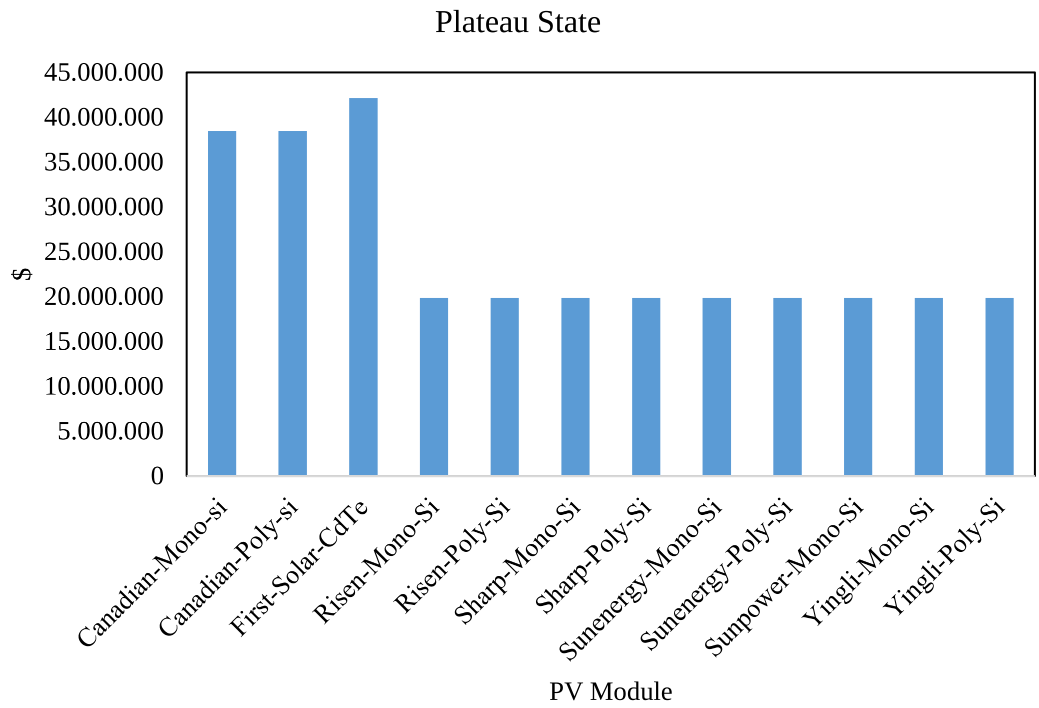
Kebbi State
50.000.000
45.000.000
40.000.000
35.000.000
30.000.000
25.000.000
20.000.000
15.000.000
10.000.000
5.000.000
0
$
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

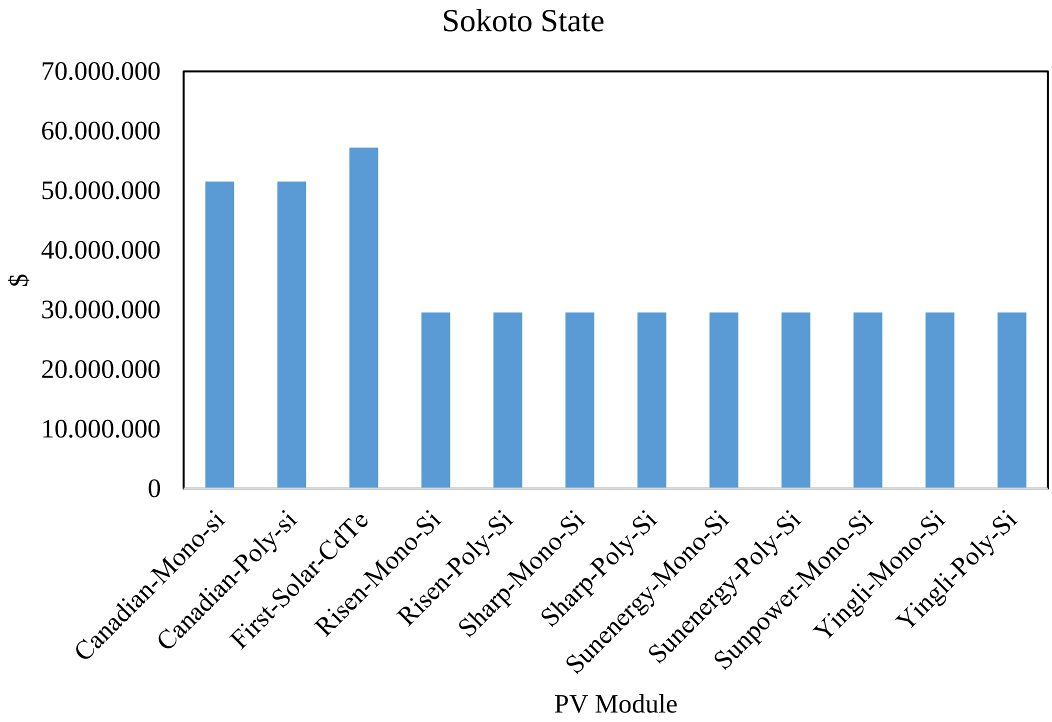



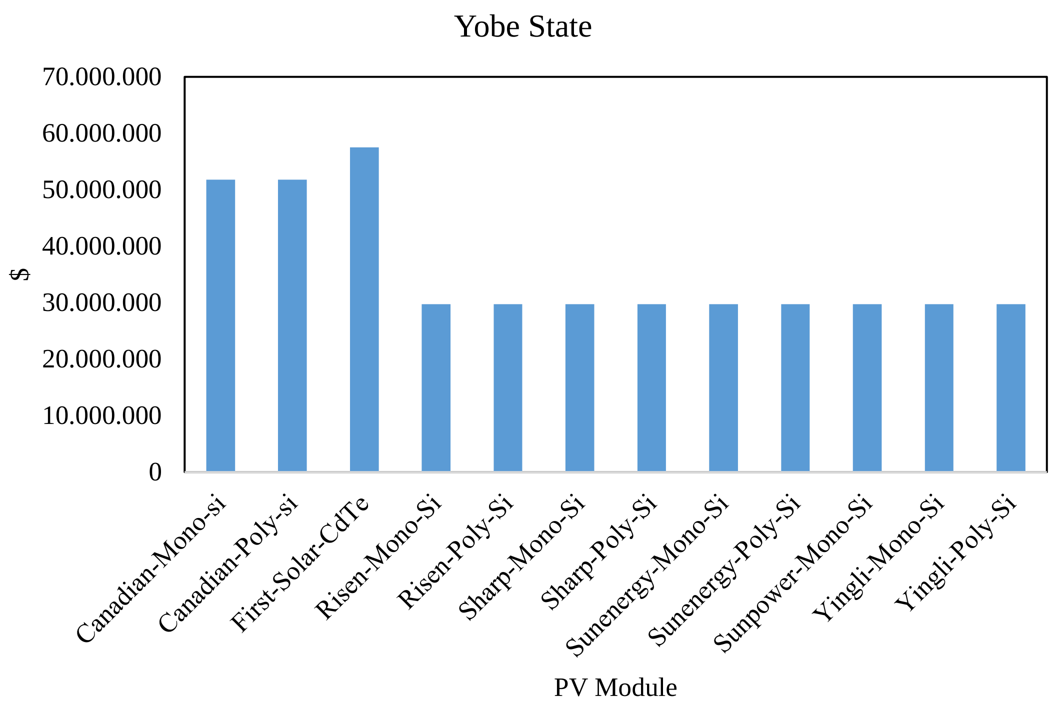
Kogi State
30.000.000
25.000.000
20.000.000
15.000.000
10.000.000
5.000.000
0
$
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

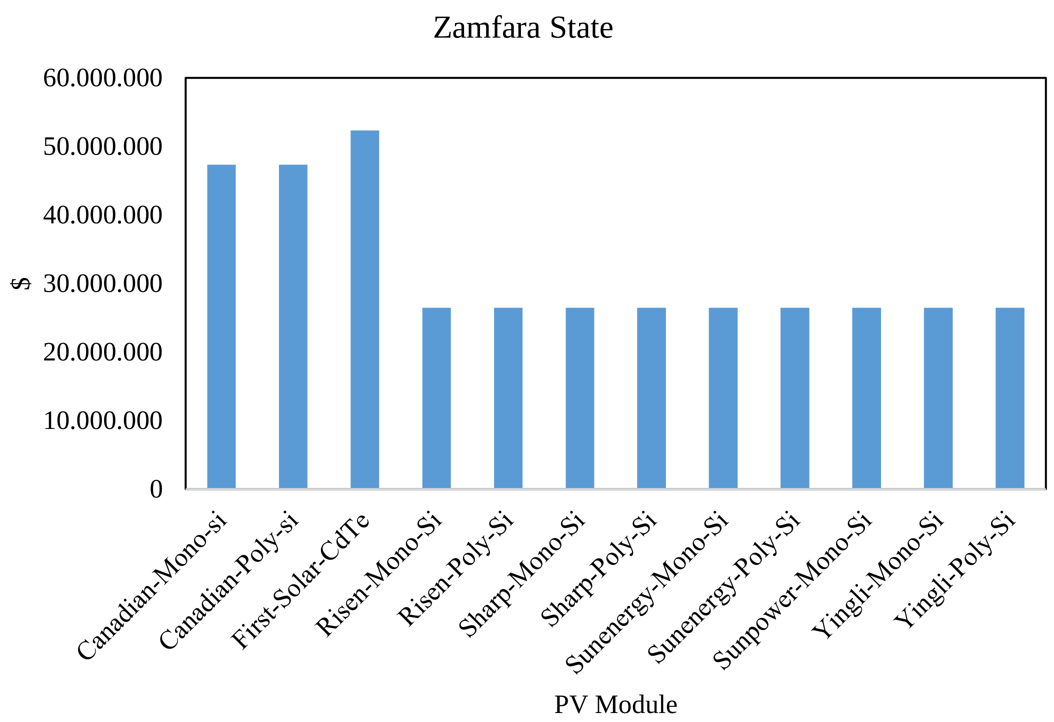

Kwara State
35.000.000
30.000.000
25.000.000
20.000.000
15.000.000
10.000.000
5.000.000
0
$
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module


Niger State
40.000.000
35.000.000
30.000.000
25.000.000
20.000.000
15.000.000
10.000.000
5.000.000
0
$
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

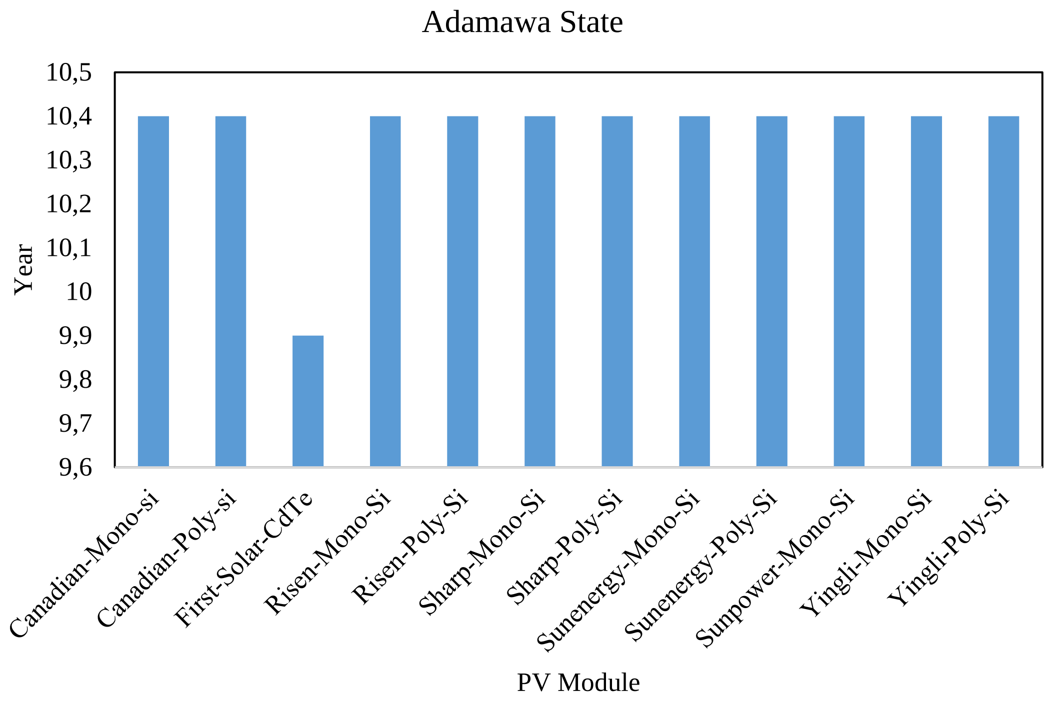

Plateau State
45.000.000
40.000.000
35.000.000
30.000.000
25.000.000
20.000.000
15.000.000
10.000.000
5.000.000
0
$
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

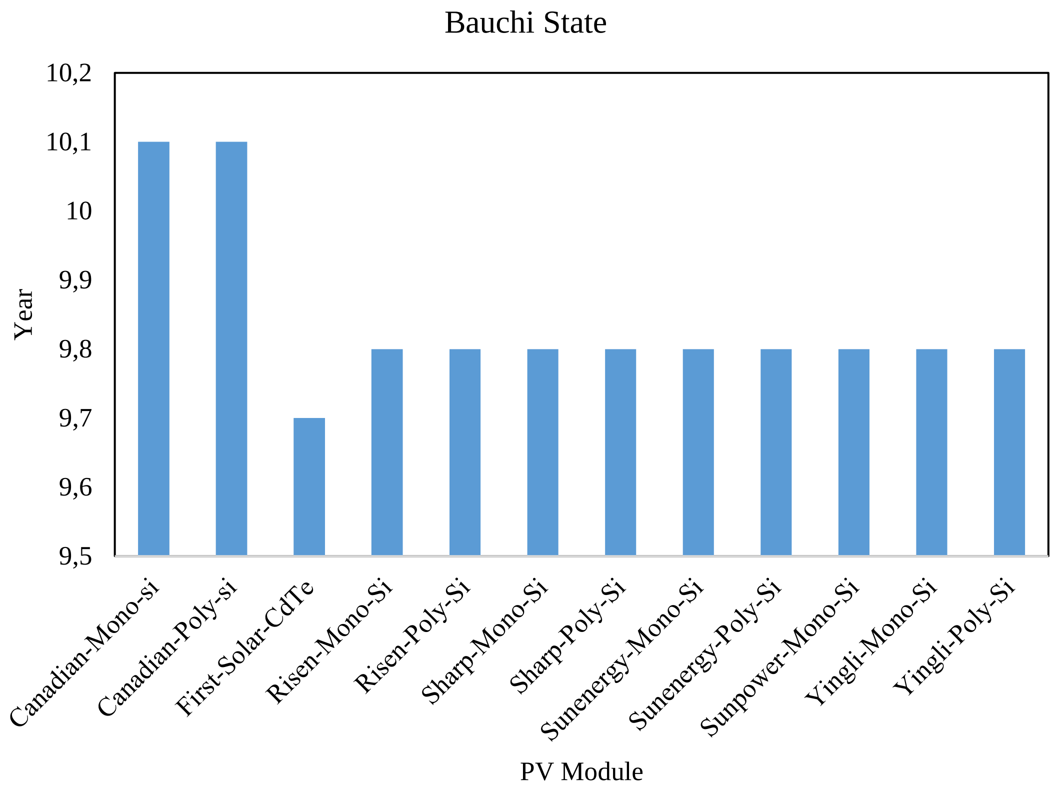

Sokoto State
70.000.000
60.000.000
50.000.000
40.000.000
30.000.000
20.000.000
10.000.000
0
$
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

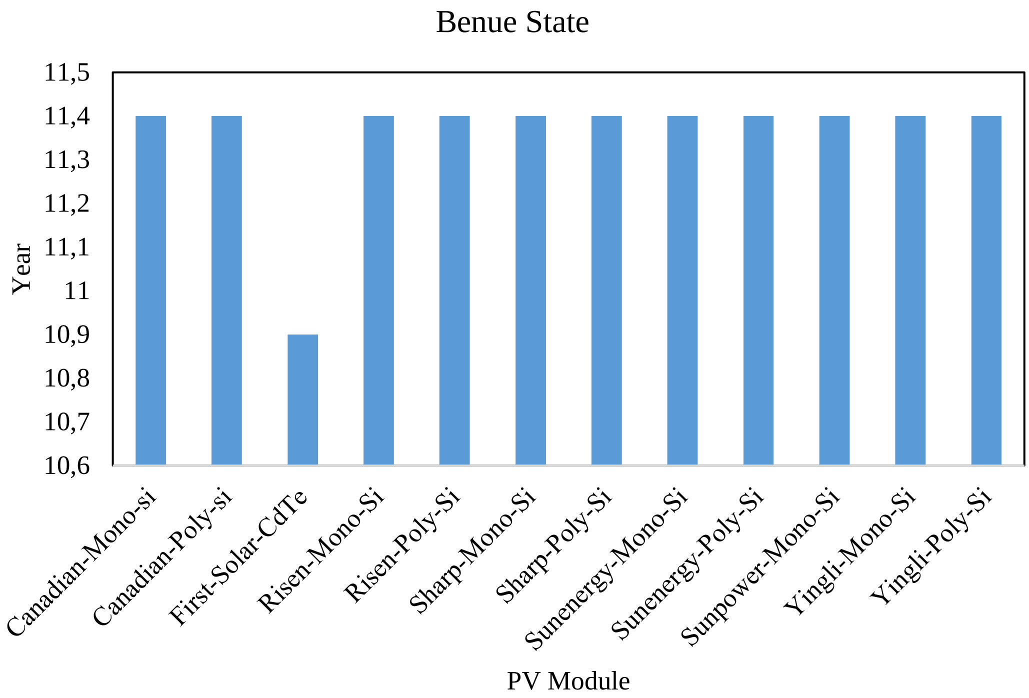


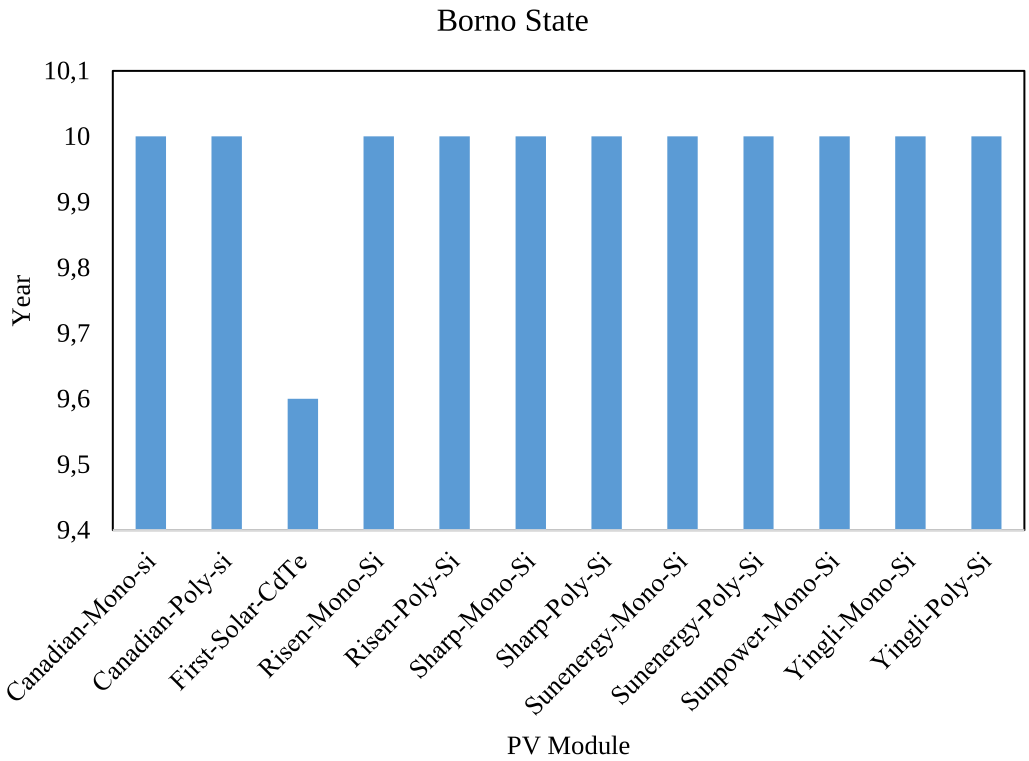



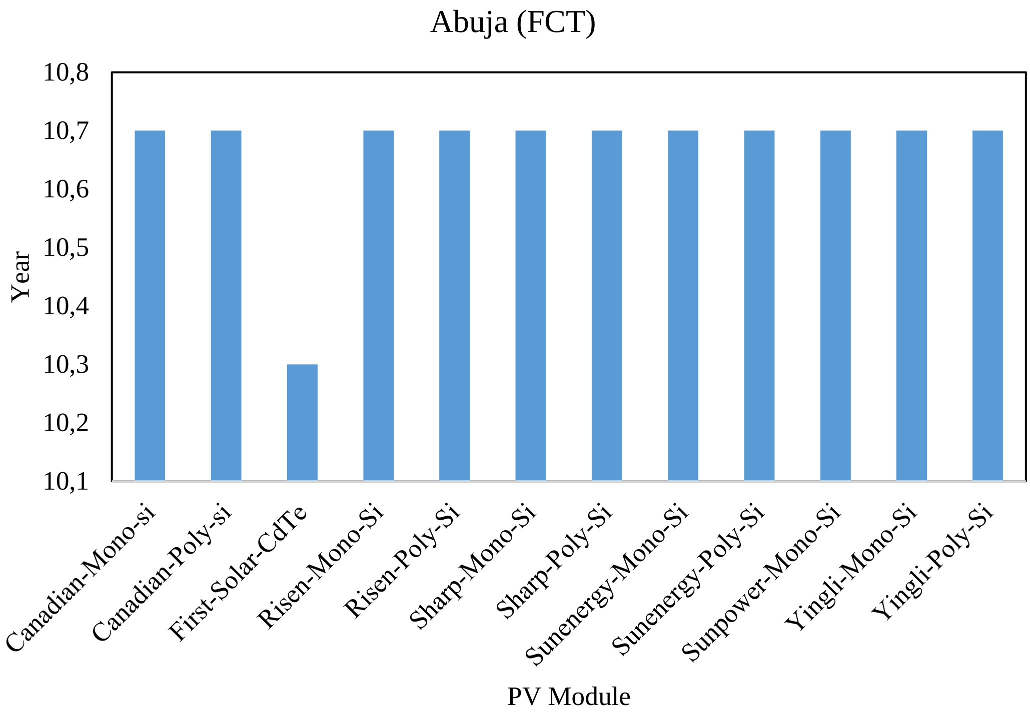

**A. Net Present Value ($)**

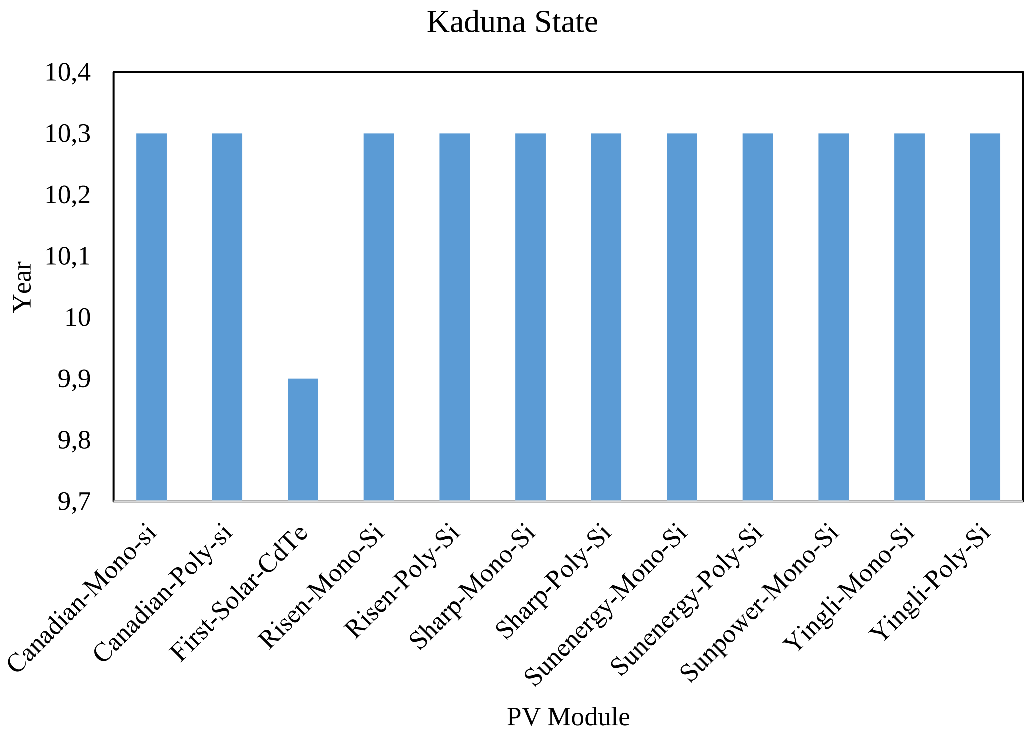

Adamawa State
Year
10,5
10,4
10,3
10,2
10,1
10
9,9
9,8
9,7
9,6
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

