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Theoretical Investigation of Solar Radiation in Bani Walid, Libya

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دراسة نظرية للإشعاع الشمسي في بني وليد، ليبيا

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Abstract:
Bani-Walid is a town located on the edge of the Libya Desert. It is characterized by great solar activation, especially in mid of June, when the sunny hours exceed the fourteen. Based on this consideration, a theoretical study was conducted to calculate the total incident solar radiation per unit area in this town. The study revealed that the total solar radiation reaches the surface of the earth at about 10.54185 kWh/m2/day, in mid of June, and the peak sun hours reached 10 hours. This allows the investor to build solar plants to supply electric power to this town instead of electric power stations that depend on fossil fuels that emit gases, dust, and cause environmental pollution.

Keywords: Solar radiation, Solar energy, PV solar cell.

الملخص
بني وليد مدينة تقع على حافة الصحراء الليبية، وتتميز بنشاط شمسي كبير، خاصةً في منتصف شهر يونيو، حيث تتجاوز ساعات سطوع الشمس 14 ساعة. وبناءً على ذلك، أُجريت دراسة نظرية لحساب إجمالي الإشعاع الشمسي الساقط على وحدة المساحة في هذه المدينة. وكشفت الدراسة أن إجمالي الإشعاع الشمسي الذي يصل إلى سطح الأرض يبلغ حوالي 10.54185 كيلوواط ساعة/م²/يوم في منتصف يونيو، وأن ذروة ساعات سطوع الشمس تصل إلى 10 ساعات. وهذا يُتيح للمستثمر إمكانية بناء محطات طاقة شمسية لتزويد المدينة بالكهرباء بدلاً من محطات توليد الطاقة الكهربائية التي تعتمد على الوقود الأحفوري الذي يُصدر غازات وغبارًا ويُسبب تلوثًا بيئيًا.

الكلمات المفتاحية: الإشعاع الشمسي، الطاقة الشمسية، الخلايا الشمسية الكهروضوئية.

Introduction

Libya is positioned in the heart of North Africa and its area consists of 88% desert areas. The south region is in the Dessert area which have a high potential of solar energy which can be harnessed for the generation of electricity through the thermal and photo effects of solar energy. Direct radiation on the horizontal plane in Libya shows that solar radiation is considered to be very high in this country. On a horizontal plane, total energy received as much as 7.1 kWh/m2/day [1] and 8.1 kWh/m2/day for southern regions (Figure 1) [2]. Libyan renewable energy indicates that the average annual duration of sunshine hours is more than 3000 to 3500 hours [3]. Each year, the land surface receives a coating equivalent to 25 centimeters of crude oil. Libya is experiencing rapid growth in the demand for electricity and potable water at a low price.

Demand for electricity in Libya will exceed 115 gigawatts by 2030 unless alternative energy sources are produced and the application of systems to conserve energy sources The total demand for raw fuel for energy, industry, transport and water will increase from 1,600000 barrels per day in 2010 to the equivalent of 3 million barrels per day by 2030 [5]. Large power cuts in Libya now last for long hours throughout the day. The use of solar energy in Libya can no longer be postponed. Depending on the climate condition, the outputs of PV systems can vary slowly or rapidly (e.g., cloud cover. squall lines, temperature, wind speed, dust, and humidity). In this article, we will study the amount and variation of the incident solar radiation onto the surface of Bani-Walid town, Libya throughout the year.

