Comparative Analysis of Temperature and Solar Radiation Data Available in Mubi-Northeastern Nigeria with Solar Photovoltaic Manufacturer's Standard Test Condition

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Abstract: In extension to the accelerated growth of the solar photovoltaic industry, the type of solar PV and reliability of solar radiation, temperature and air mass data to adopt at a particularly place has recently caught considerable attention by researchers, manufacturers, investors and consumers. Most solar panels are specified with Standard Test Condition (STC), but not all the locations are in agreement with the standard. These conditions are somehow misleading, as the values of solar radiation, temperature and air mass do not align across the full range of Earth surface. This observation encouraged the author to carryout comparative analysis to figure out whether the temperature and solar radiation data available in Mubi during 2000-2020 years align with that of manufacturer's STC specification or not. A time series analysis was adopted to compare the result obtained with STC values. It was found that the available average temperature was 28.83°C and the direct solar radiation was 3278.93W/m^2 in Mubi, which was higher than the STC values. At the same time, the values are capable for harvesting efficient energy, when compared to the respective 25°C and 1000W/m^2 of STC specification. The result also recommends poly-crystalline, thin-film or amorphous silicon as most suitable PV modules types to be adopted in Mubi region, because of their less tolerance to high solar radiation and temperature.

Keywords: *Energy, Mubi, Radiation, Solar, Temperature*

Conflicts of interest: None
Supporting agencies: None

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1. Introduction

Despite drastic increase of installing solar energy in Nigeria, the data availability and variability of incoming solar radiation and temperature pose big challenges in some region and hinders the estimation of these resources, leading to gaps in scientific research and engineering applications. During installation of solar energy, numerous factors such as solar radiation, humidity, location, latitude, moisture, elevation, seasons, wind speed, sun position, harmattan, length of daytime, rainfall, shading, dust, temperature and air mass are considered. Among these factors, solar radiation level and temperature are more prominent (Karafil et al. 2016). Solar radiation and temperature resources varies globally. The strongest effect is seen in the dependence on irradiance and module temperature, which may range from −20% to +5% at different locations (Huld and Amillo, 2015). In fact, according to Alsharif et al. (2019) the variability of solar radiation is one of the most important challenges limiting the use of solar energy. These variations are significantly differing from one place to another over the nature of the climate zone and time, and are available to all, making it appropriate to harvest for photovoltaics and thermal devices. Solar thermal energy is usually applicable for cooking, distillation, heating, furnaces, greenhouse and many more. While, in case of solar photovoltaics, it is applicable for generating electricity directly from solar radiation by the principle of photoelectric effect. PV modules are tolerance to extreme conditions of temperature (i.e., temperature surrounding the device plus the temperature increase inside the device due the internal heat that is generated due to conduction and switching losses in semiconductor) and solar radiation. These tolerances are usually displayed it impact on PV system performance, adversely affecting its operation and reliability.

The solar radiation reaching the earth's surface is expected to be uniform, but due to the effect of attenuation by reflection, scattering, absorption and other processes in the atmosphere, the solar radiation tend to non-uniformity. These factors have great affect the solar radiation incident on Earth surface. The amount of solar radiation received on a horizontal plane on Earth surface per unit area is known as the global solar irradiance. It is generally the combination of direct and diffuse. The solar radiation portion which arrives directly on to the earth is known as direct radiation while the scattered solar irradiation is known as diffuse radiation. Direct solar radiation and temperature are routinely measured at most stations in a global scale to enable researchers and engineers to select the most suitable site to implement solar energy system. A detailed description of solar radiation on the earth's surface is essential to explore the potentials of solar resources, given that a majority of places across the universe have an abundance of sunshine (Chen, et al. 2017; Apeh et al. 2021). And it is known that accurate knowledge of solar radiation availability at the site of interest is a vital aspect for solar radiation applications (Jamil, et al. 2016) As a result, it is critical to comprehend the features of variation, estimate methodologies, and modalities of solar radiation measurement (Mustafa et al. 2022), temperature and air mass to standard conditions.