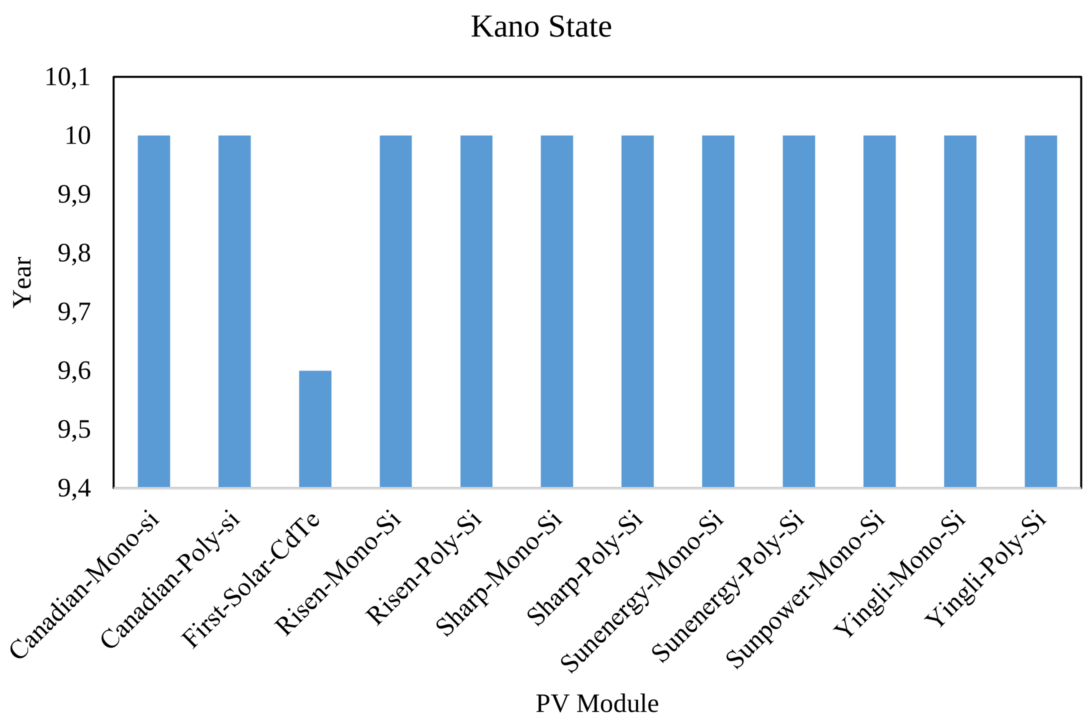

Bauchi State
Year
10,2
10,1
10
9,9
9,8
9,7
9,6
9,5
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

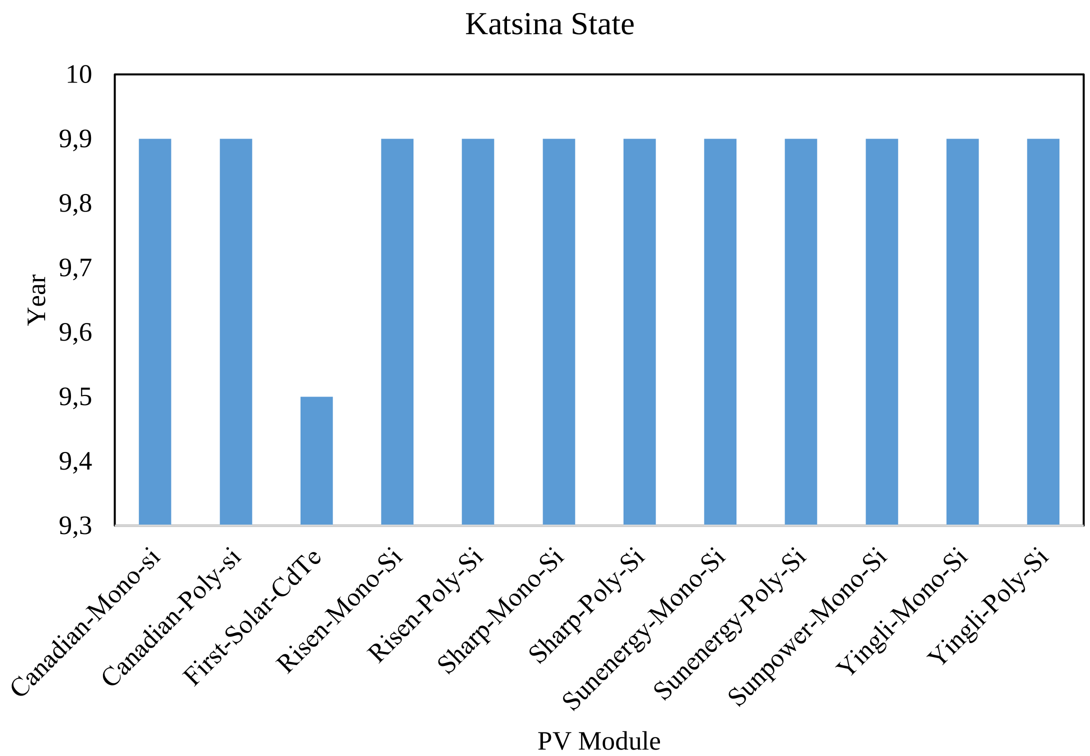

Benue State
11,5
11,4
11,3
11,2
11,1
11
10,9
10,8
10,7
10,6
Year
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

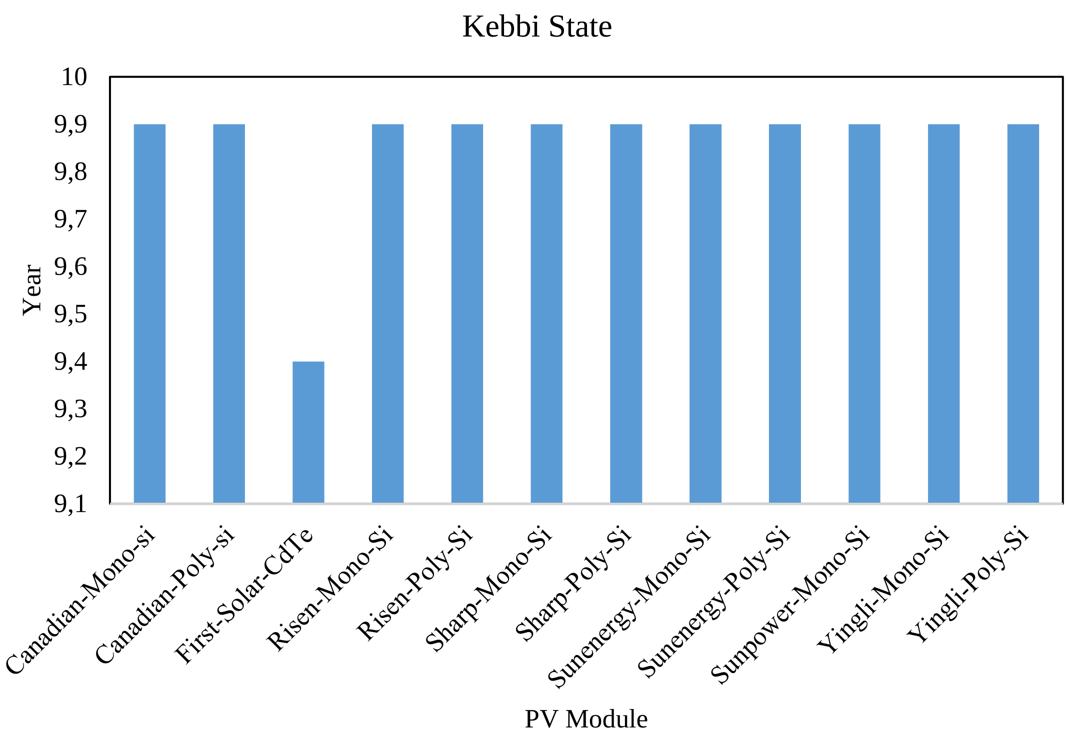

Borno State
10,1
10
9,9
9,8
9,7
9,6
9,5
9,4
Year
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

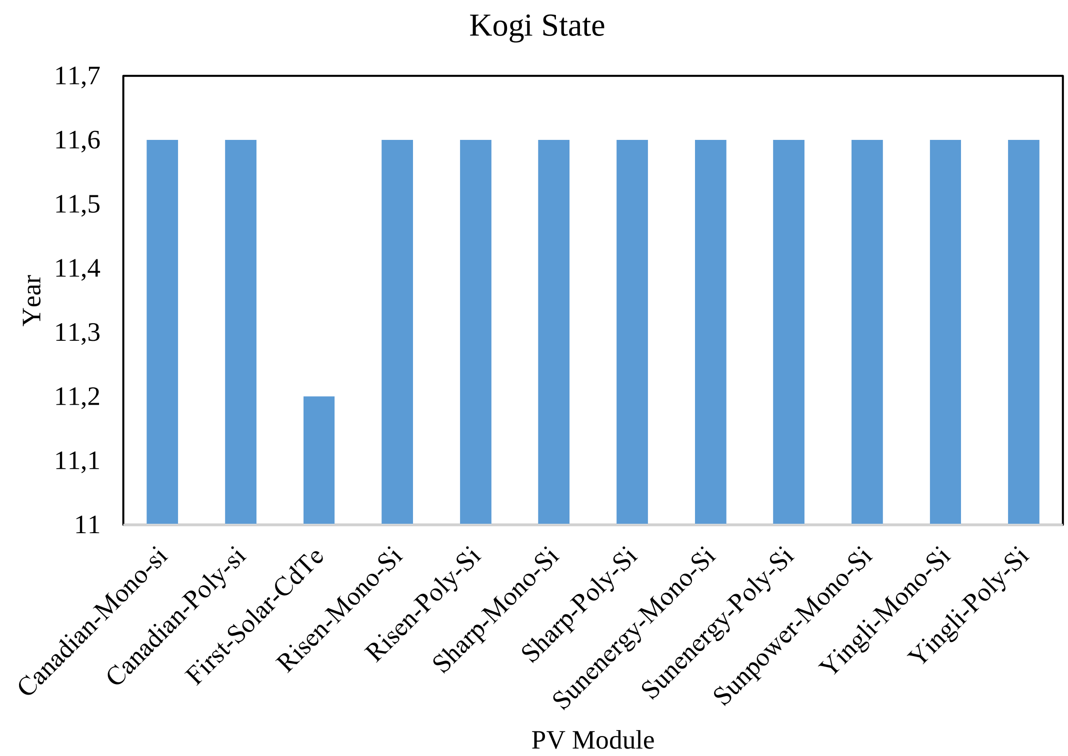

Abuja (FCT)
Year
10,8
10,7
10,6
10,5
10,4
10,3
10,2
10,1
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

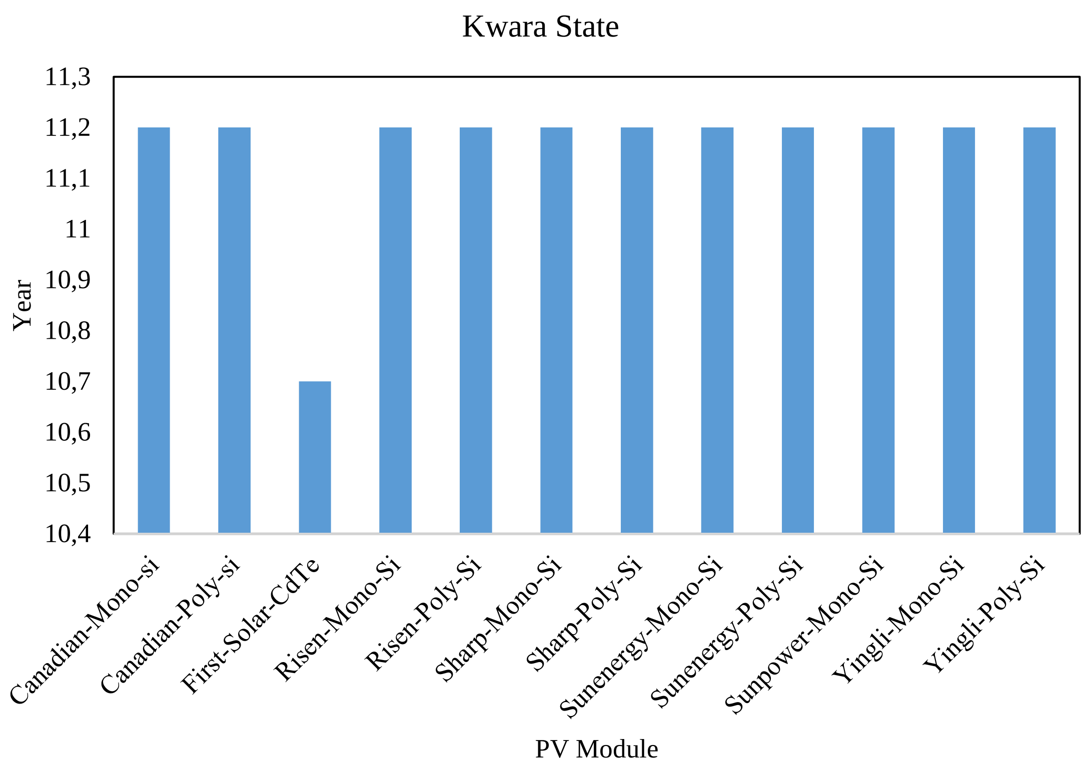

Kaduna State
Year
10,4
10,3
10,2
10,1
10
9,9
9,8
9,7
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

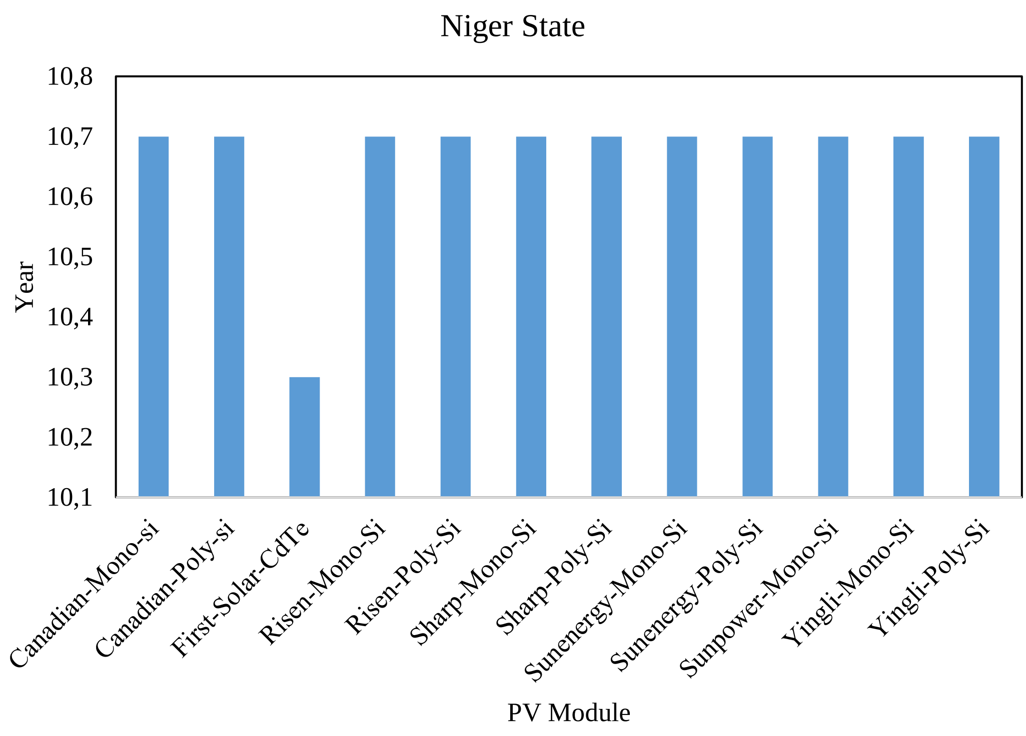

Kano State
10,1
10
9,9
9,8
9,7
9,6
9,5
9,4
Year
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

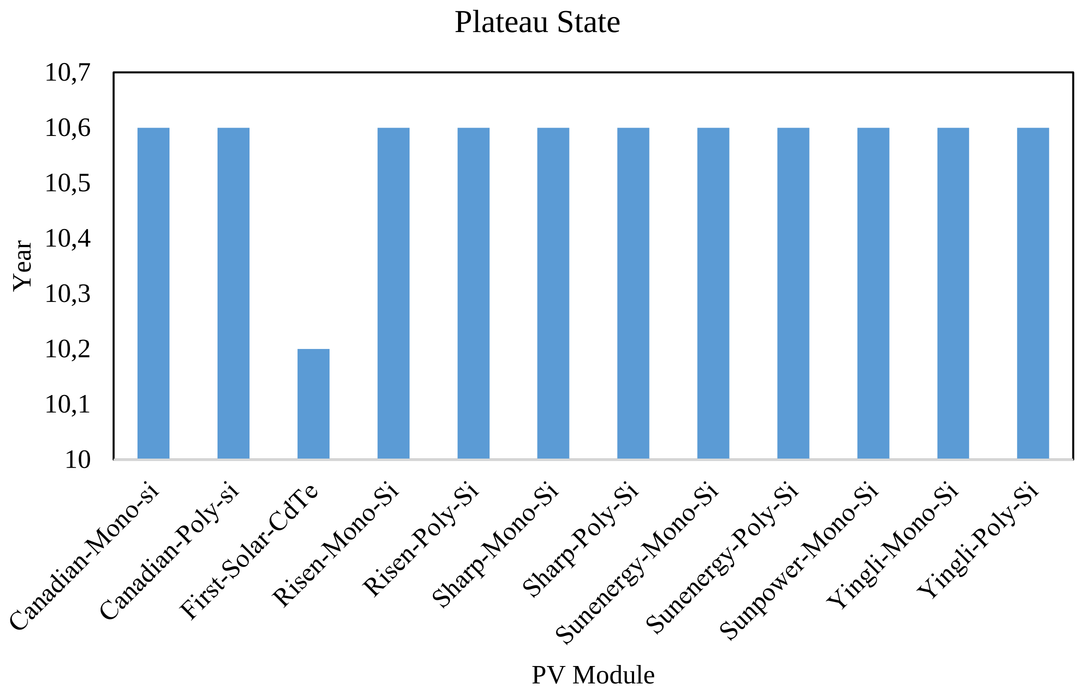

Katsina State
10
9,9
9,8
9,7
9,6
9,5
9,4
9,3
Year
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

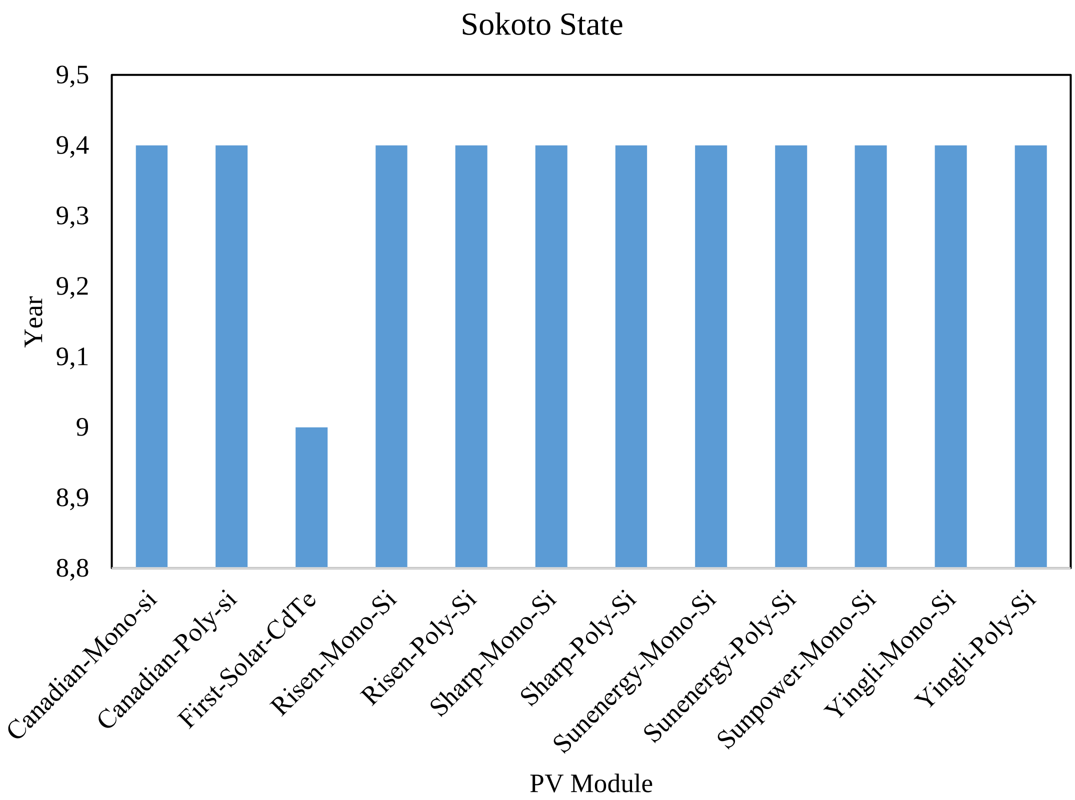

Kebbi State
10
9,9
9,8
9,7
9,6
9,5
9,4
9,3
9,2
9,1
Year
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