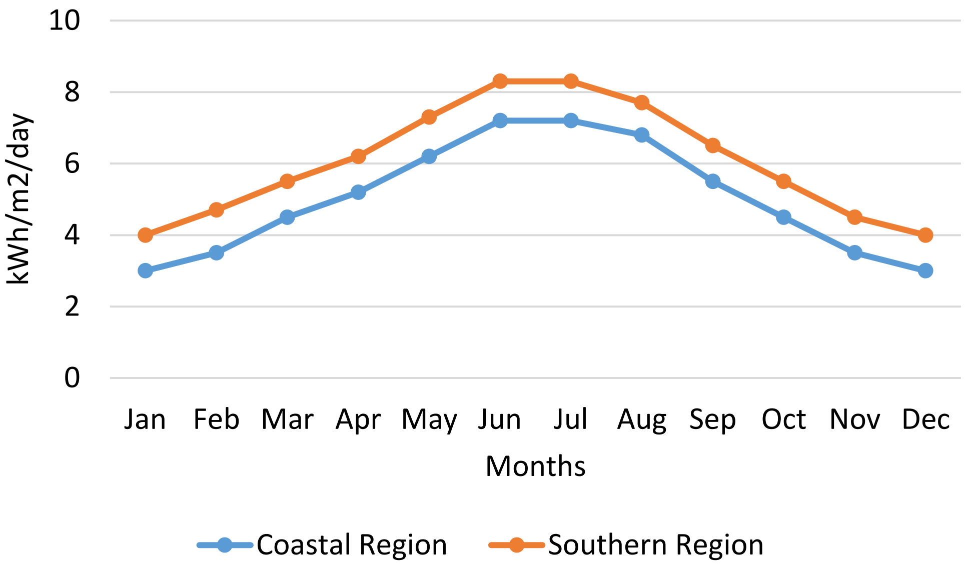

Figure 1. The average of Daily global radiation on a horizontal surface [6].

2. Case of Study

For the current work, Bani Walid Town in Libya has been selected for the purposes of calculating theoretically the amount and variation of incident solar radiation annually. Bani Walid town is located in Libya at longitude 14.0537º and latitude 31.7976º and rises from sea level by 255m (see Figure 2). The analysis of the provided solar radiation data affirms that Libya, and specifically the town of Bani Walid (as located on the map), possesses an exceptional solar resource, making it highly suitable for large-scale photovoltaic (PV) development. The instantaneous Solar Irradiance curves that demonstrate extremely high peak intensities of approximately 980{W/m} ^2$ during the summer months (June and July) around noon, with a substantial peak of around 860{W/m} ^2$ even in the winter. This high intensity is coupled with a prolonged period of solar activity, as confirmed by the Number of Sunny Hours graph (Image 2), which shows a maximum of approximately 14 hours of sunlight per day during the summer solstice. The overall quality of the solar resource is quantified by the Means of Peak Sun Hours graph (Image 3), which peaks near 12 hours per day in mid-year, indicating consistently strong, useful sunlight for PV generation. However, a critical real-world factor is revealed by the Means of Solar Irradiance graph (Image 1), which shows a multi-modal profile with a dip in irradiance during the hottest, longest days of summer, suggesting that local atmospheric phenomena, such as dust storms or increased cloudiness, likely reduce the amount of energy reaching the ground despite the high theoretical potential. Therefore, while Bani Walid is ideally placed for solar power, successful project implementation must incorporate robust mitigation strategies, such as frequent panel cleaning, to counter the effects of these atmospheric events.

Figure 2. Bani Walid location [7].

3. Results and Discussion

In the present work, two simulation programs in MATLAB have been used to build a clear weather atmospheric model with a visibility of 23 km. The first program calculates the daylight hours from sunrise to sunset depending on the latitude of the city at which the solar radiation is to be measured, and the other program, depending on a set of constants such as the height of the city above sea level, the latitude angle of the city, the constant of solar radiation, solar azimuth angle, tilt angle, declination angle, hour angle, zenith angle, and the altitude angle. The second program is designed to calculate the total beam (global) (direct and diffuse) solar radiation for any city. The second program was carried out to calculate the irradiance for each hour of the day, then the average was drawn as a function of day time for each month of the year for tilt angle (Tm = 0°).

In this work, the length of the day varies according to the sequence of the days of the year as shown in Figure 4. Figure 5 shows the variation of the average total solar irradiate daytime for all months of the year where the PV panel is at a tilt angle of 0°.