The performance of different PV modules varies from STC measurement and it depends on geographical position and climatic condition (Islam et al. 2020). Absolute values of temperature, solar radiation and air mass has been a subject of debate over the twentieth century, mainly due to its variability on the Earth surface. But the establishment, International Electrotechnical Commission (IEC), that is responsible for providing and regulating all electrical, electronic and related technologies to a standardized approach for testing and certification, proposed a Standard Test Condition (STC) for solar PV systems. STC was scheduled based on the industrial standard, the conditions are for testing and executing in attempt to adopt average temperature, solar radiation and air mass in the World. The average solar radiation, temperature and air mass reaching the top of the Earth's atmosphere, is roughly agreed between 1367-1361 W/m^2, 1500-2000°C and 0 A.M. On the process of reaching the Earth surface, these solar radiation, temperature and air mass are attenuated (due to the shielding effect of various atmospheric components such as ozone, carbon dioxide and water vapors), leaving the optimal normal surface values at approximately 1000 W/m^2, 25°C and 1.5 AM at sea level on a clear day respectively. These values are somehow misleading as these values are rarely uniform across the Earth surface. However, the panel manufacturer firms give only the electrical values of the PV panel under 1000 W/m^2 solar radiation level, 25ºC cell temperature and A.M. 1.5 air mass rate in the catalogues which are conducted in laboratory environment and called as Standard Test Conditions (STC) (Karafil et al. 2016). These conditions practically never occur during normal outdoor operation as they do not take into consideration the actual geographical and meteorological conditions at the installation site (Chikate and Sadawarte, 2015), because the solar irradiance has a variable intensity and the module is subject to considerable temperature changes (Cellura et al. 2008). Moreover, the actual output from the PV module in the field varies from its rated output due to change in ambient environmental conditions from the STC (Dash and Gupta, 2015). In other words, ambient temperature values do not always suit the standard test condition (STC) which is usually applied and referred by PV makers (Ya'acob et al. 2014).

Accounting to this study, several related studies on the influence of temperature and solar radiation effect on solar photovoltaic has been reviewed to identify the gap in the study. These studies include: Siddique and Nahri, (2016) investigate the effects of surface temperature and solar irradiance changes on the performance of three commercially available Photovoltaic (PV) modules, namely monocrystalline, polycrystalline and single junction amorphous, in three hot and days; Hassan et al. [9] analysed the temperature effect on the performance of the photovoltaic system and energy production; Ceylan et al. (2017), analysed an effect of ambient temperature on the photovoltaic module temperature; Koehl et al. (2011), validate two models for prediction module temperature in different climatic regions and getting accurate results for PV module temperature evaluation; Al-Baghdadiet al. (2022) investigates how a PV module performs throughout the year in a hot region by considering the variations in cell temperature resulting from changes in ambient temperature and solar radiation every day; Olayinkaet al. (2018) investigated the effects of some meteorological variables on the efficiency of solar panel within Benin City, South-South region of Nigeria; Al-Ghezi et al. (2022) investigated numaricaly and experimentaly the influence of operating temperature and solar radiation on the output power and efficiency of polycrystalline PV panels in Baghdad-Iraq; Chaichan and Kazem, (2016) evaluate the effect of solar radiation on the PV module in hot and humid weather in Sohar-Oman; Hamrouni (2015), investigated the effect of solar radiation and ambient temperature on the performance of a pumping system consists of a PV generator, transformer DC-DC, DC-AC inverter and submersible pump; Ibrahim et al. (2019) studied the effect of irradiation of solar cell; Karafil et al. (2016) studied the temperature and solar radiation effects on PV-panels power and concluded that the amount of solar radiation falling on the PV panels varies depending on the location of the panel and the intervals in a day; Arjyadhara et al. (2013), analyzed the overall performance of solar cell with varying irradiance, temperature and fill factor; Buni et al. (2018) investigate the relationship between solar radiations, current, voltage, and efficiency of solar panel. All these reviewed related literatures are important in improving the performance and efficiency of the PV cell, but the most related to this study were, Katsumata et al. (2001) studied the gap of the common method of estimating the PV module efficiency in STC despite the fact that it varies from actual outdoor conditions. Despite the facts from some studies that, there are great variations on regional available temperature and solar radiation in the global content for solar PV systems when compared with the STC specifications. It was also observed from reviewed literature that the impacts of solar radiation and temperature on solar photovoltaic panels are still not well understood and most of the studies find the effect without considering whether the available temperature and solar radiation data are aligning to STC. Therefore, the main aim of this study was to carryout comparative analysis to figure out whether the temperature and solar radiation data available in Mubi during 2000-2020 years align with that of manufacturer's STC specification or not. The result that would be obtained would be helpful for researchers and engineers in planning, maintaining, and operating solar energy systems in Mubi and its environs.