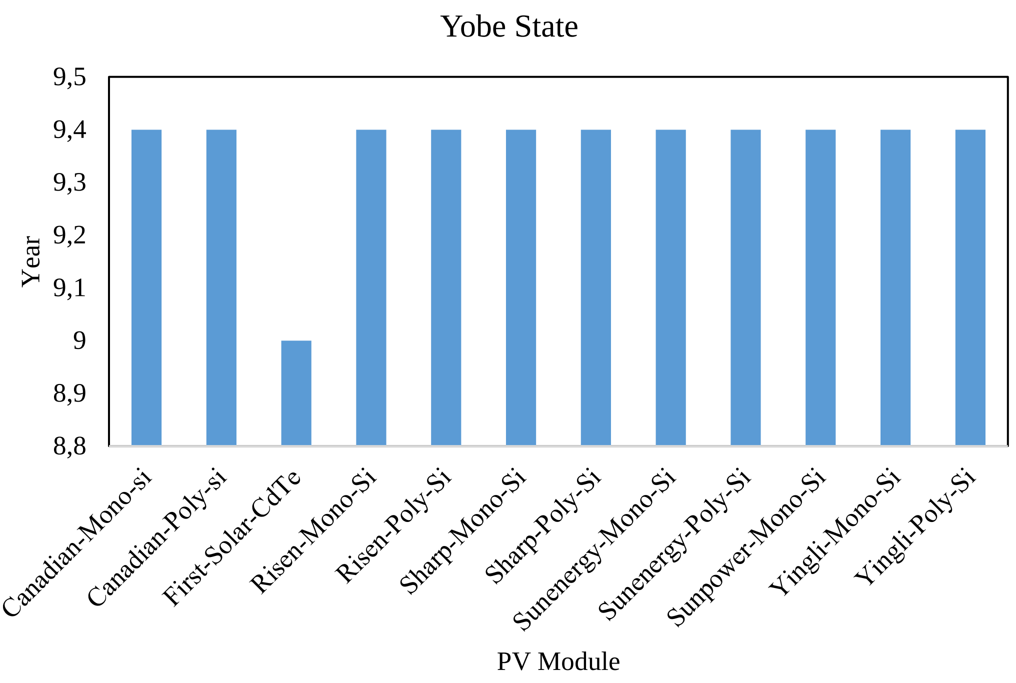

Kogi State
11,7
11,6
11,5
11,4
11,3
11,2
11,1
11
Year
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

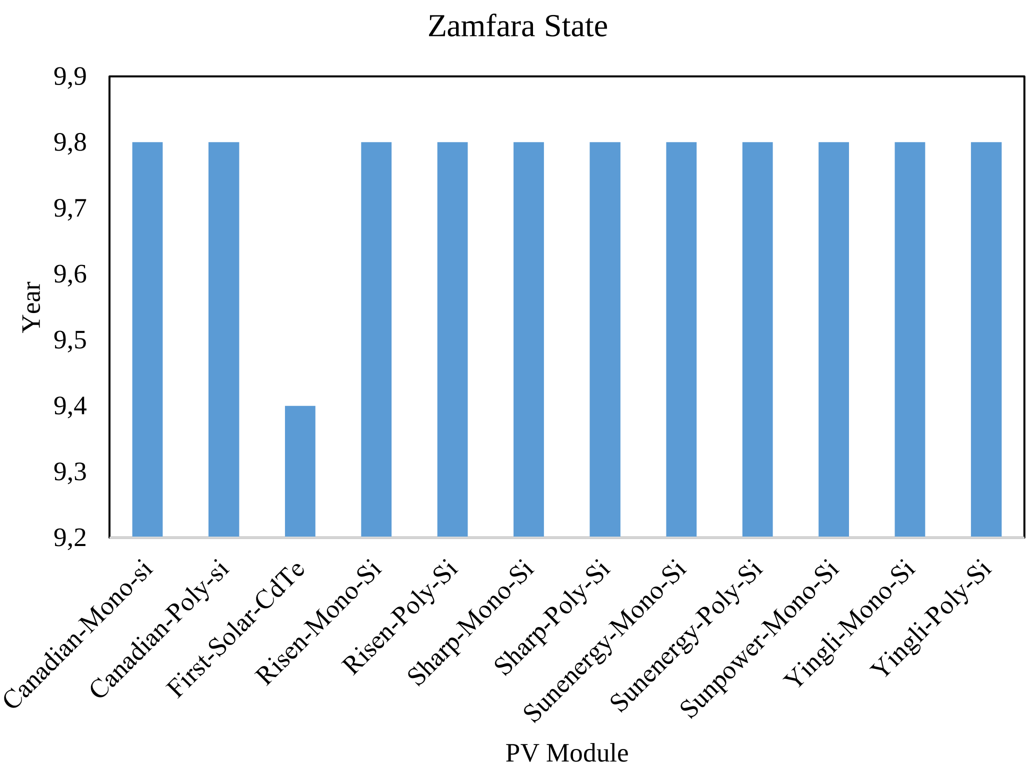

Kwara State
11,3
11,2
11,1
11
10,9
10,8
10,7
10,6
10,5
10,4
Year
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module


Niger State
10,8
10,7
10,6
10,5
10,4
10,3
10,2
10,1
Year
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

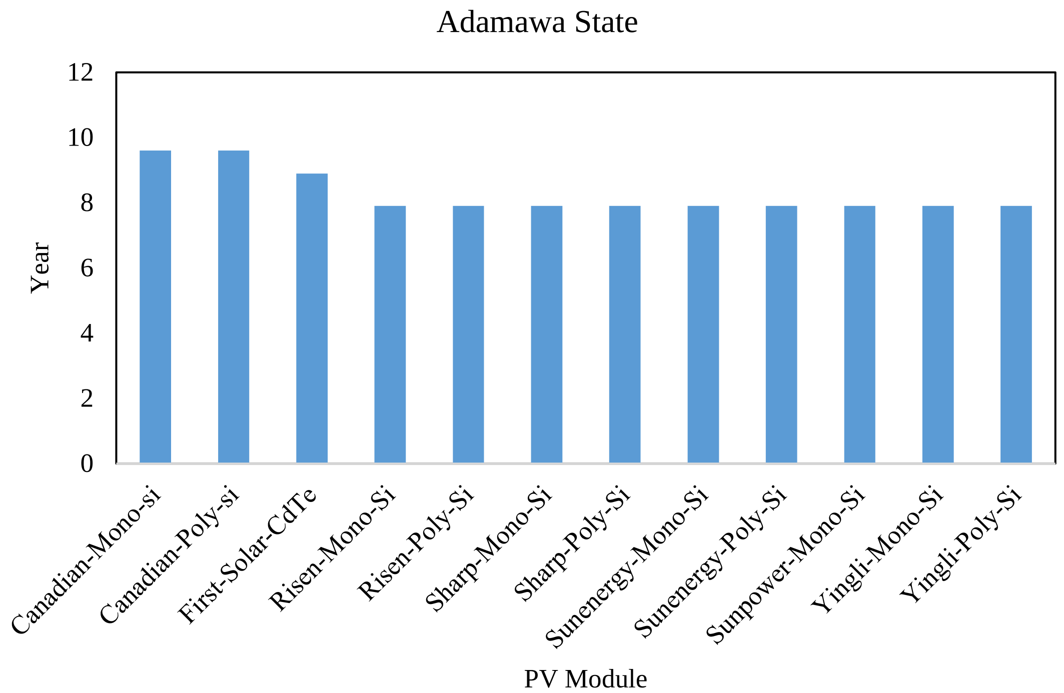

Plateau State
10,7
10,6
10,5
10,4
10,3
10,2
10,1
10
Year
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

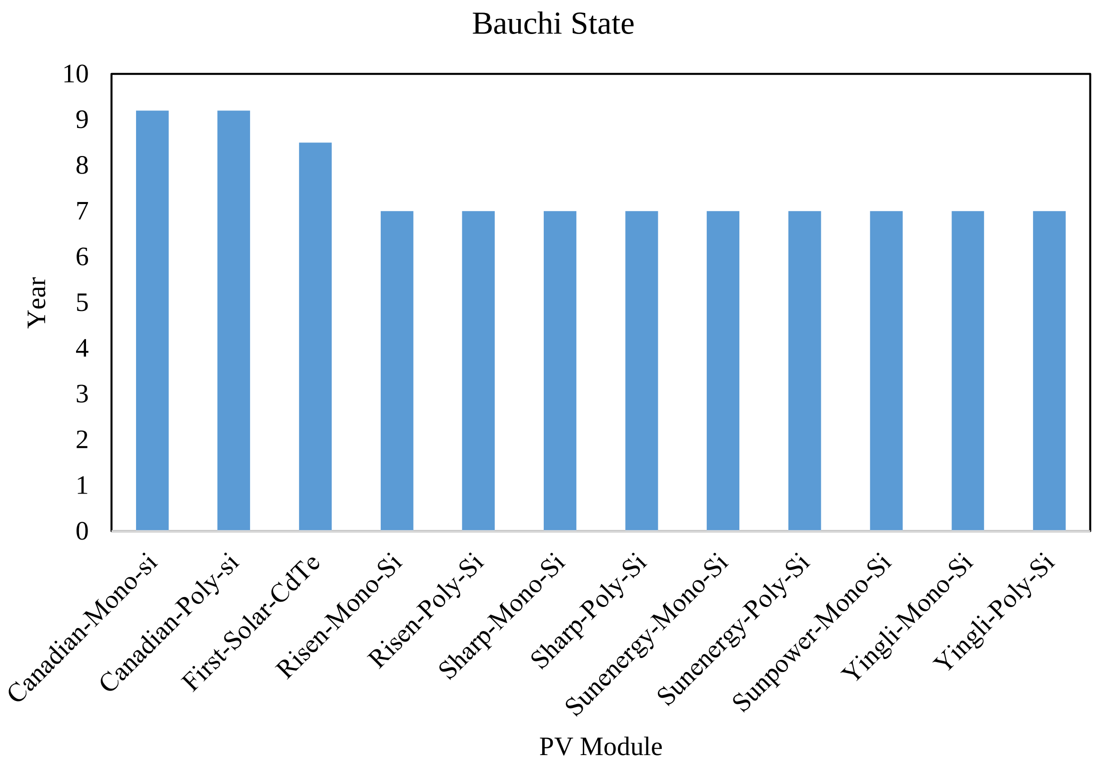

Sokoto State
9,5
9,4
9,3
9,2
9,1
9
8,9
8,8
Year
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

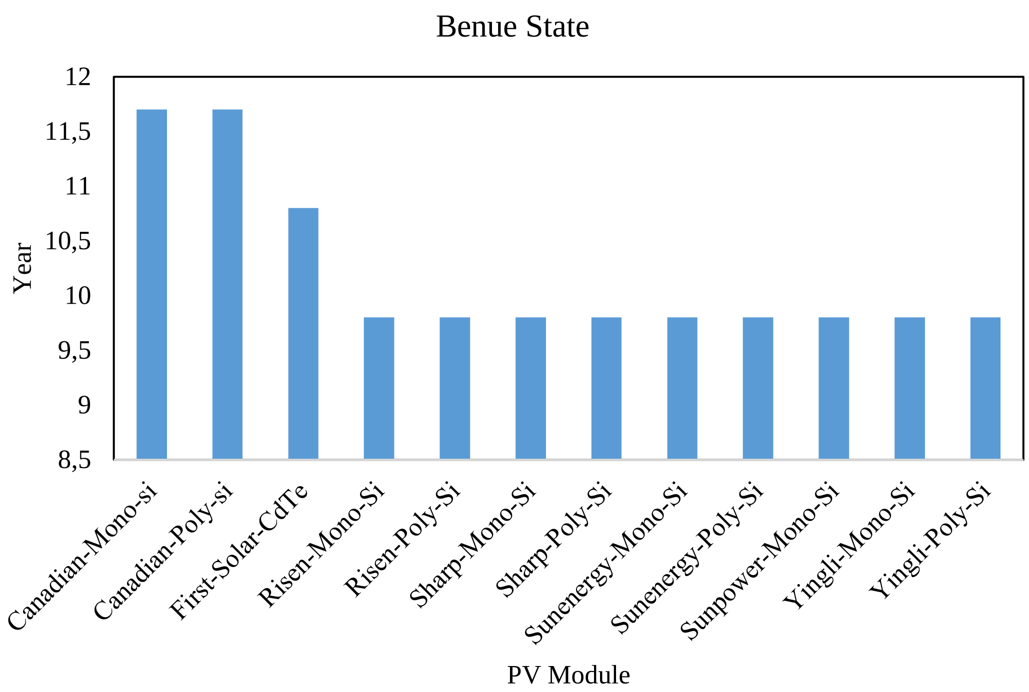


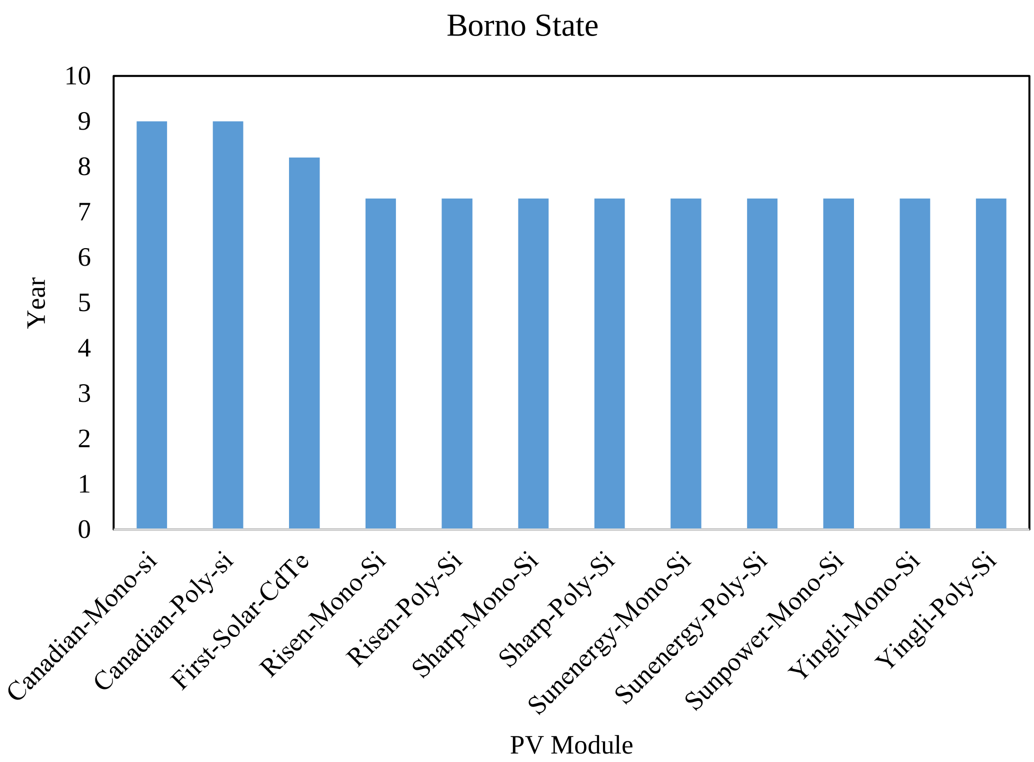



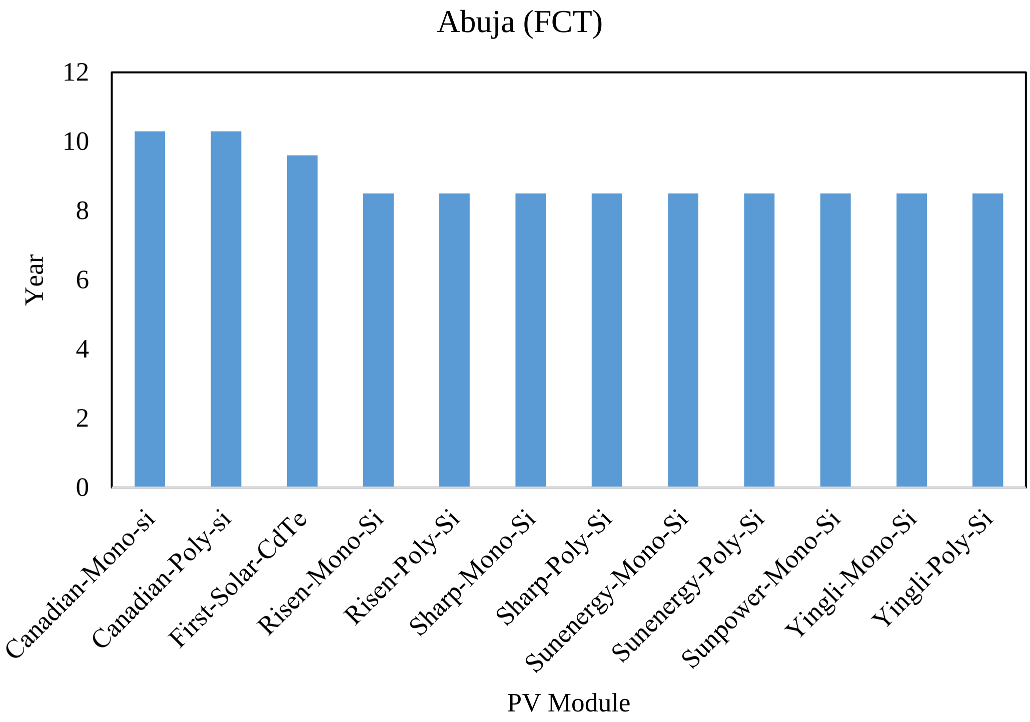

### B. Simple Payback (Year)


Adamawa State
Year
0
2
4
6
8
10
12
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

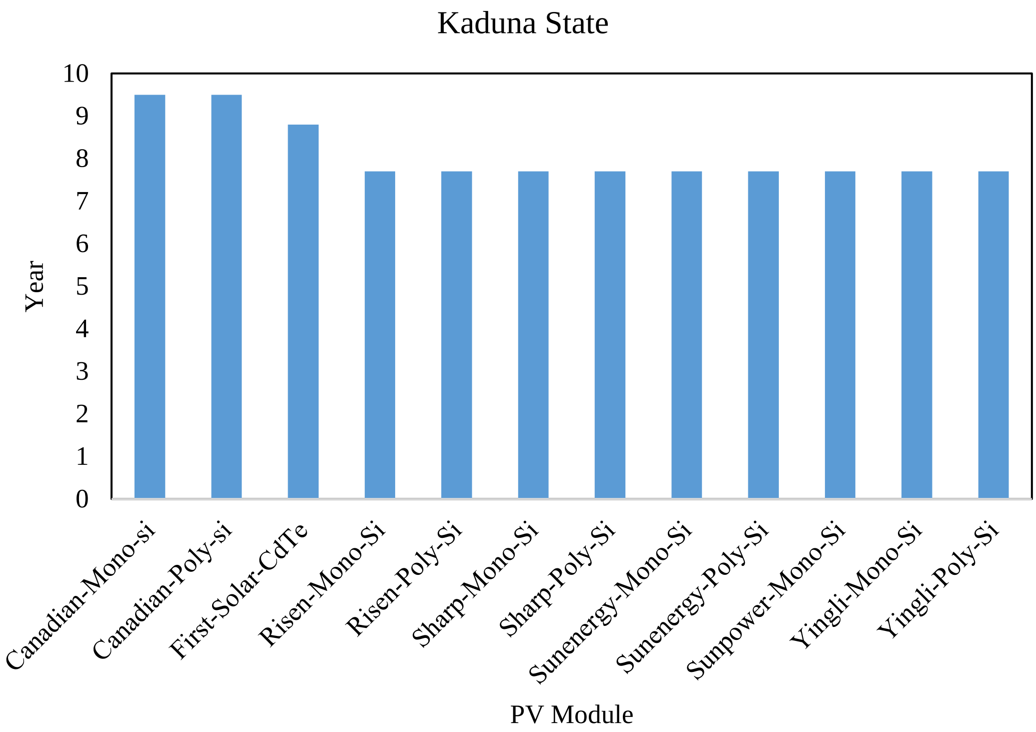

Bauchi State
Year
0
1
2
3
4
5
6
7
8
9
10
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module


Benue State
Year
12
11,5
11
10,5
10
9,5
9
8,5
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

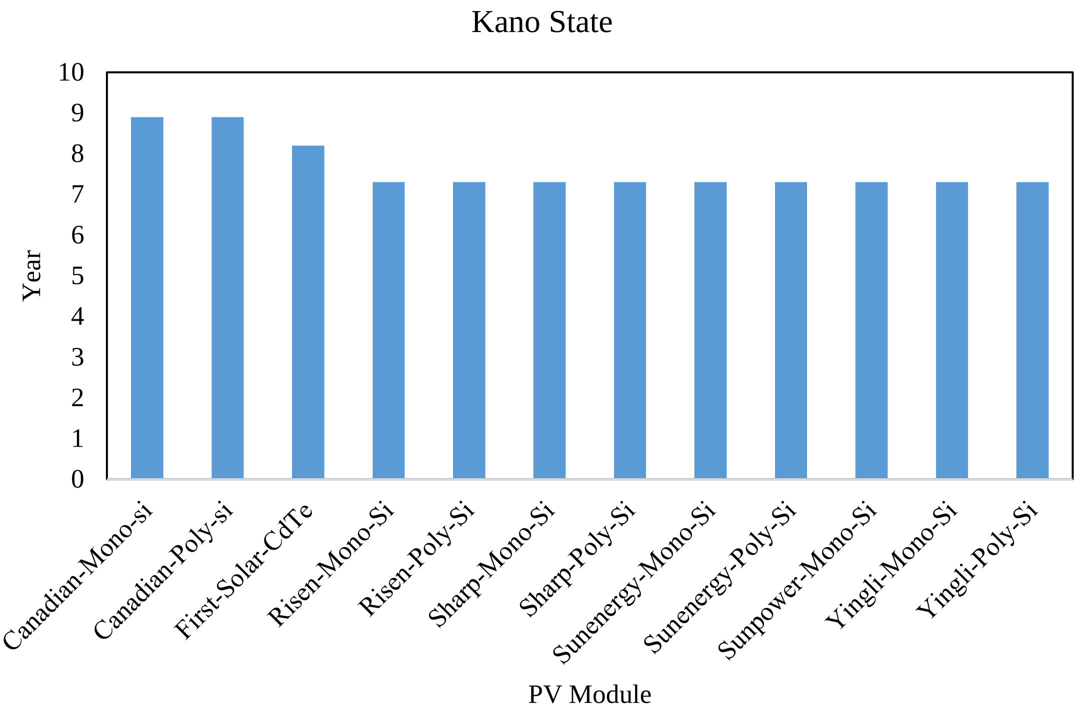

Borno State
Year
10
9
8
7
6
5
4
3
2
1
0
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