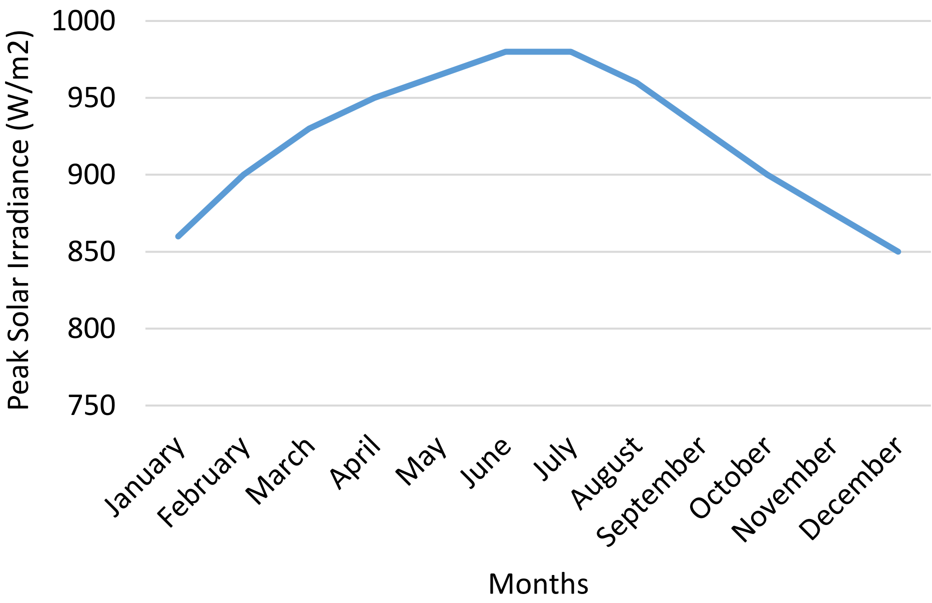

Figure 4. Variation of number of sunny hours along year.

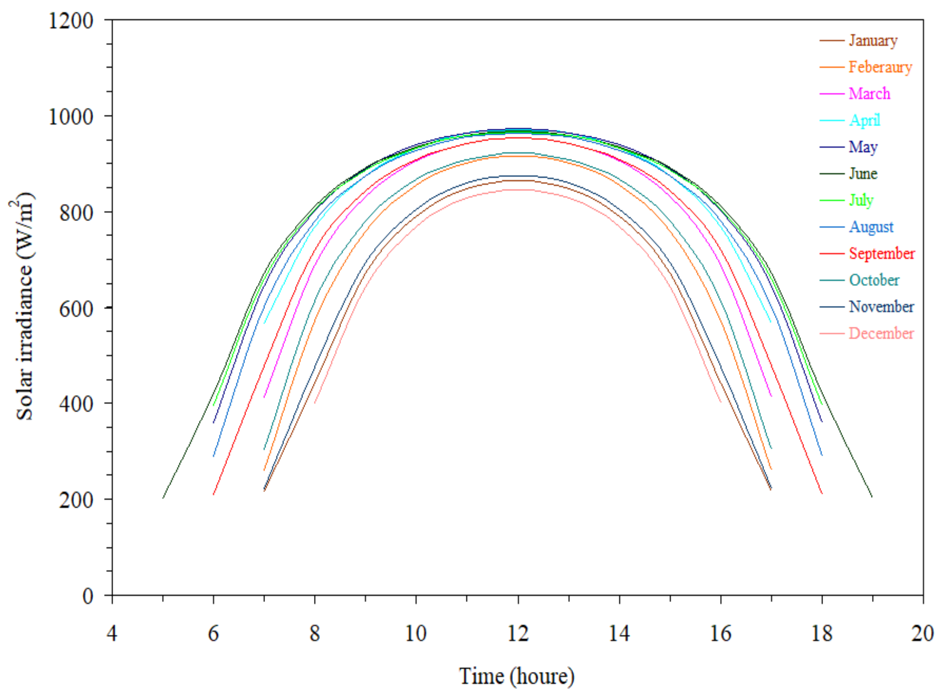

Figure 5. Variation of the total solar irradiance with time at PV tilt angle of 0º.

In general, the incident solar radiation (Irradiance W/m^2) increases with time and reaches its maximum at solar noon, then tends to decrease until sunset time on all days. This is due to the change in the optical path of solar radiation (air mass) through the atmosphere during the day, which leads to a change in the quantity of incident solar radiation, mainly by the absorption and scattering processes. Another indication can be seen from figures 6 and 7, which show that the irradiance levels were increased toward the summer and reached their maximum values in June.