2. Materials and methods

2.1. Study area

Mubi, the commercial and largest cattle market of Adamawa state, Nigeria, lies between latitude of 10.333 and longitude of 13.125 at 698m above the sea level. This study highlights Mubi because the city is one of the most energy consumption compared with other towns around it. Mubi experiences an average temperature of 28.83°C. The seasonal variation of Mubi were dry (in the months November, December, January, February, March and April) and rainy (in the months of May, June, July, August, September and October) season, with an annual distribution of rainfall between 1400 - 800 mm. Due to the attributes of topography and climate, Mubi serve as one of the major commercial center in Nigeria, that required energy.

2.2. Source of data

The availability of solar radiation data from satellite has made it possible to estimate the solar resource at any location over very large geographical areas, typically on a continental scale (Huld and Amillo, 2015). The available data obtained for this study are averaged daily sunshine hours, global, direct, diffuse solar radiation on a horizontal Earth surface and temperature at 2m height above the Earth surface for Mubi location Nigeria. It is the historical weather simulation data, with a spatial resolution between 4 and 30 km, obtained from Meteoblue product for the period of 20 years (2000-2020).

Among the available data, researcher choose temperature and direct solar radiation for the analysis. Both temperature and direct solar radiation data were explored in periods equivalent to 7306 days, 240 months and 20 years, prevailing from 2000-2020.

2.3. Data analysis

In trying answer the objective of this study, comparative analysis was chosen. It is the multidisciplinary scientific tool used to compare and contrast variables, and to evaluate the similarities and differences between the historical datasets. The data obtained went through series of averaging to daily, monthly and annually time intervals of temperature and solar radiation datasets. The datasets were filtered, processed and computed in Mathematica and Microsoft Excel softwares using the time series analysis method for 20 years (2000-2020). The reason for choosing time-series analysis method is because it has been proven effective, feasible and popular to support and analyze long-time historical data. The results are accomplished by constructing series of temperatures, solar radiations and manufacturer's STC values in time graph. The trends in graphs are instrument that explain the similarities and differences between the available datasets for monthly and annual solar radiation and temperature with STC dataset.

3. Results and discussion

Figure 1 shows a comparison between the daily direct solar radiation in Mubi and STC value. The daily solar radiation ranges from -1.55 to 5230.45W/m^2, which is compatible with the general trends of the highest and lowest fluctuations. As shown only few values of solar radiation are below STC (1000W/m^2), that is to say, most of the values are above the given standard, which spans up to 5000W/m^2. Having solar radiation above the STC would not always have negative effect on solar panels performance, but to the current standard, the solar PV may experience decrease in performance due to the increasing the temperature. The excess solar radiation above the given standard turns to waste, because not all radiations are useful to the solar panels. At the same time the solar radiation, the higher the temperature.

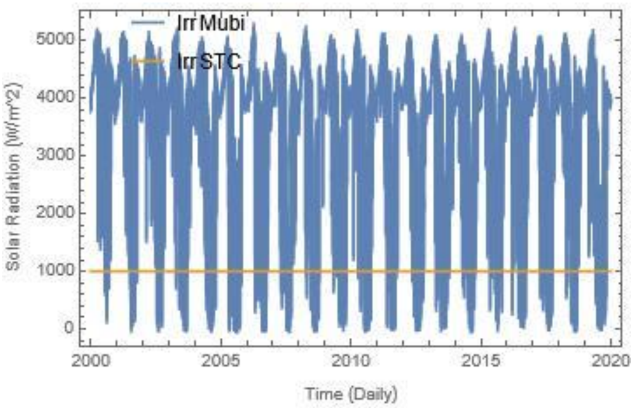

Figure 1: Comparison between STC irradiation and daily direct solar radiation for Mubi from 2000 to 2020.