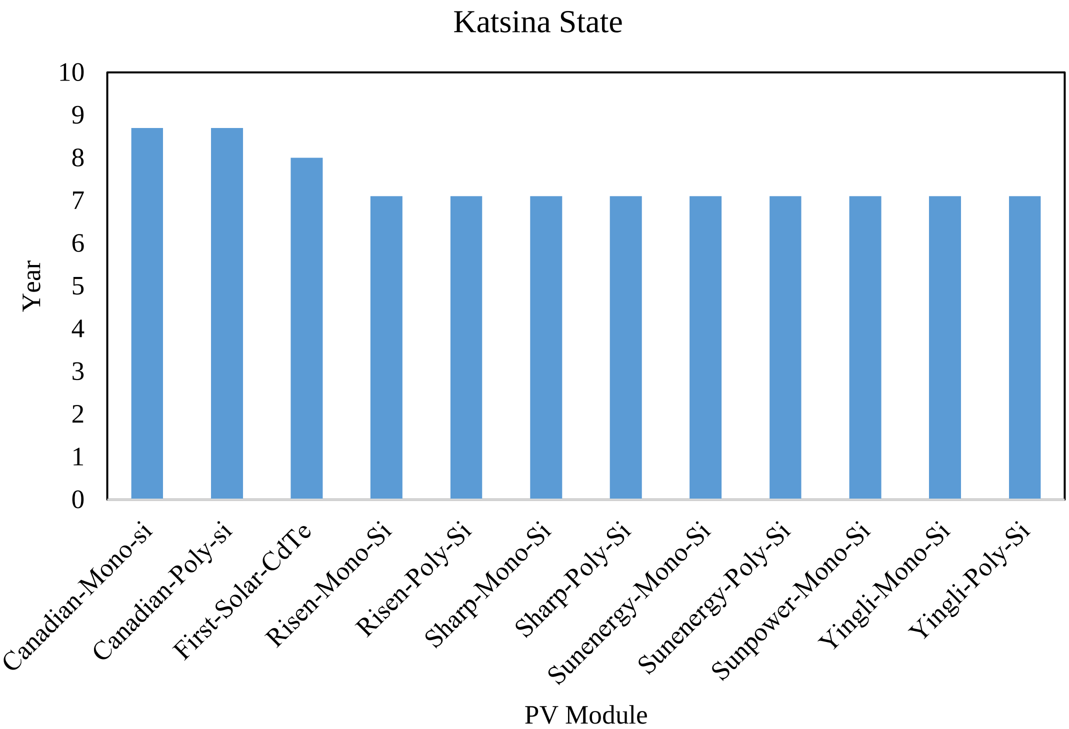


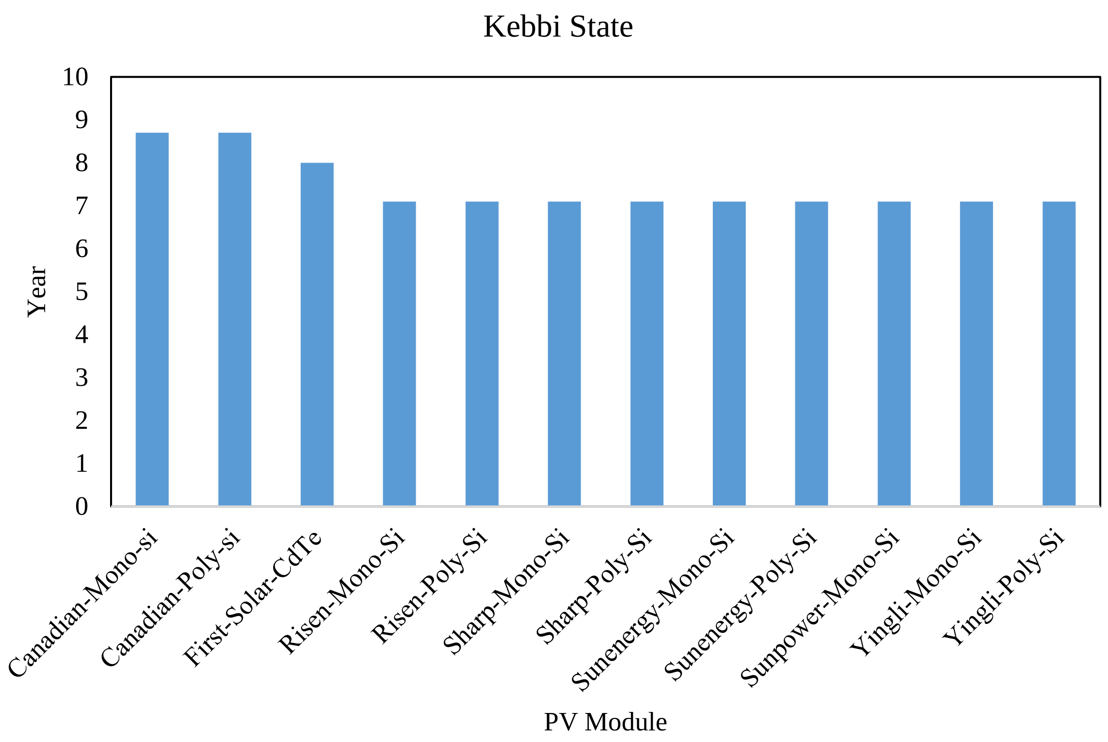
Abuja (FCT)
Year
PV Module
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si

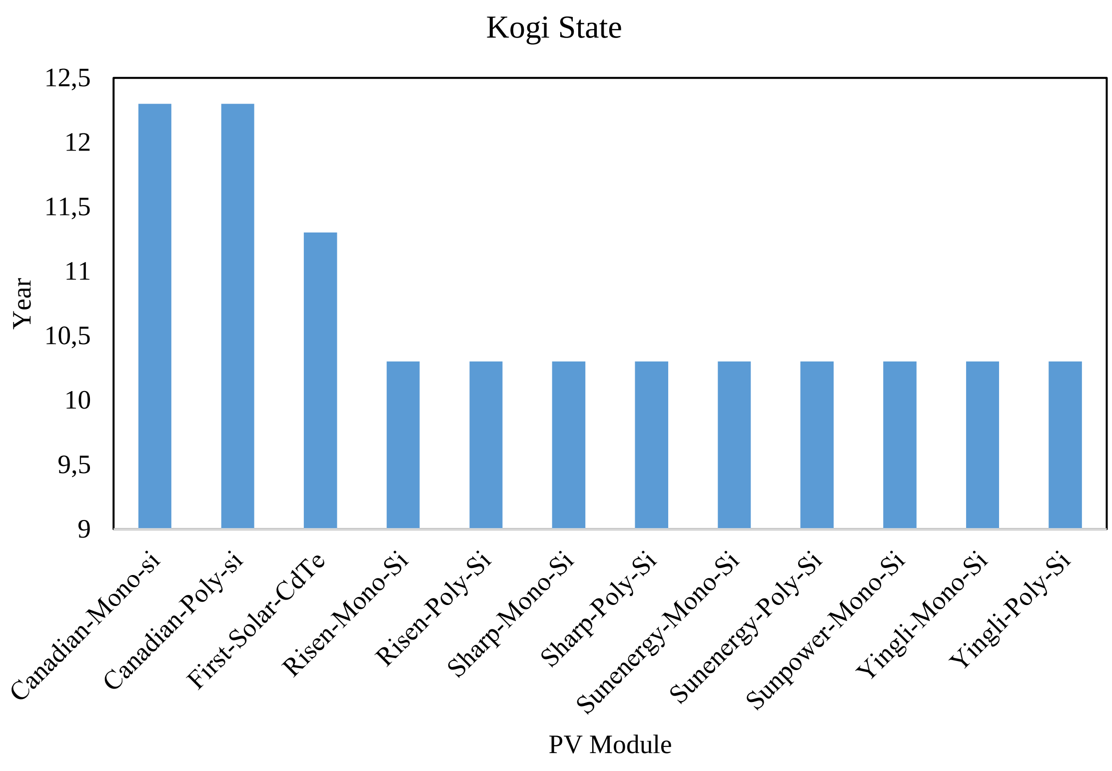



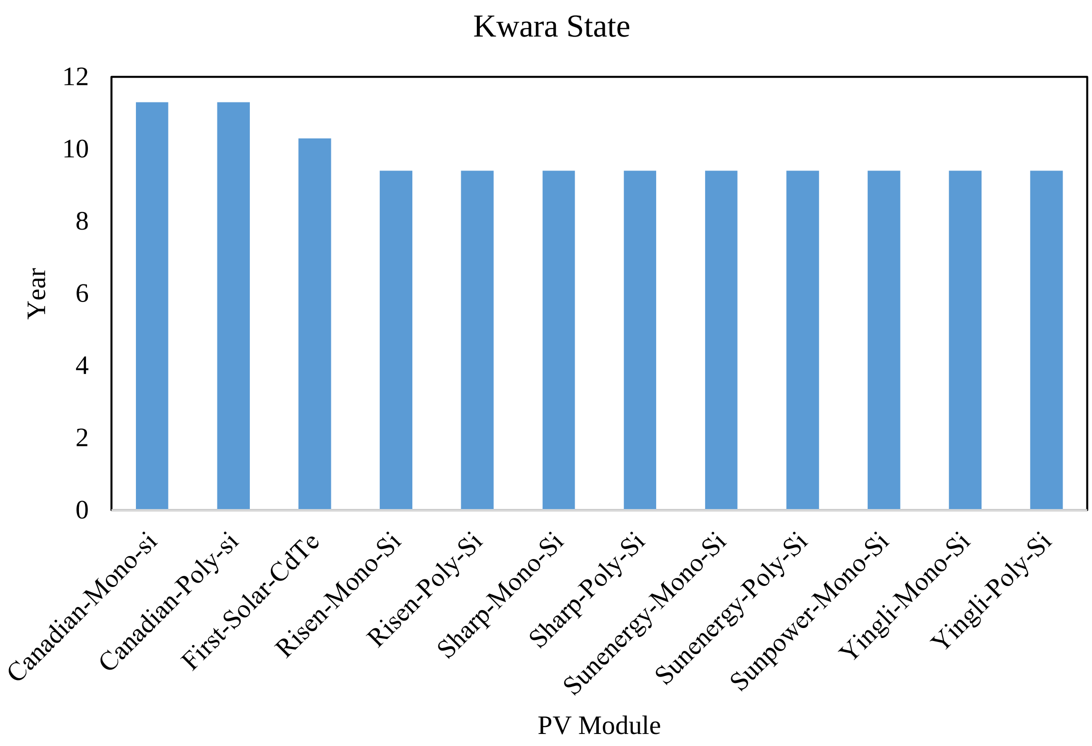
Kaduna State
Year
PV Module
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si

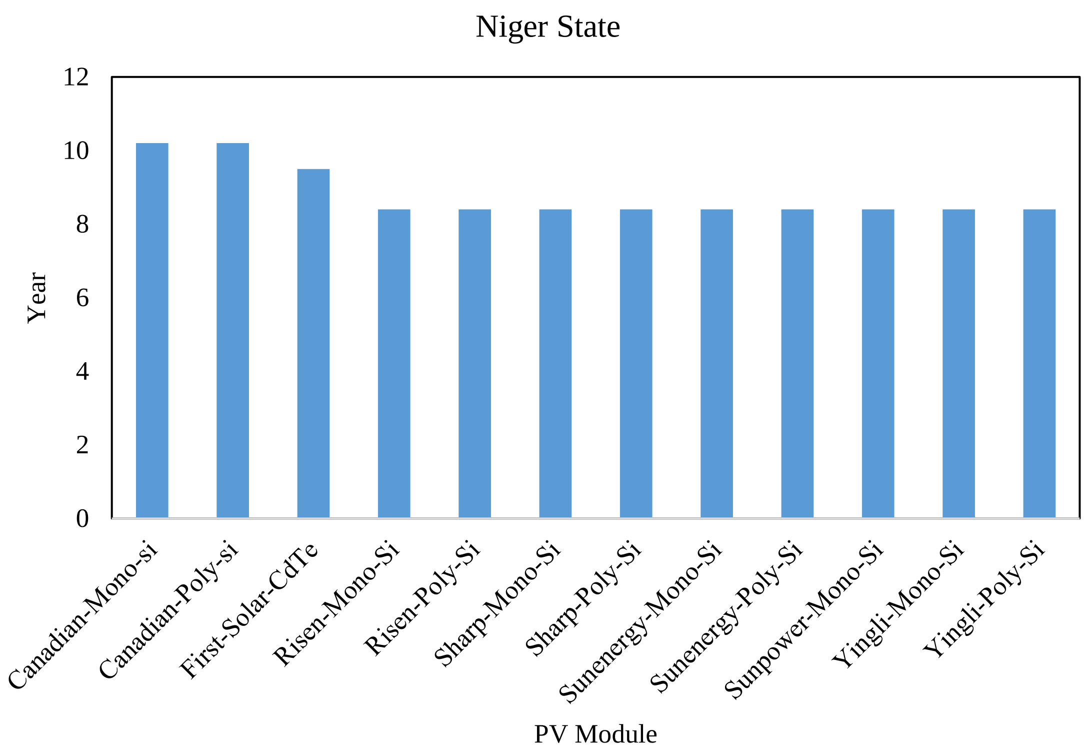

Kano State
Year
0
1
2
3
4
5
6
7
8
9
10
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

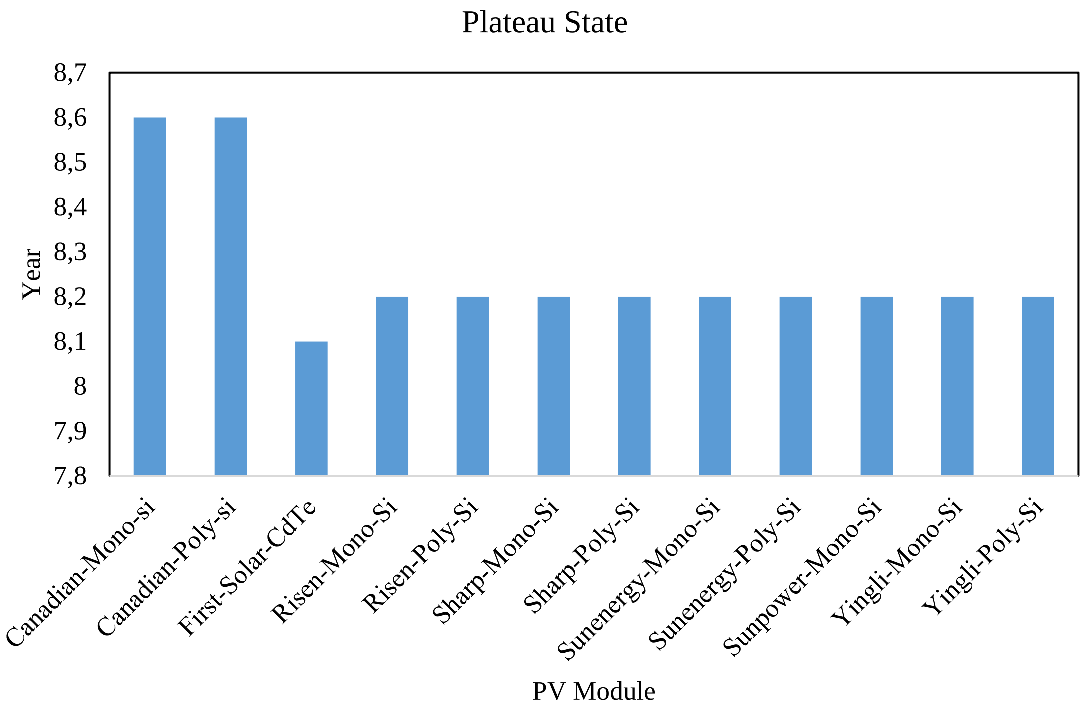

Katsina State
Year
0
1
2
3
4
5
6
7
8
9
10
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

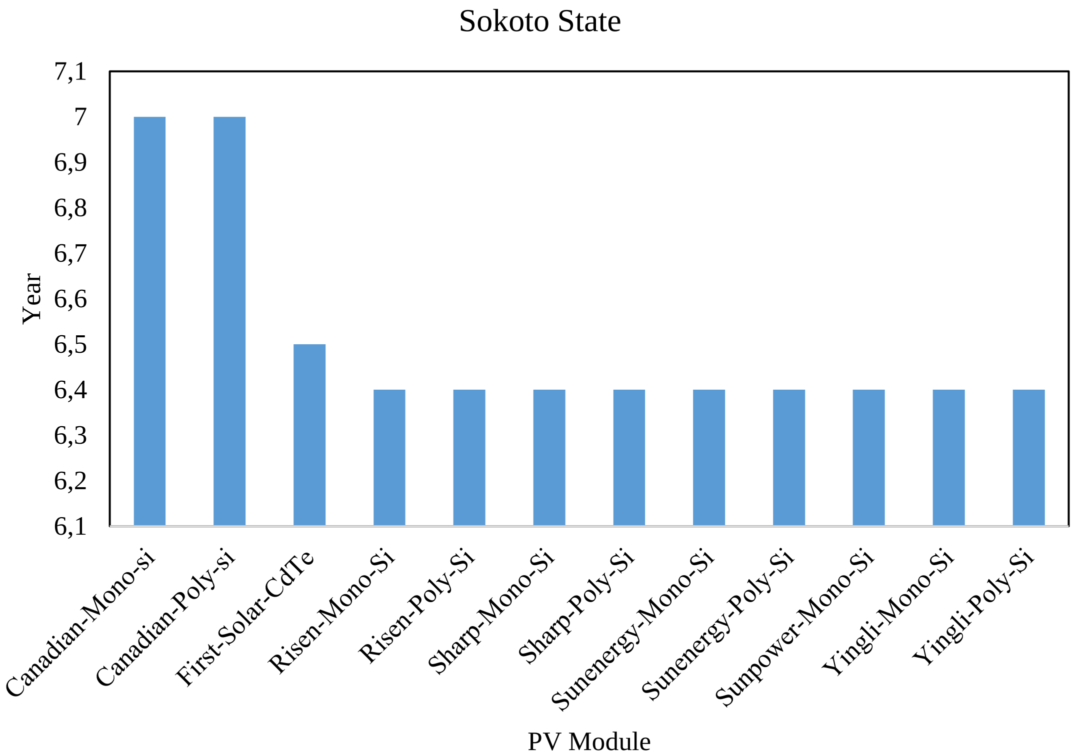

Kebbi State
10
9
8
7
6
5
4
3
2
1
0
Year
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

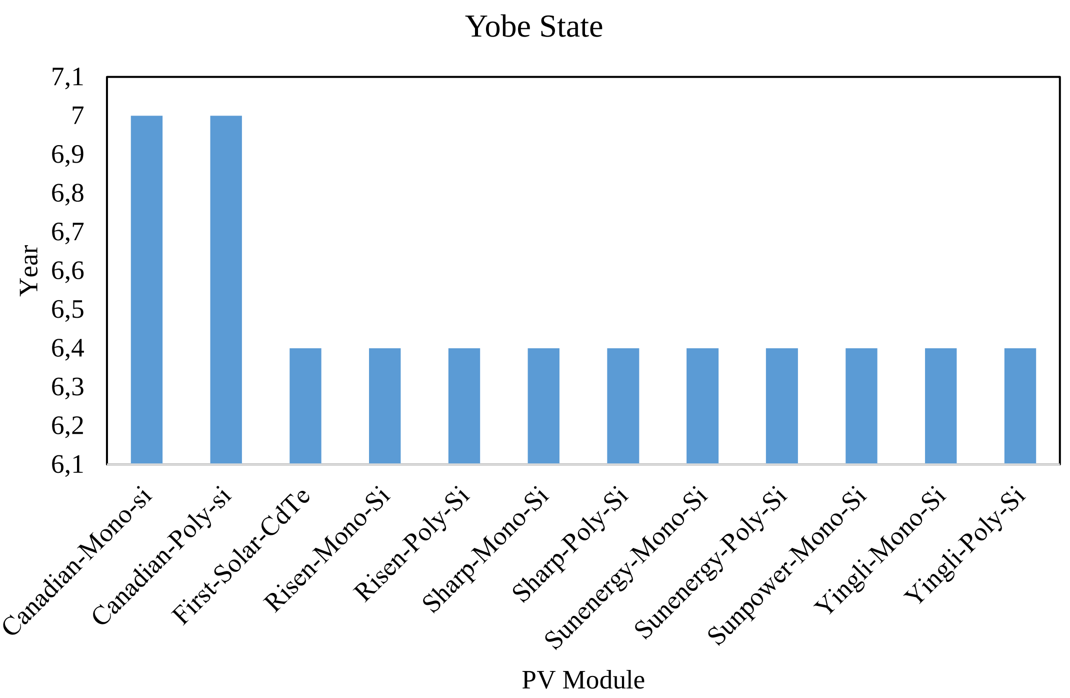

Kogi State
12,5
12
11,5
11
10,5
10
9,5
9
Year
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