Solar energy production is more severely affected in hot regions due to increased temperature resulting from climate change (Al-Baghdadi et al., 2022). High temperature affect performance of solar panels negatively due to thermal effect generated in the cells. It was observed that the temperature in Mubi (Figure 2), mostly above the given standard conditions of 25°C for STC. Despite the facts that, higher ambient temperature and solar radiation result in higher PV cell temperature and, therefore, the reduction in PV module power output and efficiency (Al-Baghdadiet al. 2022). In the meanwhile, some studies that conducted in various tropical locations show that the ambient temperature values also do not always suit the standard test condition (STC) (Amin et al. 2009; Ahmed et al. 2011; Ya'acob et al. 2014). Although, solar panels could withstand temperature between 25°C to 35°C. According to Garg & Arun (2016) the module works efficiently not only for ambient temperature greater than 25°C but far greater than 40°C. Therefore, with this result solar panels in Mubi could produce efficient energy as required with significant loss of energy due to the increase in temperature above the given standard.

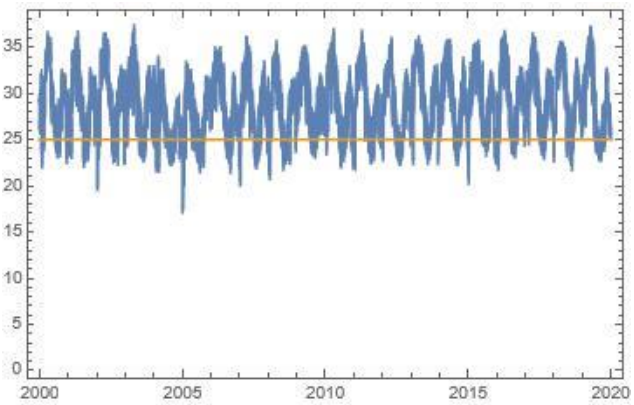

Figure 2: Comparison between STC temperature and daily temperature for Mubi from 2000 to 2020.

As shown in Figure 1 and 2, it is not feasible to use estimated daily data generated in this way because of large number reading would not be easily capture in the graph. In order to have a better understanding of the solar radiation and temperature changes over the 20-year period (2000-2020), atmospheric conditions need to be considered. These conditions can be explained because magnitude of solar radiation is highly influenced by local weather formation which might be affected by physical properties such as albedo, atmospheric humidity, location, latitude, moisture, elevation, seasons, wind speed, sun position, harmattan, length of daytime, rainfall, shading, dust, temperature stratification and other related-meteorological conditions. Another reason could be the presence of cloud, which may allow only a small part of solar radiation to reach the ground surface due its ability to reflect a good part of the solar radiation (Arya, 2001; Nwaokoro & Nymphas, 2020).

However, the direct solar radiation received at the Mubi region was mostly more than 1000 W/m^2. As revealed (Fig. 4), the month of August, 2007 has the least value of 461.53W/m^2 and the month of March, 2017 has the highest solar radiation of 4919.76W/m^2. The result also revealed that the month of August, would not be always possible to obtain significant amount of solar radiation demands from solar panels in Mubi compared to others months. It can be explained that solar radiation is lower in rainy season than dry. Thus, all months are allocated to perform better, especially the months of March for solar PV systems except in the of few August. Meanwhile, in August, there was heavy rain and cloud cover compared with the others months in Mubi. This keep balancing lower solar radiation and leads the surface temperature to be cooler (Figure 7). Implying that higher solar radiation defines higher temperature at the same time. In addition, the observed solar radiation in Mubi show much higher differences. Principally, the differences of solar radiation play major role in circulating the seasonal variations. As already mentioned that solar radiation at the Mubi was much higher (reaching 4919.76 W/m^2) and few lower than 1000W/m^2. The reason for this is that solar radiation released from the Sun to the Earth surface was attenuated or exchanged it energy with atmospheric substances, causing solar radiation fluctuations, thereby misleading values proposed by STC.