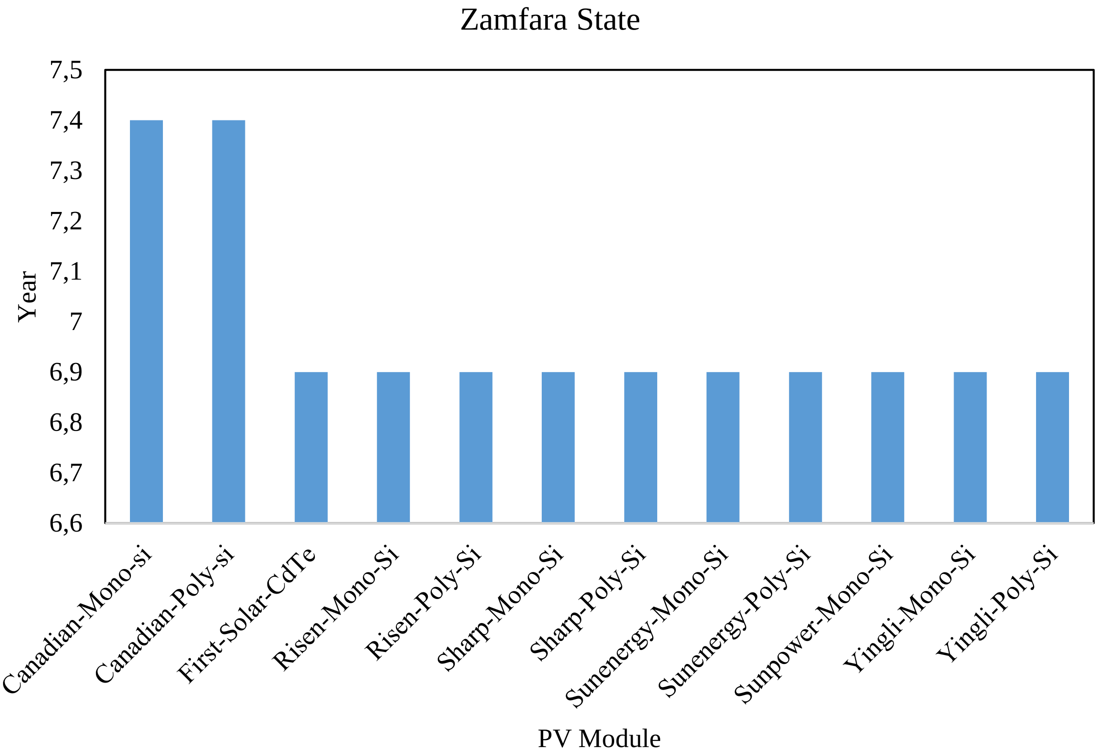

Kwara State
12
10
8
6
4
2
0
Year
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module


Niger State
12
10
8
6
4
2
0
Year
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

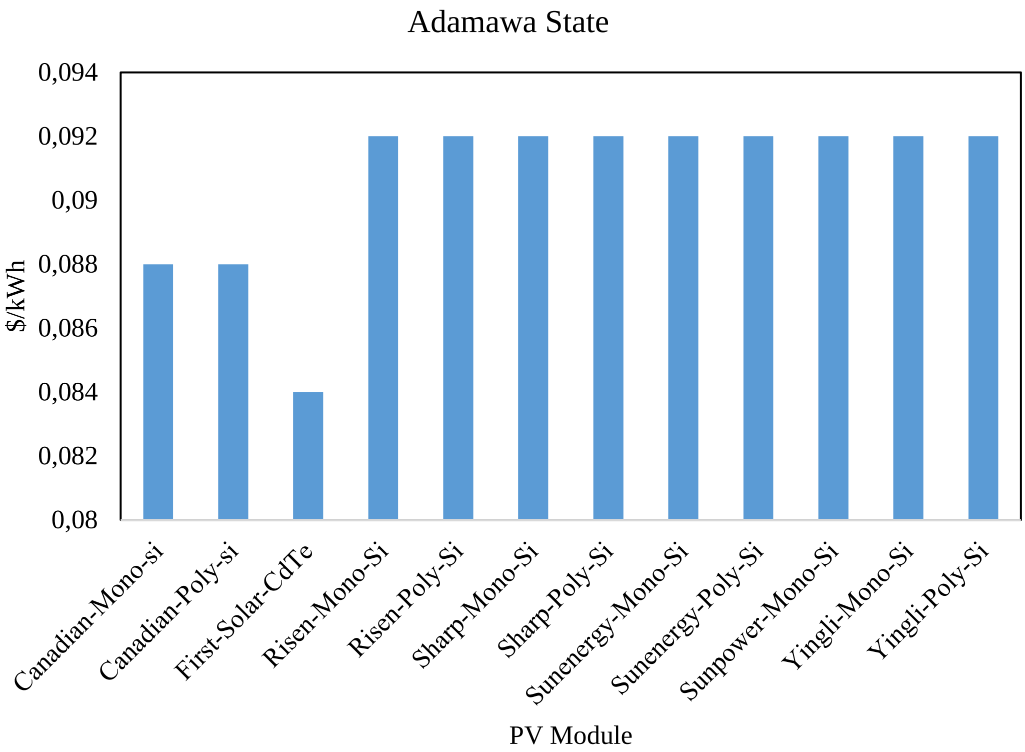

Plateau State
Year
8,7
8,6
8,5
8,4
8,3
8,2
8,1
8
7,9
7,8
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

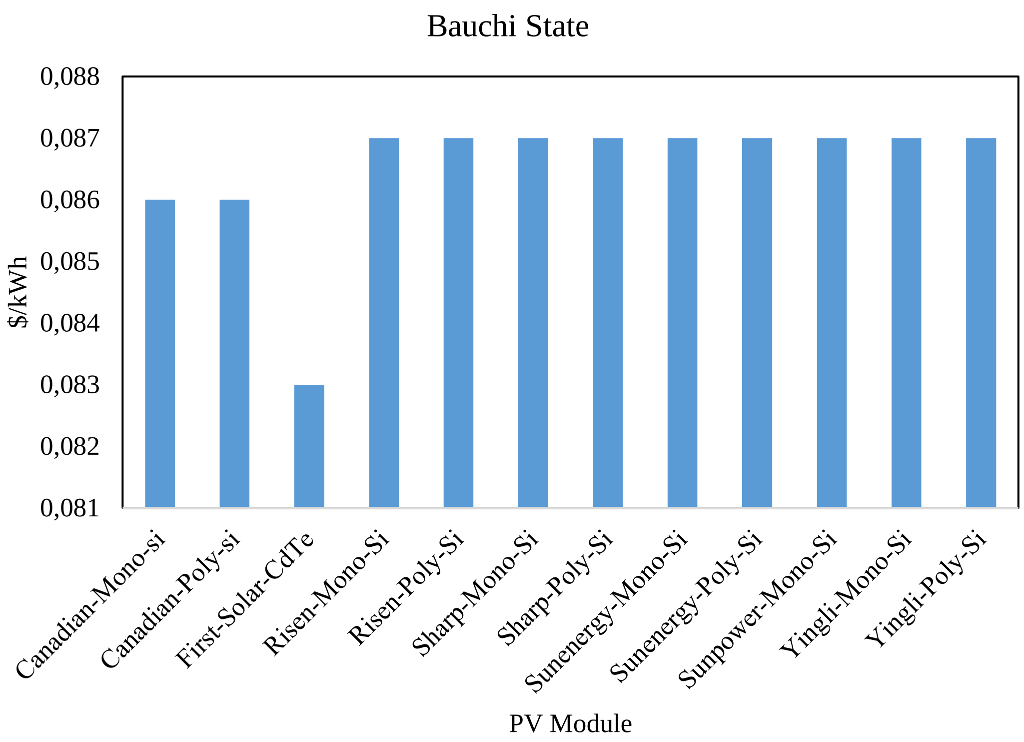

Sokoto State
Year
7,1
7
6,9
6,8
6,7
6,6
6,5
6,4
6,3
6,2
6,1
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

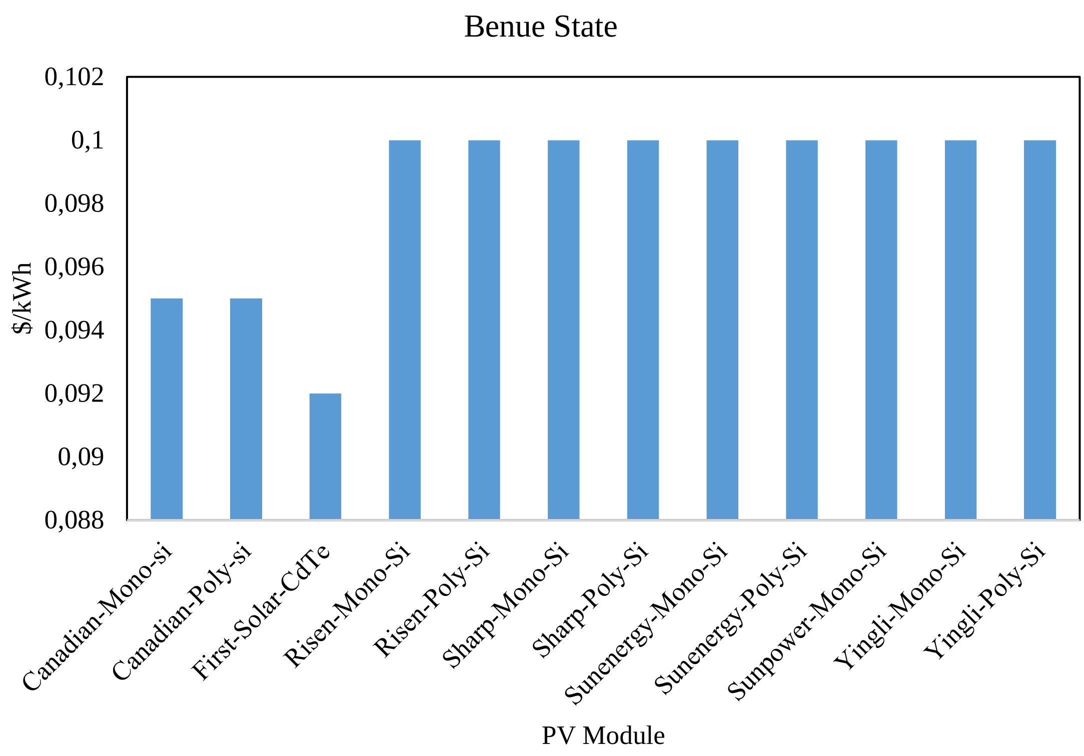


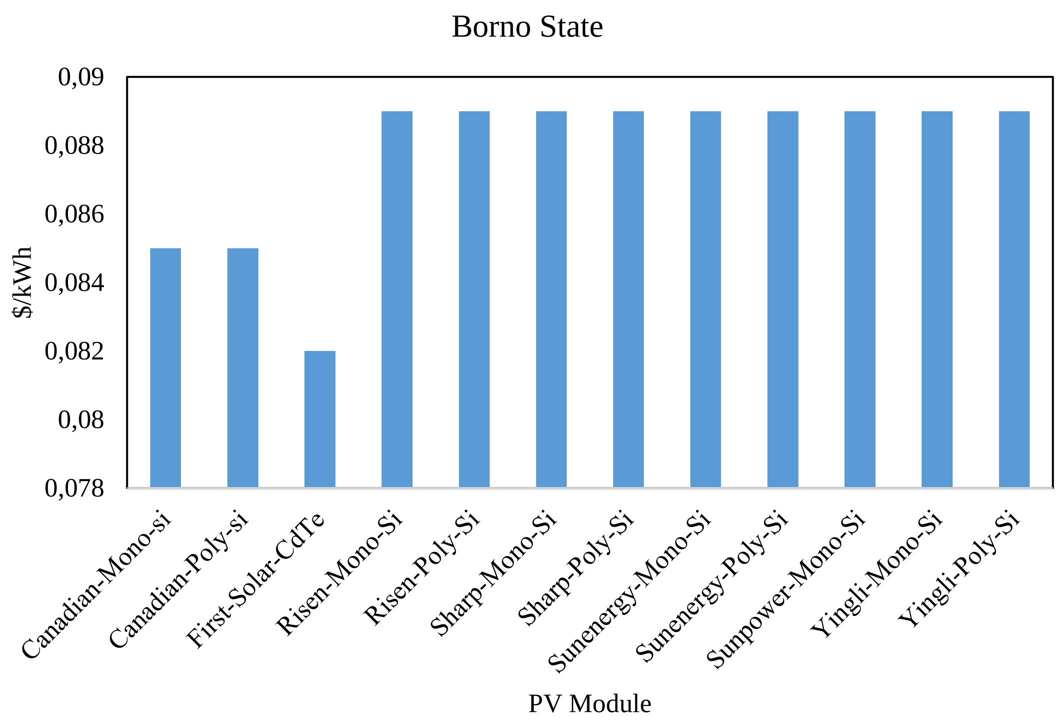

**C. Equity Payback (Year)**


Adamawa State
0,094
0,092
0,09
0,088
0,086
0,084
0,082
0,08
$/kWh
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

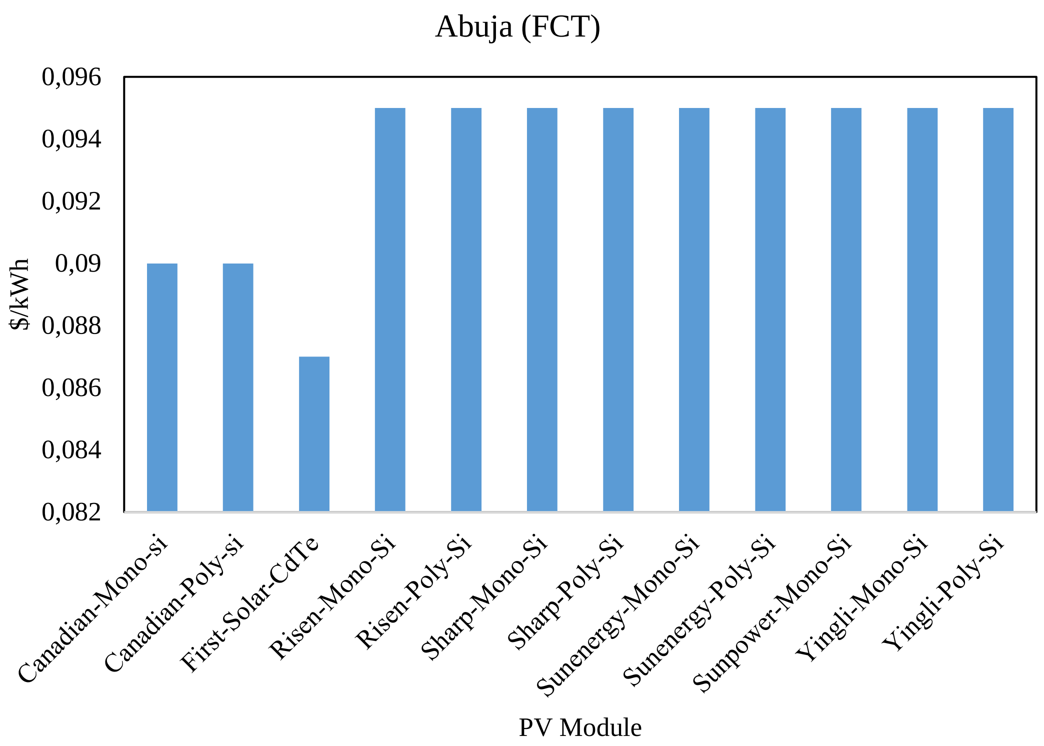

Bauchi State
0,088
0,087
0,086
0,085
0,084
0,083
0,082
0,081
$/kWh
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

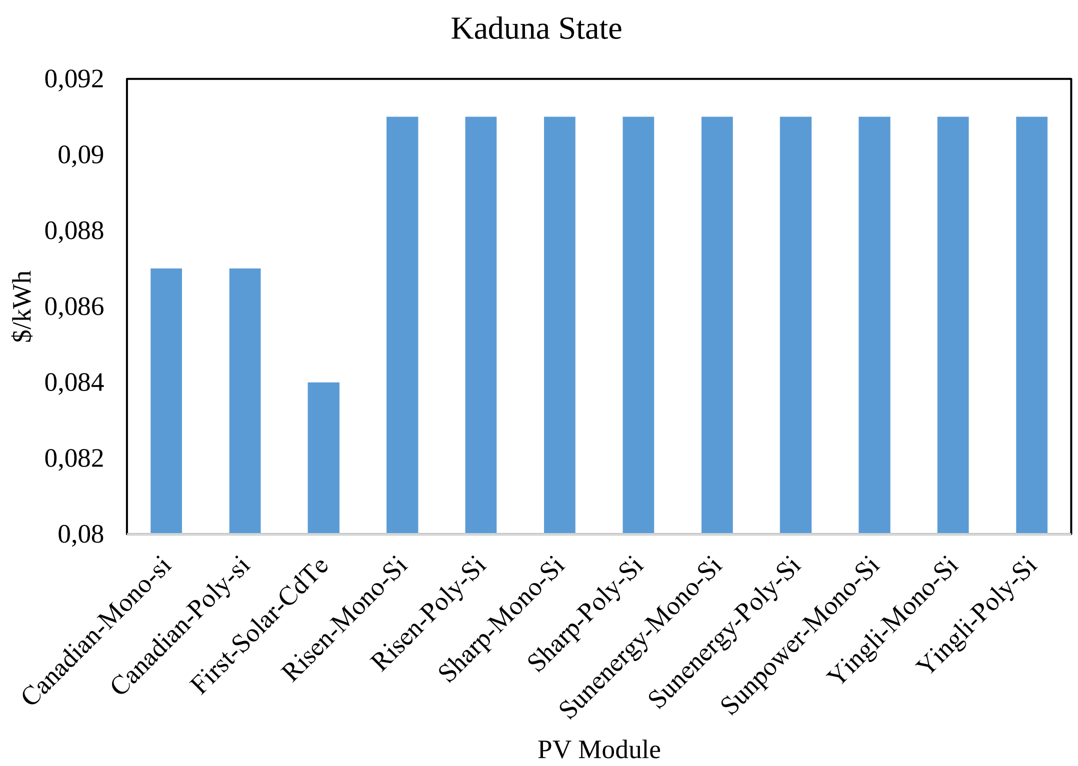


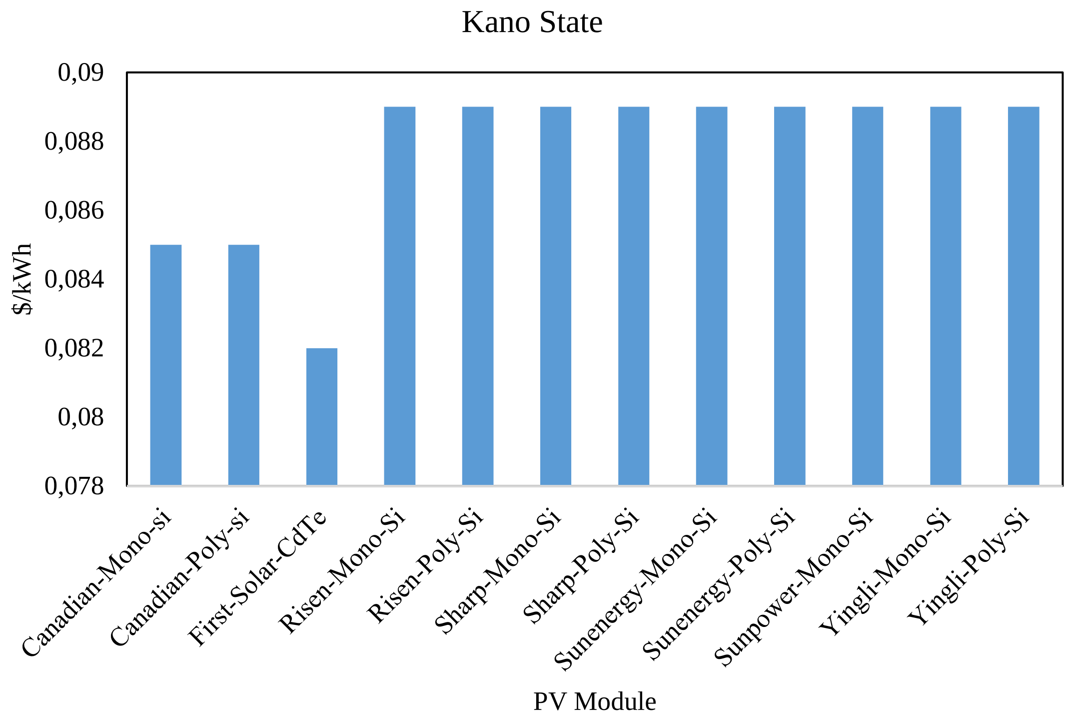
Benue State
0,102
0,1
0,098
0,096
0,094
0,092
0,09
0,088
$/kWh
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

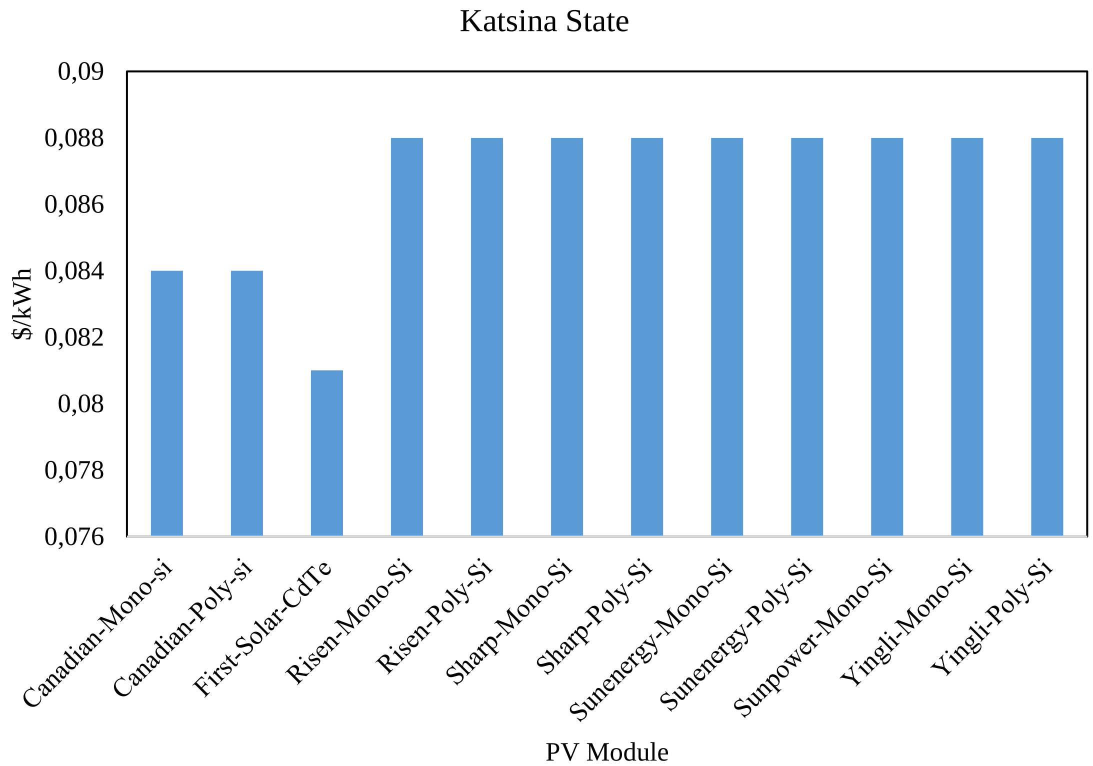
Borno State
0,09
0,088
0,086
0,084
0,082
0,08
0,078
$/kWh
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module


Abuja (FCT)
0,096
0,094
0,092
0,09
0,088
0,086
0,084
0,082
$/kWh
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

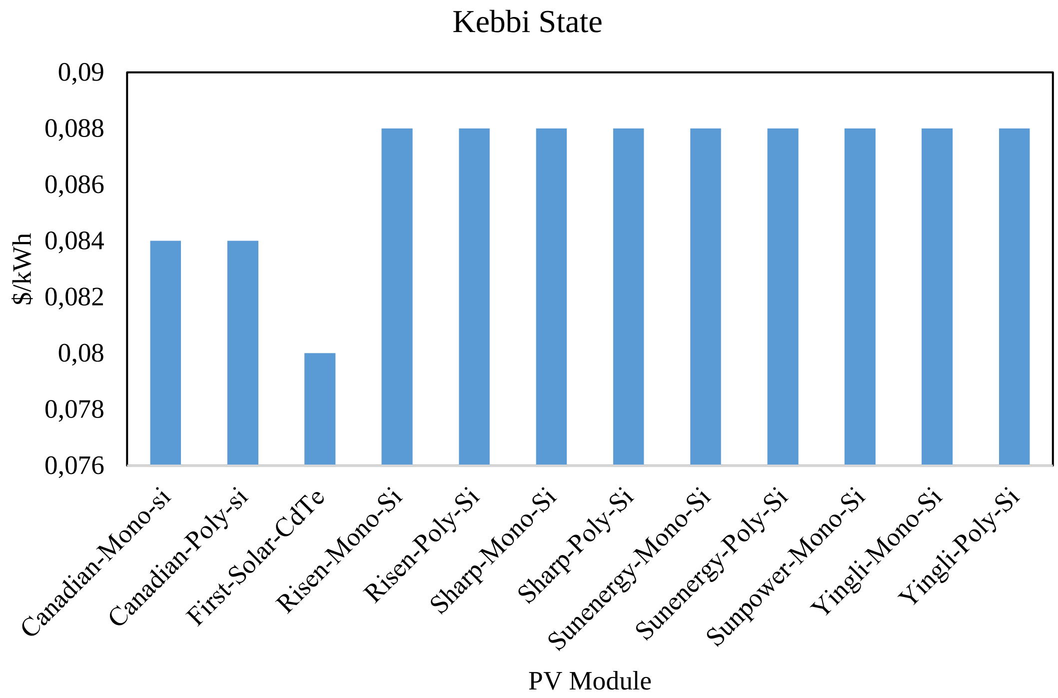

Kaduna State
0,092
0,09
0,088
0,086
0,084
0,082
0,08
$/kWh
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

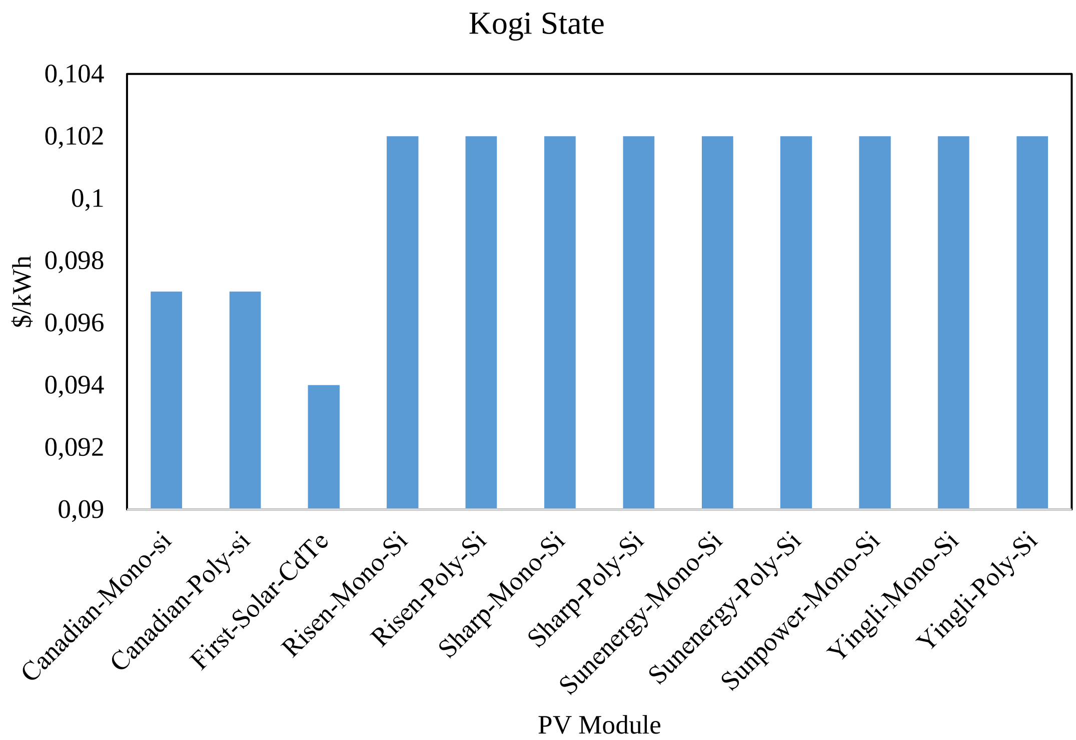


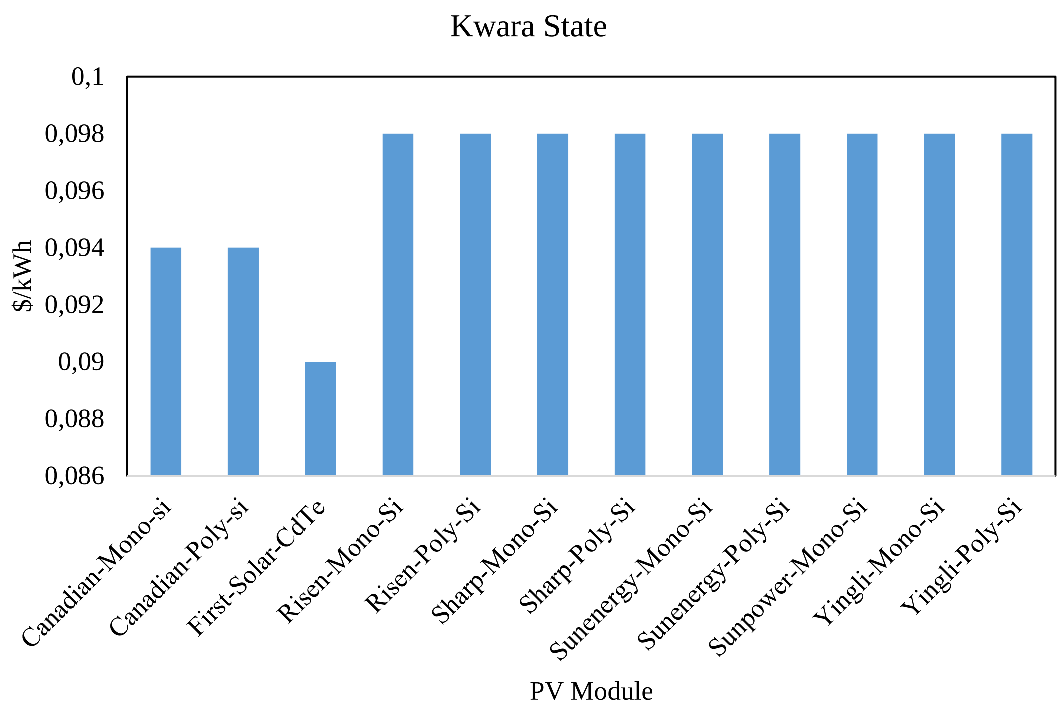
Kano State
0,09
0,088
0,086
0,084
0,082
0,08
0,078
$/kWh
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

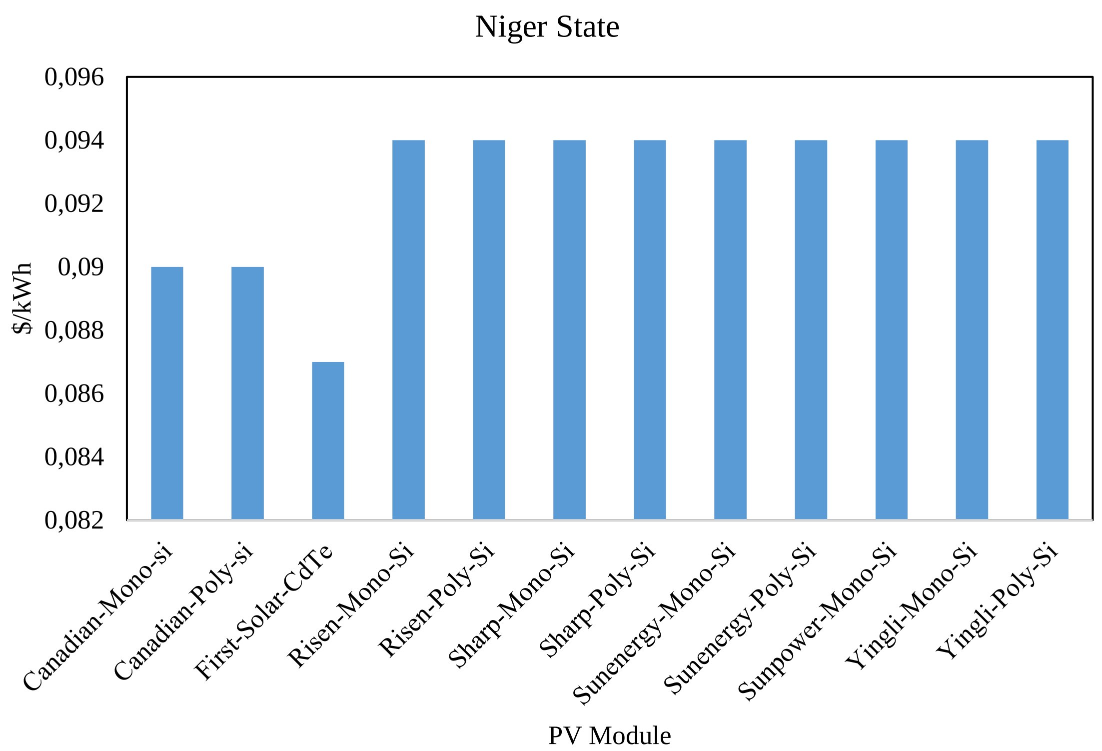



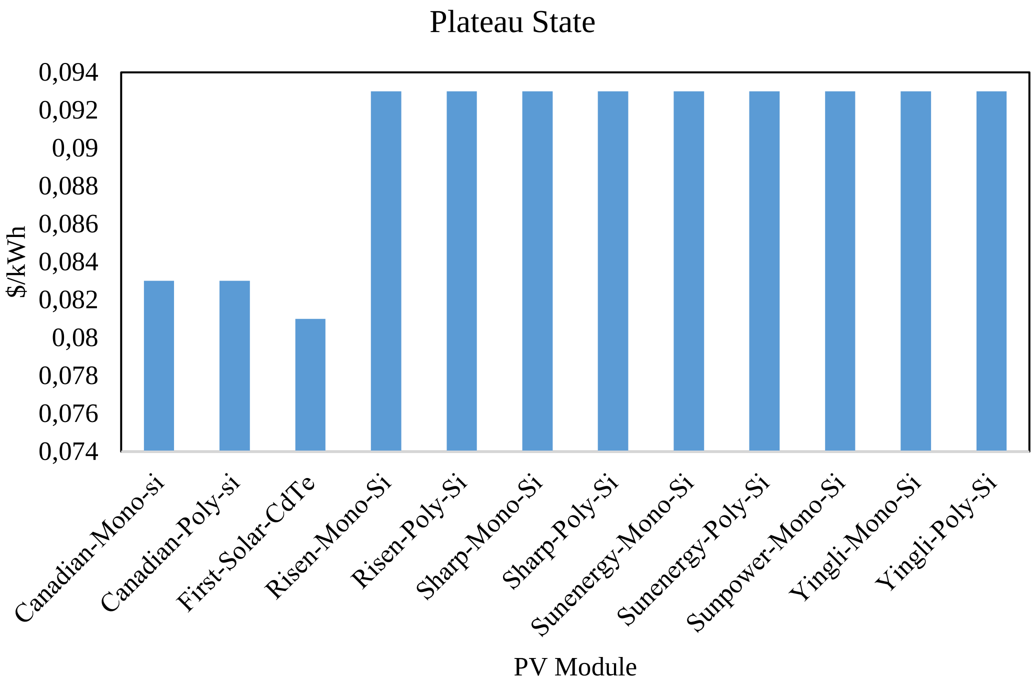
Katsina State
0,09
0,088
0,086
0,084
0,082
0,08
0,078
0,076
$/kWh
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

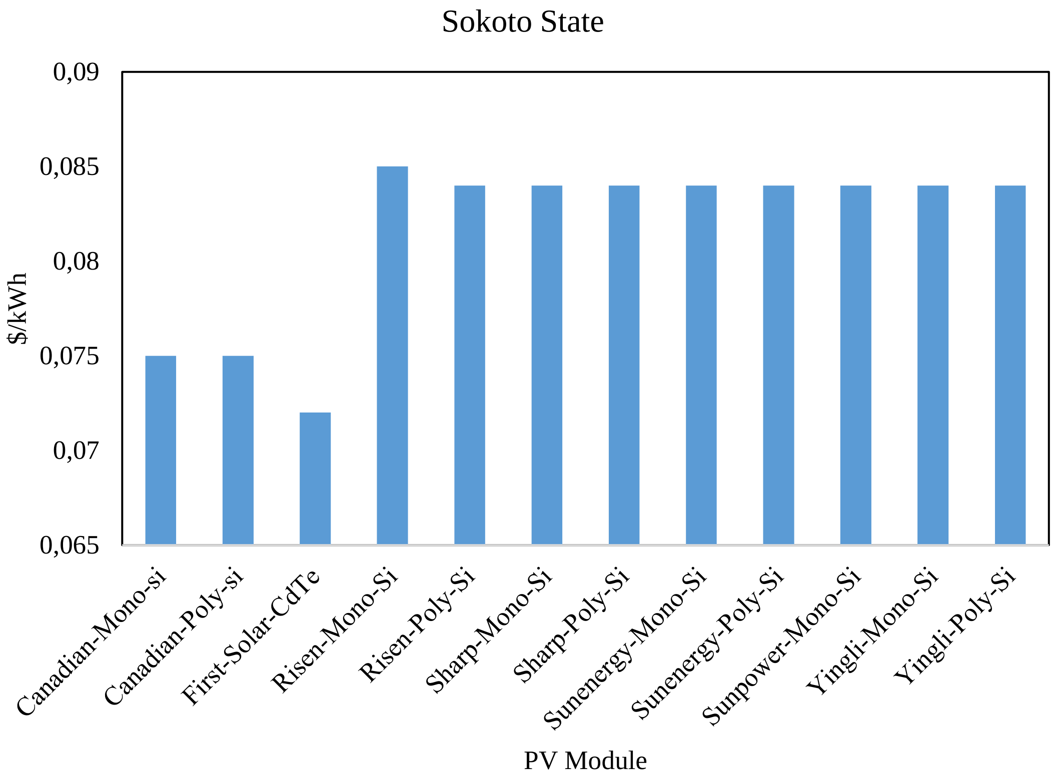

Kebbi State
0,09
0,088
0,086
0,084
0,082
0,08
0,078
0,076
$/kWh
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

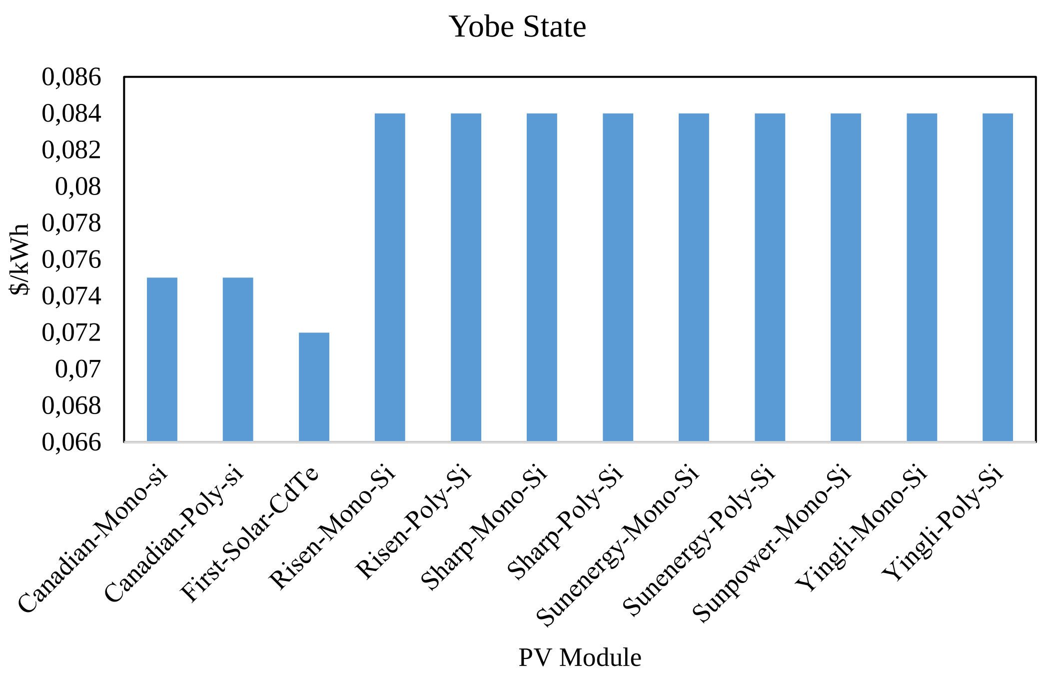

Kogi State
0,104
0,102
0,1
0,098
0,096
0,094
0,092
0,09
$/kWh
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

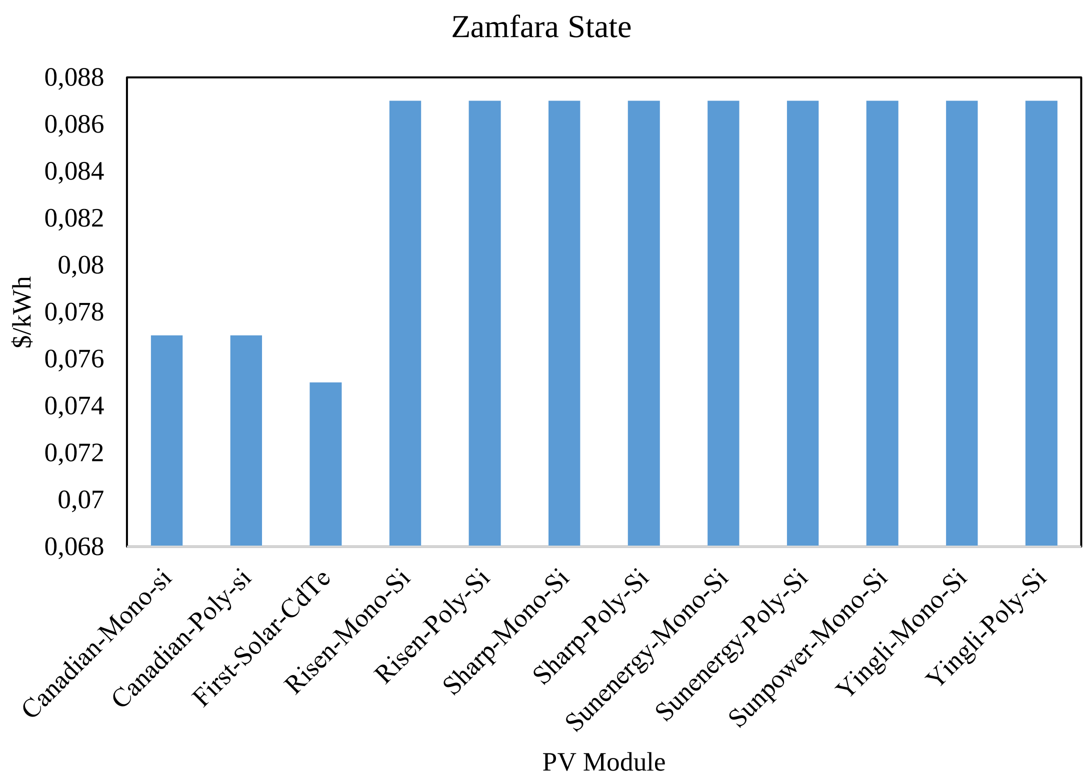

Kwara State
0,1
0,098
0,096
0,094
0,092
0,09
0,088
0,086
$/kWh
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module


Niger State
0,096
0,094
0,092
0,09
0,088
0,086
0,084
0,082
$/kWh
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

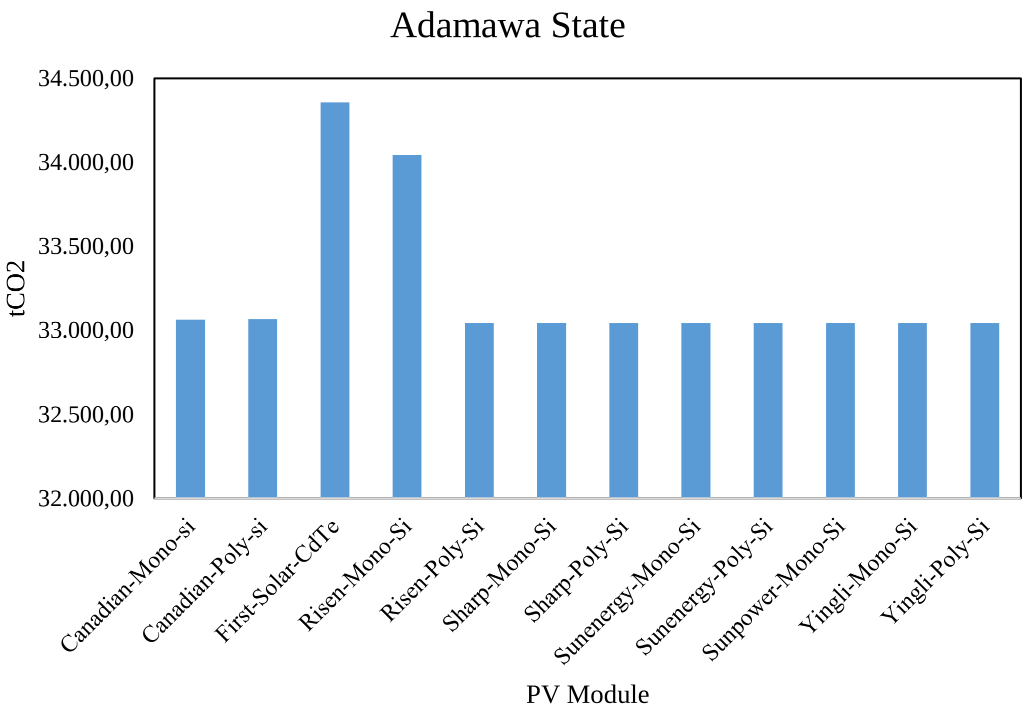

Plateau State
0,094
0,092
0,09
0,088
0,086
0,084
0,082
0,08
0,078
0,076
0,074
$/kWh
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