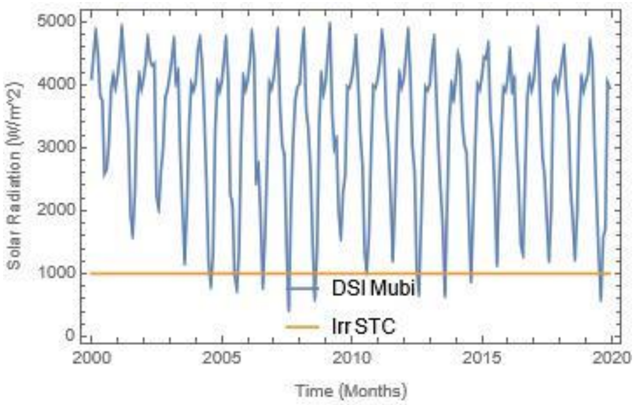

Figure 3: Comparison between irradiation and monthly direct solar radiation of Mubi from 2000 to 2020.

Accordingly, as shown in Figure 4, the monthly average temperature varies from least value of 23.63°C in the month of August, 2005 to the highest value of 35.35°C in the month of April, 2019, with an average value of 28.83°C. Furthermore, the figure shows the values that are felt below and above above the STC.

While some regions on the Earth surface are experiencing temperature at 25°C others are not. Mubi felt among region with temperature above 20°C. Most installed solar modules in sunny countries easily reach higher temperatures than 25˚C (Takyi and Nyarko, 2020). With increasing the photovoltaic temperature, the current increase but the voltage decreases and final effective electrical power decrease (Baltus et al. 1997). DC output voltage decreases slightly with increase in panel temperature only after panel temperature crosses 52°C but the output obtained even at 68°C is much higher than that obtained at 30-35°C panel temperature roughly corresponding to 25-28°C ambient temperature (Garg & Arun, 2016).

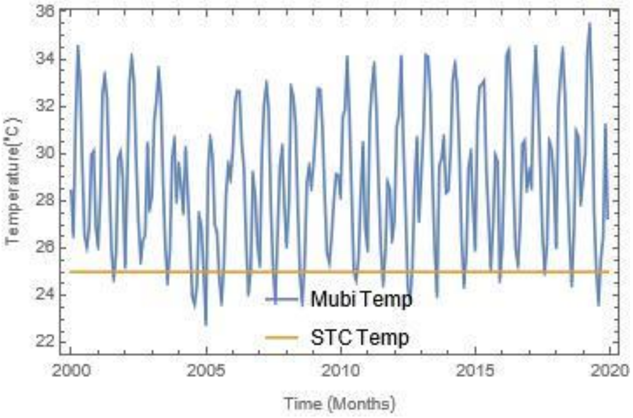

Figure 4: Comparison between STC temperature and monthly temperature for Mubi from 2000 to 2020.

Considering the annual distribution of solar radiation for 20 years in Mubi, it was observed from figure 5, that the average annual average solar radiation surpasses STC by almost two (2) times. This result revealed to us that the Mubi solar radiations are not in line with the given a STC and is always greater when considering annual values. This is because the standard too is proposed based on an annual average value.

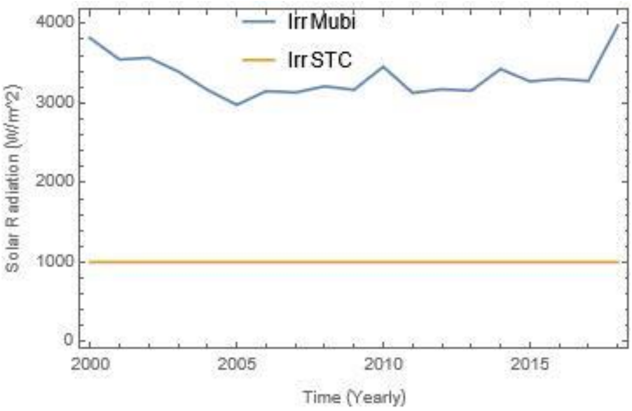

Figure 5: Comparison between STC irradiation and annual direct solar radiation for Mubi from 2000 to 2020.

From Figure 6, it was observed that the annual distribution of temperature for 20 years was all above the STC temperature. Despite having no problem for implementing solar photovoltaic energy, the result is also encouraging to the development solar thermal energy. As shown the temperature differences are, of course, not uniform throughout a year and therefore cannot be compare directly with STC.