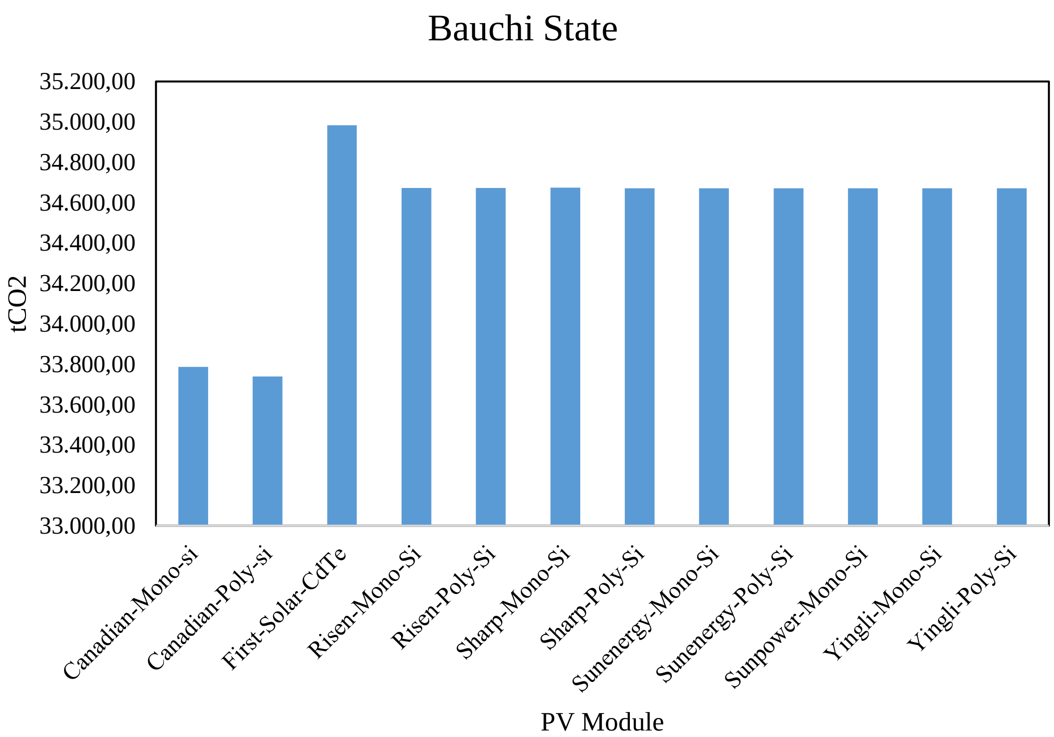

Sokoto State
0,09
0,085
0,08
0,075
0,07
0,065
$/kWh
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

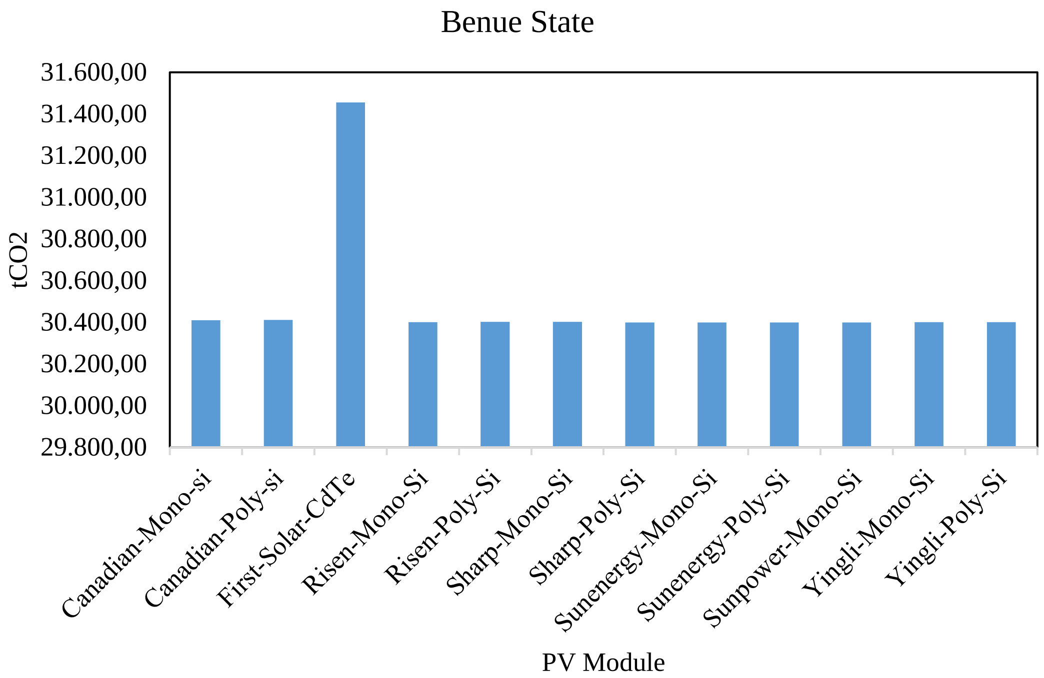


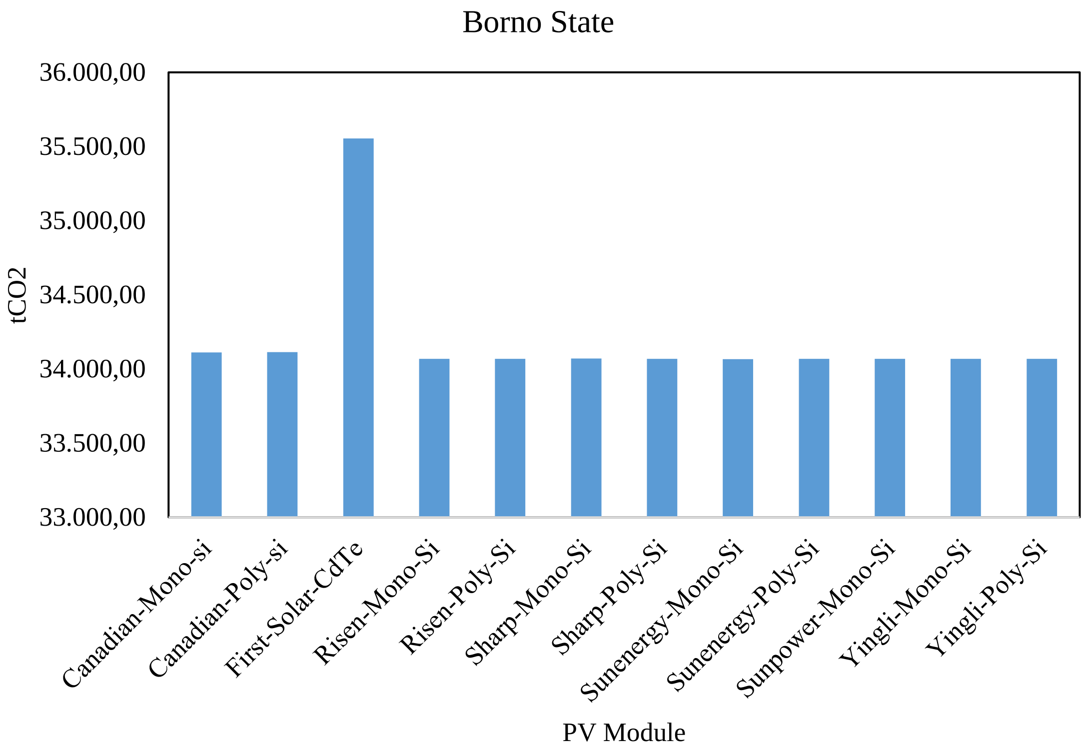



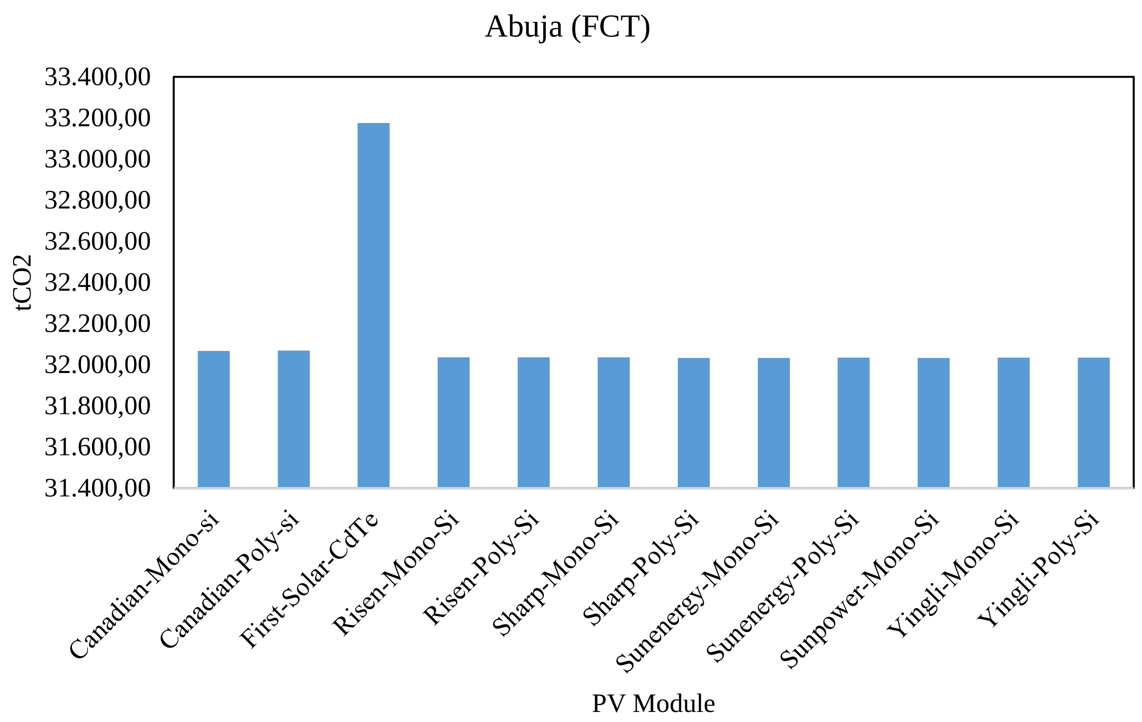

### D. Energy Production Cost ($/kWh)

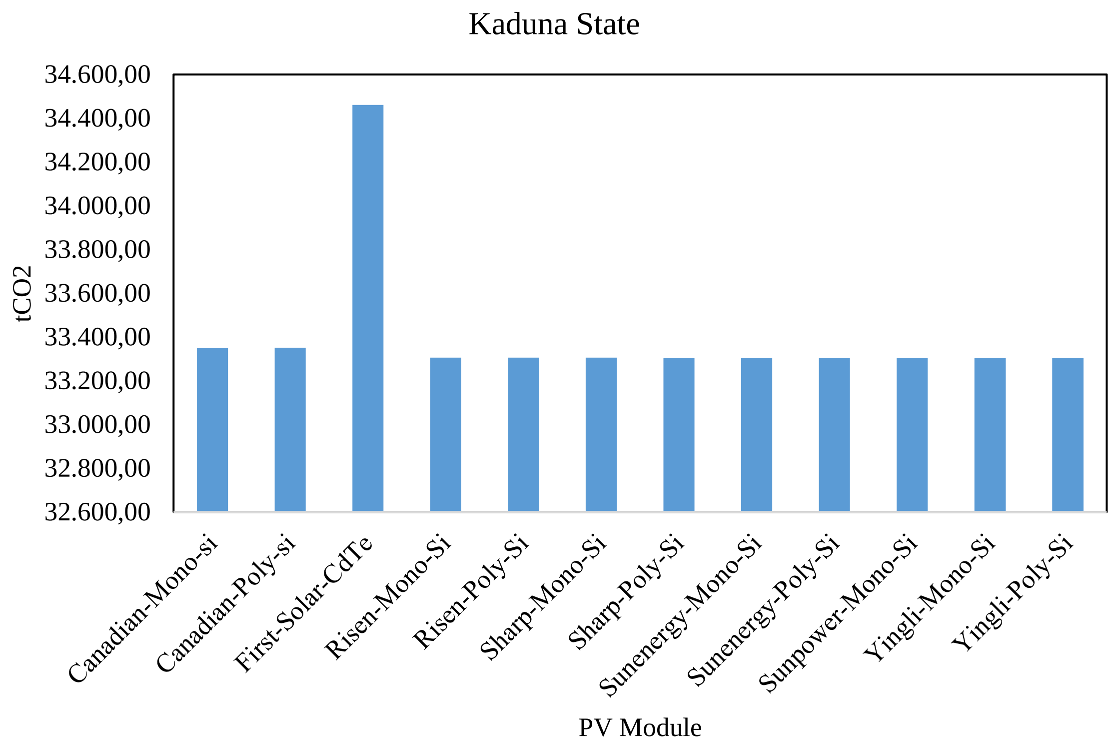

Adamawa State
34.500,00
34.000,00
33.500,00
33.000,00
32.500,00
32.000,00
tCO2
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

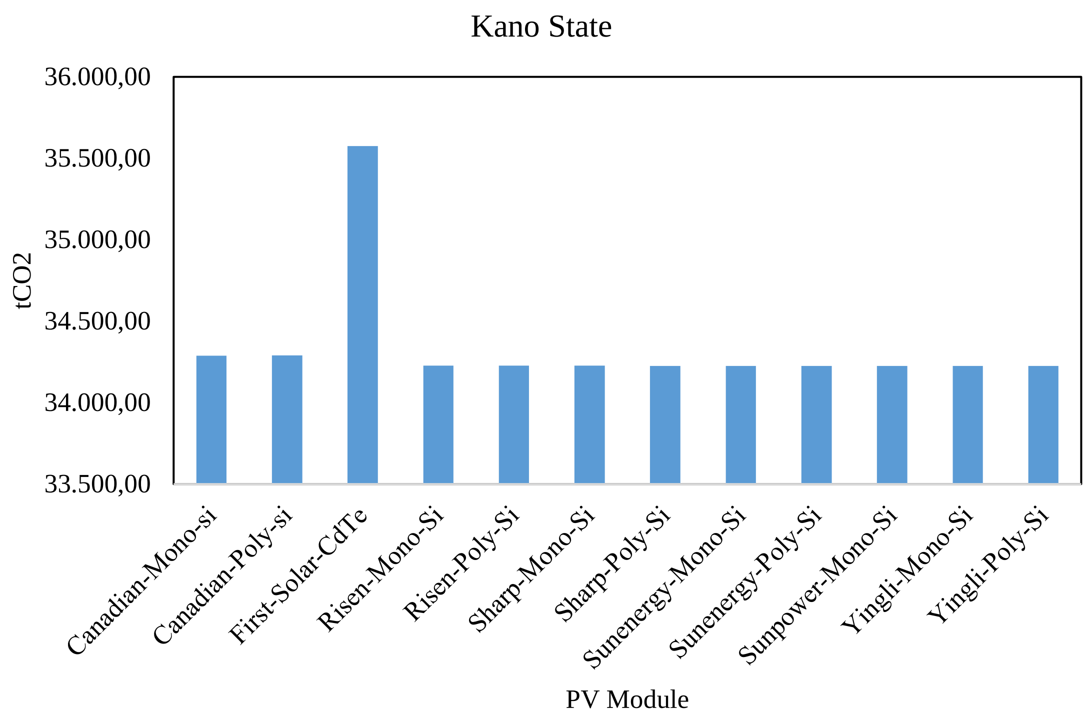

Bauchi State
35.200,00
35.000,00
34.800,00
34.600,00
34.400,00
34.200,00
34.000,00
33.800,00
33.600,00
33.400,00
33.200,00
33.000,00
tCO2
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

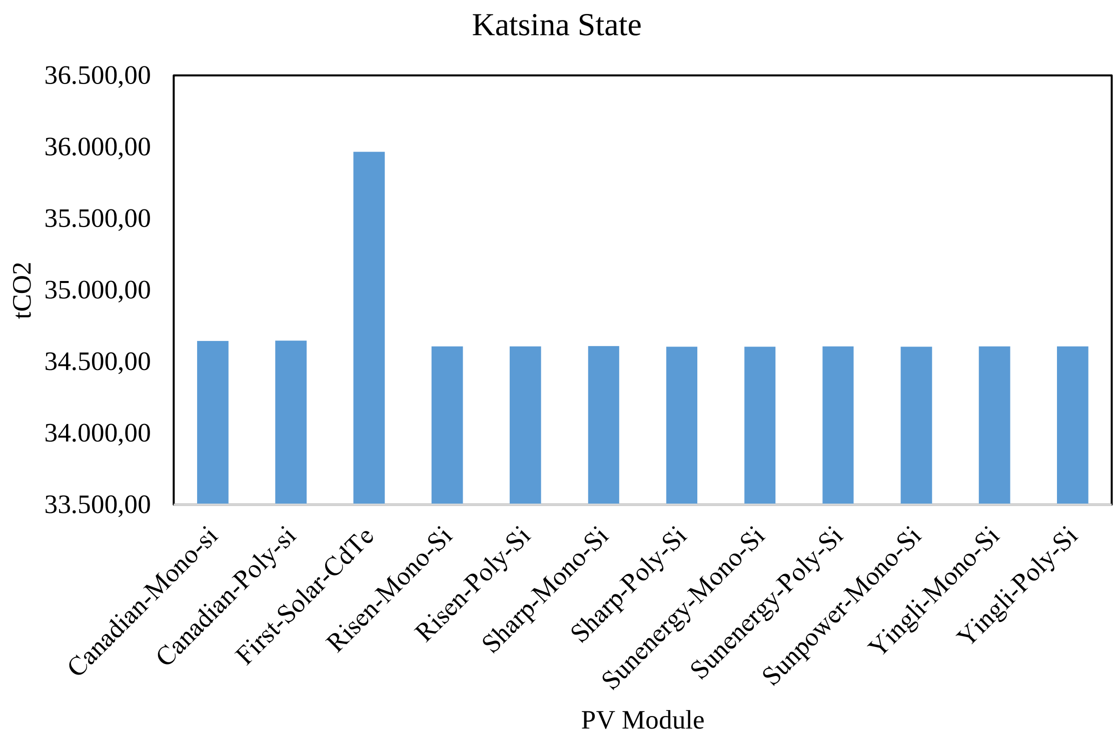

Benue State
31.600,00
31.400,00
31.200,00
31.000,00
30.800,00
30.600,00
30.400,00
30.200,00
30.000,00
29.800,00
tCO2
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

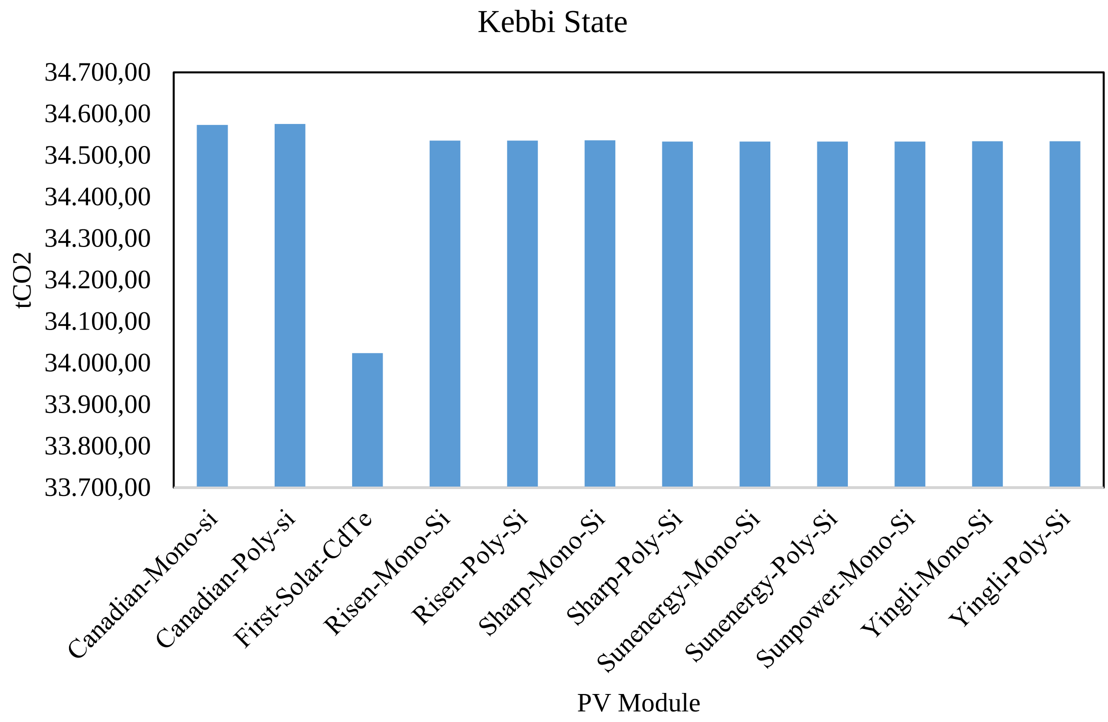

Borno State
36.000,00
35.500,00
35.000,00
34.500,00
34.000,00
33.500,00
33.000,00
tCO2
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

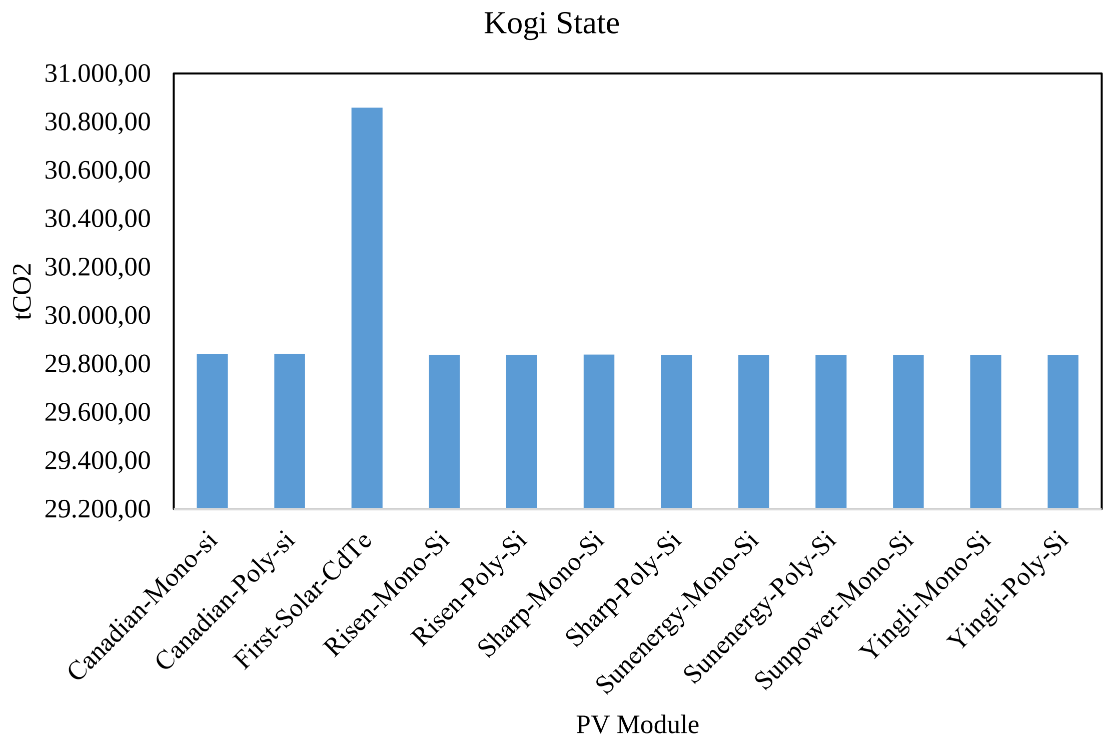

Abuja (FCT)
33.400,00
33.200,00
33.000,00
32.800,00
32.600,00
32.400,00
32.200,00
32.000,00
31.800,00
31.600,00
31.400,00
tCO2
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