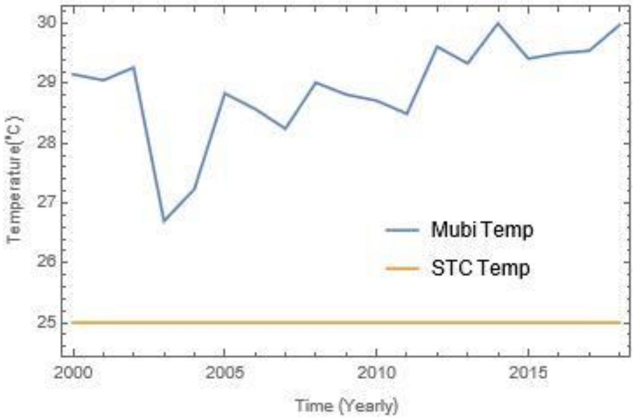

Figure 6: Comparison between STC temperature and annual temperature for Mubi from 2000 to 2020.

Considering monthly variations of solar radiation for 20 years (2000-2020) in Mubi (Figure 7), the highest value of solar radiation of 4698.59W/m^2 was observed in March and the lower value is 1140.17W/m^2 in August. As expected, the highest value of average solar radiation was found in dry seasons throughout the study periods. This were characterized by decreased levels of atmospheric harmattan and clouds. Moreover, relatively large Earth's axial tilt causes considerable seasonal variations of monthly solar radiation values, that are negligible on the Earth surface. In support of this results, the average annual solar radiation proposed by STC should be of minimal of 1000W/m^2 for a particular site. So, it is expected that solar panels could produce positive output when installed in Mubi, because the available solar radiation is beyond the minimal requirement.

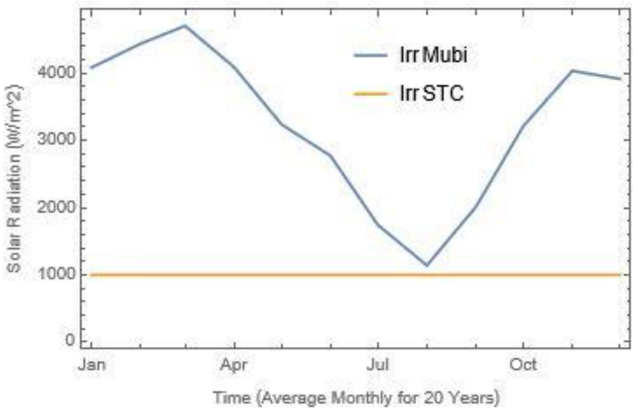

Figure 7: Comparison between STC irradiation and average monthly direct solar radiation for Mubi for 20 years (2000-2020).

Considering monthly variations of temperature for 20 years (2000-2020) in Mubi (Figure 8), the highest range of temperature is seen from February to May, with the peak in April which has temperature of 33.34°C. The month of August has the least temperature of 24.63°C, followed by September which is 24.77°C. To further explore the effects of seasonal differences, it was found that the temperature varied around the average of 28.83°C, with an increase for the dry season months and a considerable decrease for the raining season months. The largest variation in temperature may be attributed to seasonal weather fluctuations.

The climate change and global warming have affected solar cells and their ability to produce electrical energy (Al-Baghdadiet al. 2022; Jatav, 2022). According to Wysocki, and Rappaport (1960) the performance specifications given by the manufacturers of different types of silicon solar PV modules are usually related to environmental and weather conditions. A high quality, safe and durable PV module delivers the expected rated power (Wp) withstanding extremely wide range of environmental conditions (Ya'acob et al. 2014). It was observed throughout the period of 2000-2020, local weather conditions vary every year. The revealed that the average daily, monthly and annually solar radiation and temperature of Mubi are not that appropriate for generating solar energy when compared to STC. Therefore, the information provided in this study explored the recent changes concerning solar radiation and temperature over the period of 20 years. However, the challenges that is required to support the study is choosing the best types of solar PV that is suitable for Mubi region.