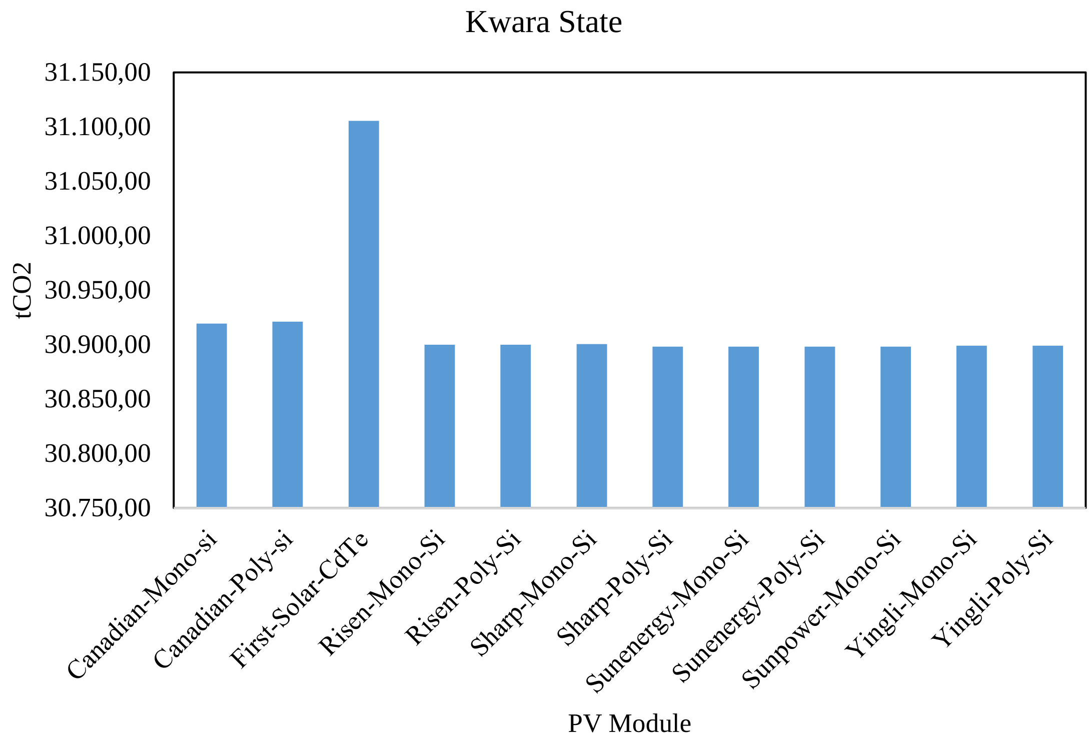

Kaduna State
34.600,00
34.400,00
34.200,00
34.000,00
33.800,00
33.600,00
33.400,00
33.200,00
33.000,00
32.800,00
32.600,00
tCO2
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

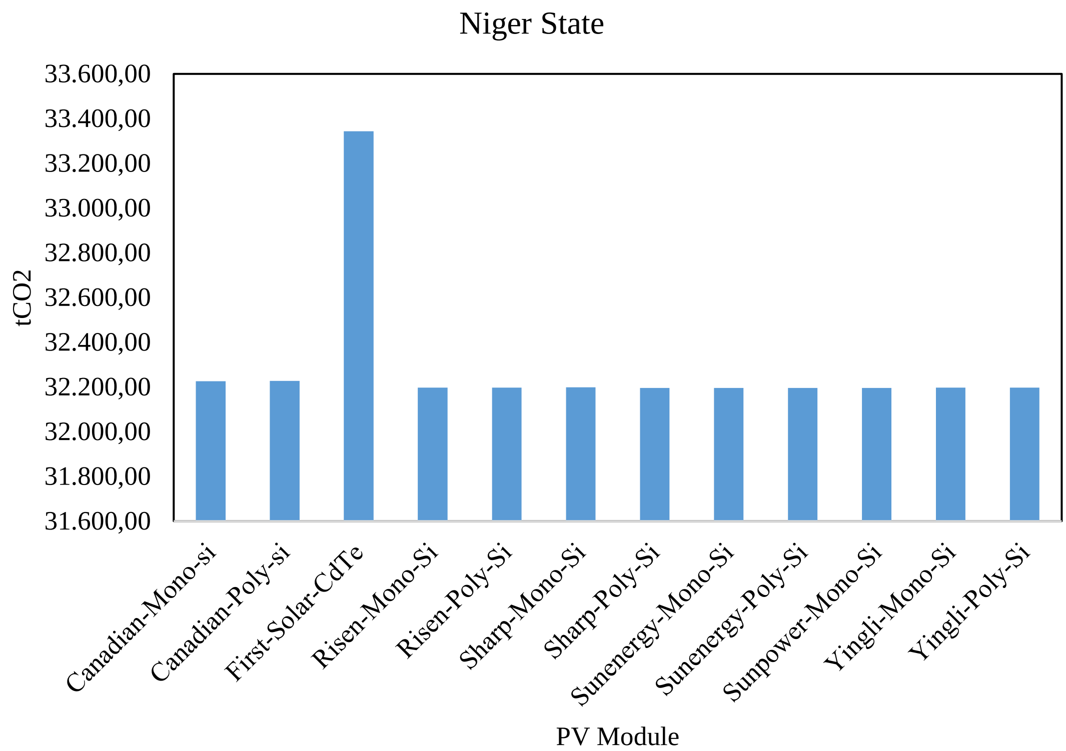

Kano State
36.000,00
35.500,00
35.000,00
34.500,00
34.000,00
33.500,00
tCO2
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module

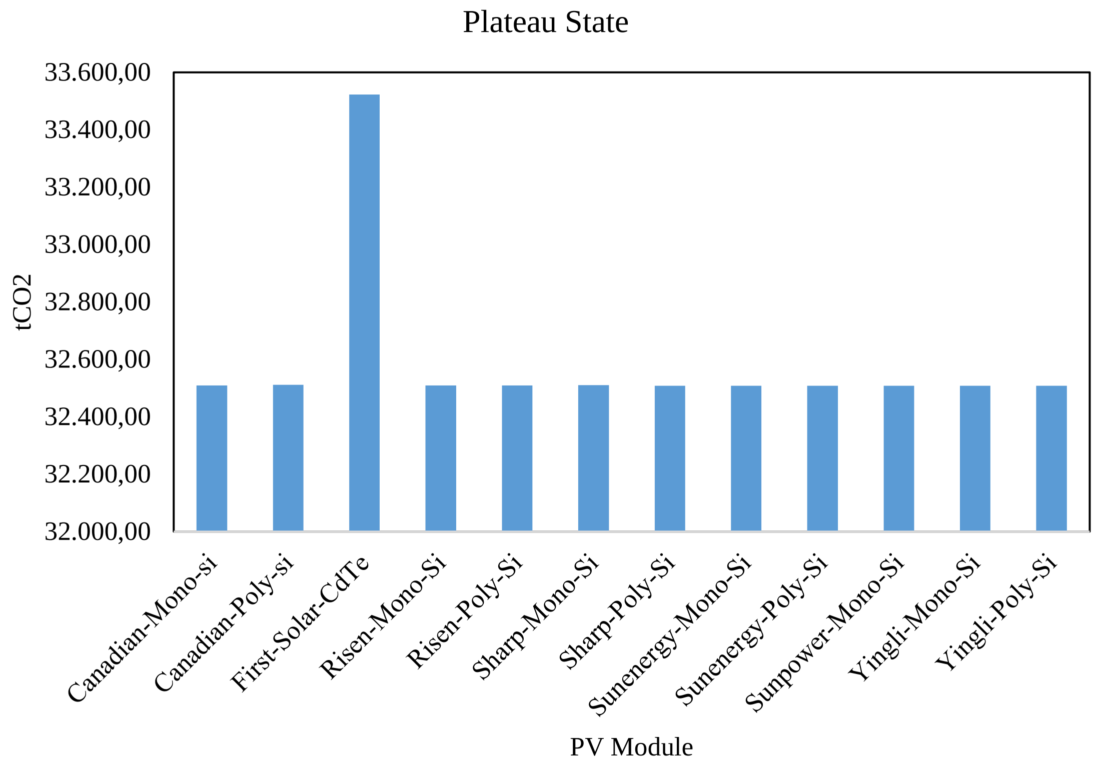

Katsina State
36.500,00
36.000,00
35.500,00
35.000,00
34.500,00
34.000,00
33.500,00
tCO2
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module


Kebbi State
34.700,00
34.600,00
34.500,00
34.400,00
34.300,00
34.200,00
34.100,00
34.000,00
33.900,00
33.800,00
33.700,00
tCO2
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module


Kogi State
31.000,00
30.800,00
30.600,00
30.400,00
30.200,00
30.000,00
29.800,00
29.600,00
29.400,00
29.200,00
tCO2
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module


Kwara State
31.150,00
31.100,00
31.050,00
31.000,00
30.950,00
30.900,00
30.850,00
30.800,00
30.750,00
tCO2
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module


Niger State
33.600,00
33.400,00
33.200,00
33.000,00
32.800,00
32.600,00
32.400,00
32.200,00
32.000,00
31.800,00
31.600,00
tCO2
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module


Plateau State
33.600,00
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32.600,00
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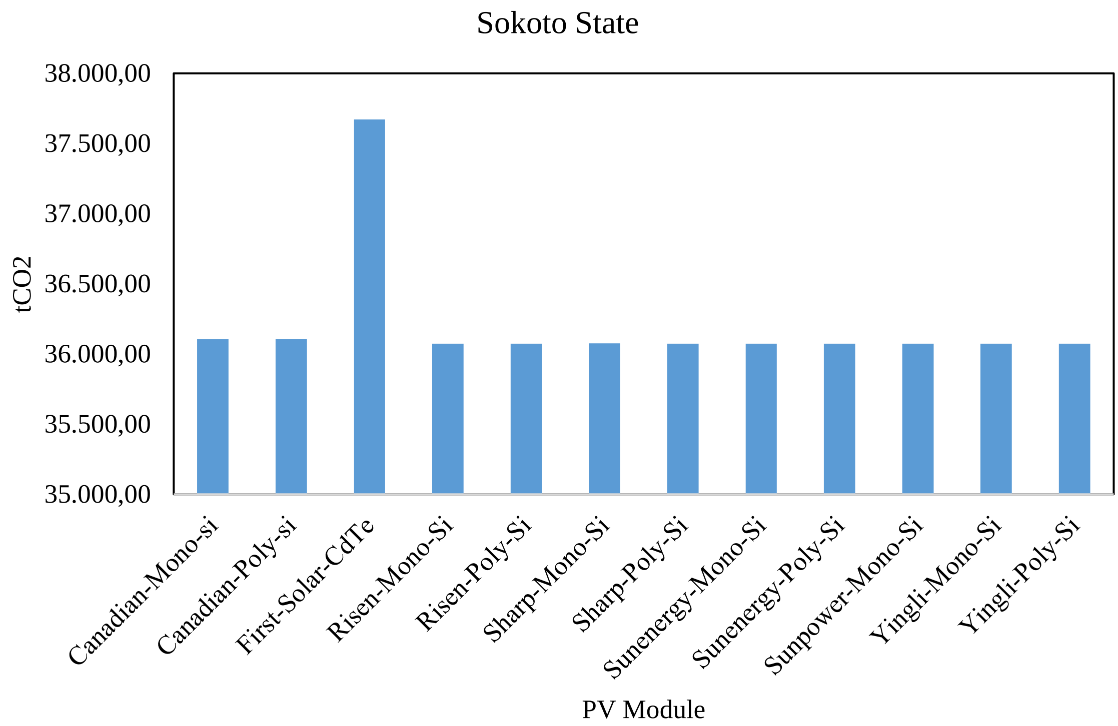
32.000,00
tCO2
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
Sunenergy-Poly-Si
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module


Sokoto State
38.000,00
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tCO2
Canadian-Mono-si
Canadian-Poly-si
First-Solar-CdTe
Risen-Mono-Si
Risen-Poly-Si
Sharp-Mono-Si
Sharp-Poly-Si
Sunenergy-Mono-Si
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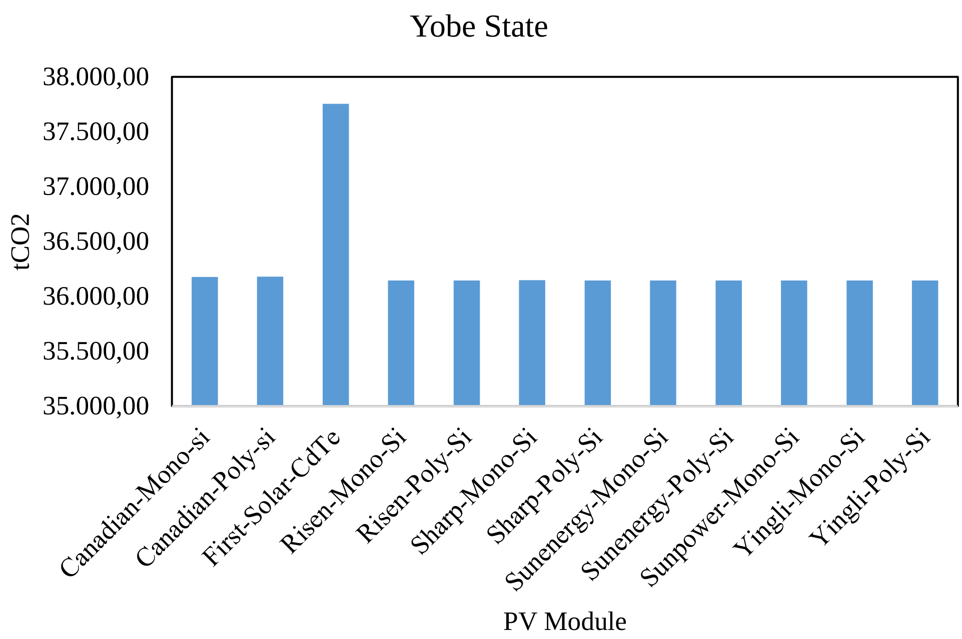
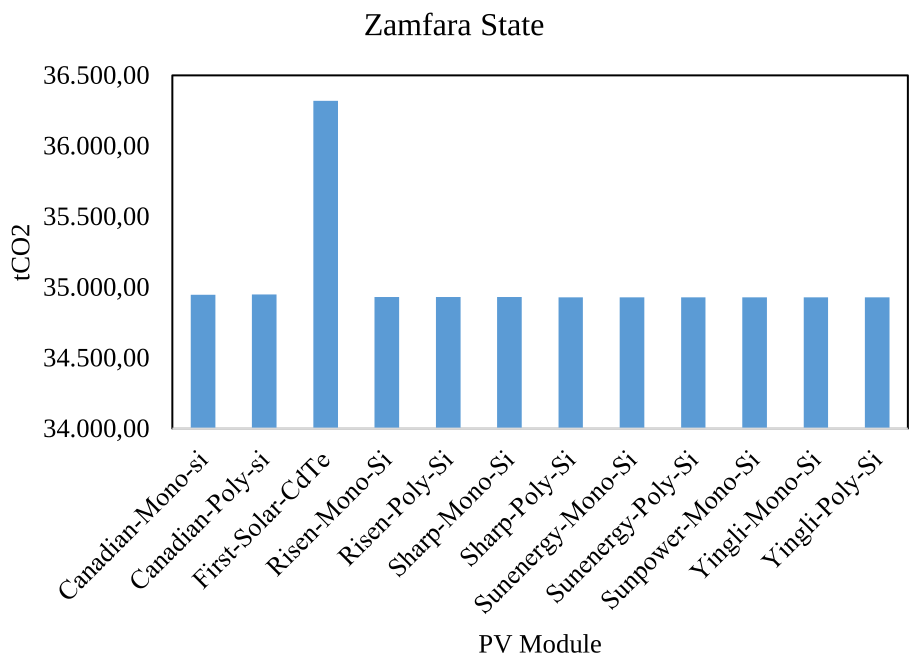
Sunpower-Mono-Si
Yingli-Mono-Si
Yingli-Poly-Si
PV Module




**E. Greenhouse Gas Emission Reduction ($tCO^2$)**

**Figure 4. 11**: Sensitivity study for the grid-connected solar PV system with a capacity of 50 MW.

In addition, the proposed PV project has the longest payback period in the Kogi State, ranging from 11.3 to 12.3 years, followed by Benue State within 10.8 to 11.7 years, while

Sokoto State and Yobe State have the shortest payback period, ranging from 10.8 to 11.7 years. Moreover, Kogi and the Benue States have the highest equity payback, while Sokoto and the Yobe States have the lowest equity payback, ranging from 10.9 to 11.6 and 6.9 to 7.5 years, respectively, as shown in Figure 4.11.

In addition, the Sokoto and Yobe States were found to have the lowest electricity cost of 0.074$/kWh, followed by Zamfara States with value of 0.0763 $/kWh averaged, while the Kogi and Benue States have the highest average electricity cost of 0.095 $/kWh, as shown in Figure 4.11.

RETScreen program calculated the total yearly GHG emission reductions for each state illustrated in Figure 4.11. The project in Yobe State achieved the highest GHG emission reduction of 37,753.60 tCO2, followed by the project in Sokoto State with an emission reduction of 37,670.10 tCO2, and the project in Kogi State with the smallest emission reduction of 37,670.10 tCO2.

## 4.4. 50 MW Grid-Connected PV/Wind System Economic Analysis and Feasibility Study

The initial investment cost of PV system for the selected locations, estimated between $72,500,000-$72,505,800. While the wind farm initial investment costs estimated between $125,000,000-$125,125,000.

Out of 15 selected locations, only 8 locations found suitable for both wind and PV project (Table 4.4) while all 15 selected locations are suitable for a future PV project. However, to select the best system for the future power plant in the 8 selected locations that suitable for both are suitable for wind and PV project, the study compares the viability in terms of technology and economy; sensitivity analysis of both PV and wind system of the 8 locations based on Figure 4.10 and Figure 4.11. The results of the comparison of the 8 locations, the annual electricity export rate, CF and gross annual GHG reduction of a wind system are much higher than that of PV systems. The wind systems found to have the shortest payback period than PV systems in all locations except Borno and Zamfara State where the wind system has the longest payback period than PV systems. Similarly, NPV and annual life cycle savings of wind system found to be higher compared to the PV systems in all locations except Borno and Zamfara State where the wind system has the lowest NPV and annual life cycle savings than the PV systems.

Although energy production costs generated for both wind and PV systems for all eight locations are found to be less expensive compared to current Nigeria's feed-tariff of approximately $0.265, the energy production cost varies from location to location, wind system found to be much higher than the PV systems in Borno and Zamfara states, while Sokoto state the wind system is slightly higher than PV systems while Kano and Plateau state wind system found to have lowest energy production cost compared to the PV system. However, in Yobe state CdTe (PV) system found to have lower energy cost production compare to wind and other two PV systems. While Kaduna and Katsina wind system and CdTe found to be lower than other PV systems

As stated above, the project type for each location varied because of the economic viability, therefore, based on the suitability comparisons (Table 4.4) and the sensitivity analysis for both wind and PV systems, the study identifies the best suitable system for each location presented in Table 4.7.

**Table 4. 7:** Best Suitable System for Each Location

| States | Suitable System |
|---|---|
| Adamawa | CdTe (PV System) |
| Bauchi | CdTe (PV System) |

**Table 4.7. continued**

| States | Suitable System |
|---|---|
| Benue | CdTe (PV System) |

| | |
|---|---|
| Borno | CdTe (PV System) |
| Federal Capital Territory | CdTe (PV System) |
| Kaduna | Wind System |
| Kano | Wind System |
| Katsina | Wind System |
| Kebbi | CdTe (PV System) |
| Kogi | CdTe (PV System) |
| Kwara | CdTe (PV System) |
| Niger | CdTe (PV System) |
| Plateau | Wind System |
| Sokoto | Wind System |
| Yobe | Wind System |
| Zamfara | Wind System |

# CHAPTER 5

# CONCLUSION AND RECOMMENDATION

## 5.1. Conclusions

The power demand has increased because of the country's rising population and the industrial sector. As a consequence, renewable energy sources such as wind and solar energy can assist to reduce GHG emissions and maybe the greatest answer for fixing the country's energy problems. As a result, the goal of this study was to look into the wind and solar potential of the 14 northern Nigerian states as well as the Federal Capital Territory (FCT).

Data from earlier research have been used to evaluate the wind energy potential. According to the earlier wind speed analysis, wind turbines both small and big are excellent for energy generation at the selected sites. In addition, the solar potential of all selected places was analyzed using monthly solar radiation for the future installation of PV systems in Nigeria. The data show that all places considered have plenty of solar resources and are classed as exceptional, excellent or exceptional levels of potential. Furthermore, Sokoto, Yobe and Zamfara states solar resources have been assessed as great and excellent (class 7 and 6). It is therefore considered that chosen sites are suitable for future construction of large-scale PV systems.

In the context of planned large-scale renewable projects, the RETScreen Expert software was also used to assess the economic viability. The photovoltaic system employed three different PV technologies. Three wind turbines were considered for the wind farm project. The economic efficiency gained from the planned wind/PV analyzes for the appropriate sites has been decided to be extremely promising and beneficial. Although the results of the research showed that the wind project is more economically feasible than the PV project at certain sites while the PV project at others is financially feasible rather than the wind/PV due to the high NPV, ALCS and LCOE, the EP values were lower. The analysis further indicates that the use of PV and wind system significantly reduces GHG emissions.

The financial parameters were the main limitation of this study that influenced the interpretation of the outcomes from this research. Based on Nigeria's historical financial values, the financial studies employed assumptions of financial factors. Also, due to the limitation of RETScreen software, the effect of climate characteristics, notably air temperature and relative humidity, which can be essential parameters in PV performance study, was overlooked. Nigéria doesn't have a solar PV sector in general, but its current low price of PV modules makes it an attractive option for the country. Detailed research should be conducted on future research directions that may improve the economic performance and the influence of economic parameters.

Developing a grid-connected solar PV/wind system will help conserve energy and reduce consumption and pollution because to the country's strong solar and wind potential in some regions, which allows for significant cost reductions and technical improvements in the PV/wind industry.

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