Solar cells need to be cooled in hot regions to improve their efficiency, ensure their continual function, and increase their power production and lifetime (Al-Baghdadiet al. 2022). This may lead solar PV to expensive. Therefore, it is important to select the proper solar cell technology that performs better at a specified location considering its average temperatures (Adeeb et al. 2019). Different types of PV panel technology play different roles in generating output power caused by their sensitivity to the operating temperature (Takyi and Nyarko, 2020). Different modules differ in their characteristic and efficiency due to difference in material, structure and packing, responding differently in various environmental conditions like solar irradiation, ambient temperature, cell temperature, wind speed, humidity, air pressure, dust, tilt angle etc (Garg & Arun, 2016), and certain types of modules are more resilient to temperature increase than others (Dajuma et al. 2016). For instance, at solar irradiance of 600 W/m^2, the mono-crystalline silicon produced less power than amorphous silicon at the same panel temperature (Guide for Solar, 2018; Takyi and Nyarko, 2020); a polycrystalline module operating typically at 45°C will therefore produce roughly 10% less power than predicted by its nominal STC rating (Didier and Richmond, 2005; Garg & Arun, 2016). Suwapaet and Boonla, (2014) indicated that amorphous PV panel is most efficient than monocrystalline silicon when operated under high operating temperature conditions; Adeeb et al. (2019) results demonstrated that energy yield for Thin-film PV modules is less affected by temperature than Mono-crystalline and Poly-crystalline PV modules; Cañete et al. [2014] studied the performance of four different technologies in southern Spain; it was found that the performance of thin-film modules is better in summer, while in the case of poly-crystalline modules, their performance is better in winter; Makrides et al. (2012) showed maximum module temperatures of 54°C. On average, both modules' temperature remained below 58˚C (maximum temperature of a–Si and c–Si is 62.9˚C and 59.9˚C respectively) (Islam et al. 2020). The mean value of the PV modules temperature varies between 25 to 42 °C (Dhimish and Tyrrell, 2022).
Therefore, the distinction of temperature matters here, because the electrical characteristics of solar PV STC are evaluated indoors by manufacturers, not necessarily tested for Mubi region. And the knowledge of its effects will allow potential buyers of PV modules to compare the suitability of different module types before the details of a PV installation have to be chosen. Hence, it is recommended for Mubi region to look for poly-crystalline, thin-film or amorphous silicon PV modules, because of their less tolerances to high temperature based on reviewed literatures. This shows that mono-crystalline PV is only suitable for cool region with temperature below 25°C.

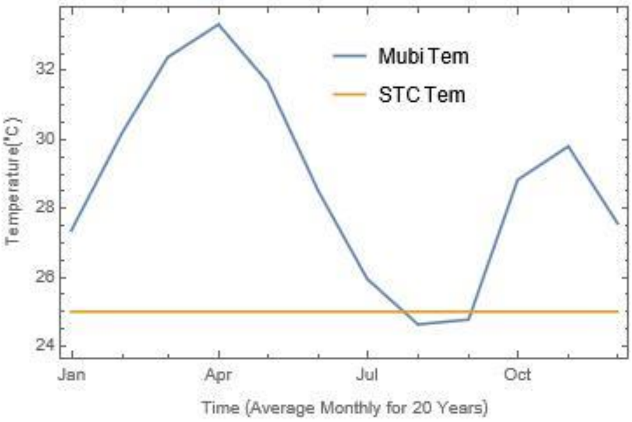

Figure 8: Comparison between STC temperature and average monthly temperature for Mubi for 20 years (2000-2020).

4. Conclusion

Knowing the accurate values of solar radiation and temperature for a particularly place is crucial before selecting the type solar PV to be install. Consideration this challenge, the current study aimed to figure out whether the temperature and solar radiation available data for the period of 2000-2020 in Mubi are in line with that of manufacturer's Standard Test Condition (STC) of solar PV systems. It was concluded based on this study, that the average direct solar radiation and temperature fluctuates around 3278.93W/m^2 and 28.83°C respectively, which can be considered a reference values for estimating potential solar energy in Mubi, and are capable for harvesting efficient energy when compare to the respective 25°C and 1000W/m^2 of STC. It was also recommended that the best types of solar PV modules for Mubi region are poly-crystalline, thin-film or amorphous silicon, because of their less tolerances to high temperature. Therefore, knowing the available temperature and solar radiation data in Mubi-Northeastern Nigeria, can help to allocate solar energy budgets and the deployment of renewable energy technology in area.

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