The increase in irradiance levels can be justified as follows: The sunny hours will increase in the summer season. The path of the sun in the sky tends to be vertical. Thus, the optical path of solar radiation through the atmosphere will be diminished. This leads to an incident a large amount of radiation on the earth's surface. The provided graphs illustrate the solar energy characteristics of a specific location throughout the year. The first two images, which are identical, show the instantaneous Solar Irradiance {W/m} ^2) versus Time of Day (hours) for each month. These curves are nearly symmetrical around noon (12:00 hours), reflecting the sun's path. Irradiance peaks in the summer months (June and July) at approximately 980\ W/m} ^2, indicating the strongest sun intensity. Conversely, the irradiance is lowest in the winter months (December and January), peaking around 850\ W/m} ^2, demonstrating a significant seasonal variation in solar energy intensity. The third graph, showing the Number of Sunny Hours versus Day of Year, confirms this seasonal trend. It displays a minimum of approximately 10 sunny hours per day around the beginning and end of the year (winter), and a maximum of approximately 14 sunny hours per day around Day 180 (June/July), consistent with the longer daylight hours of summer. Collectively, these figures demonstrate that the location experiences a clear annual cycle where both the intensity of the sun's radiation and the duration of available sunlight peak in the summer and are at their minimum in the winter.

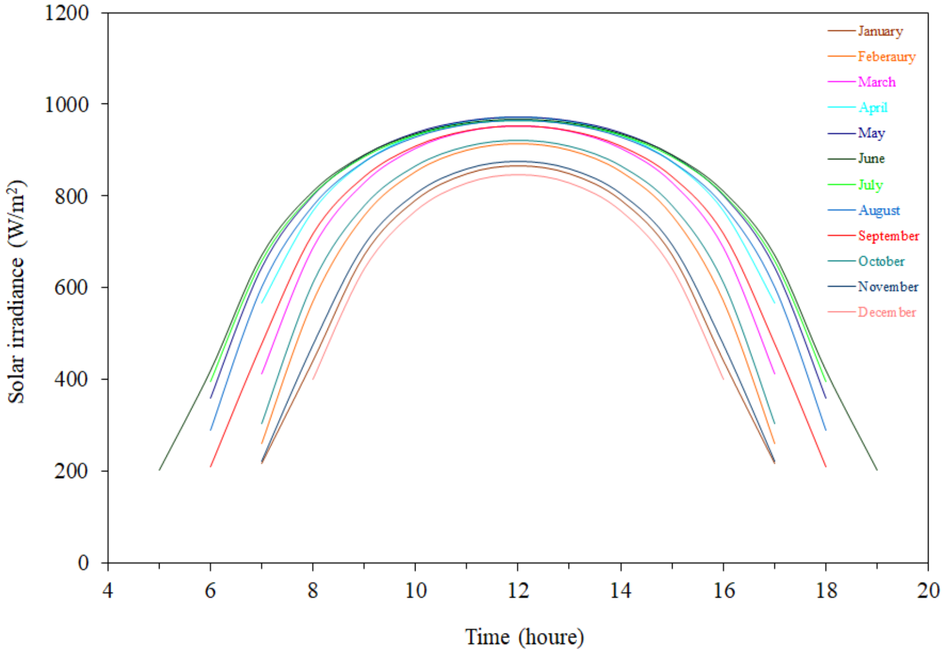

Figure 6 Variation of the total solar irradiance with time.

The set of provided graphs comprehensively details the solar energy resources for a location over the course of a year. The two identical bottom graphs illustrate the instantaneous Solar Irradiance {W/m} ^2$) over the Time of Day (hours) for each month, showing that the peak intensity occurs around noon (12:00 hours) for all months. The intensity is highest in June and July, peaking near 980\W/m} ^2$, and lowest in December and January, peaking around 860\ W/m} ^2$. This strong seasonal variation is further confirmed by the middle graph, which plots the Number of Sunny Hours versus the Day of the Year (DOY). This figure shows a predictable, smooth annual cycle: minimum sunny hours (~ 10 hours) occur near DOY 0 and 365 (winter), while the maximum (~ 14 hours) is reached near DOY 180 (summer solstice). Lastly, the top graph displays the Mean Daily Solar Irradiance versus Day of the Year and exhibits a multi-modal annual cycle. It shows a primary peak around DOY 100 ($\sim 840 W/m} ^2), a secondary peak around DOY 200 (sim 780\{W/m} ^2), and a drop in between, which might suggest the influence of local weather patterns like cloud cover or dust storms around the summer solstice period, slightly obscuring the expected simple sinusoidal summer maximum.

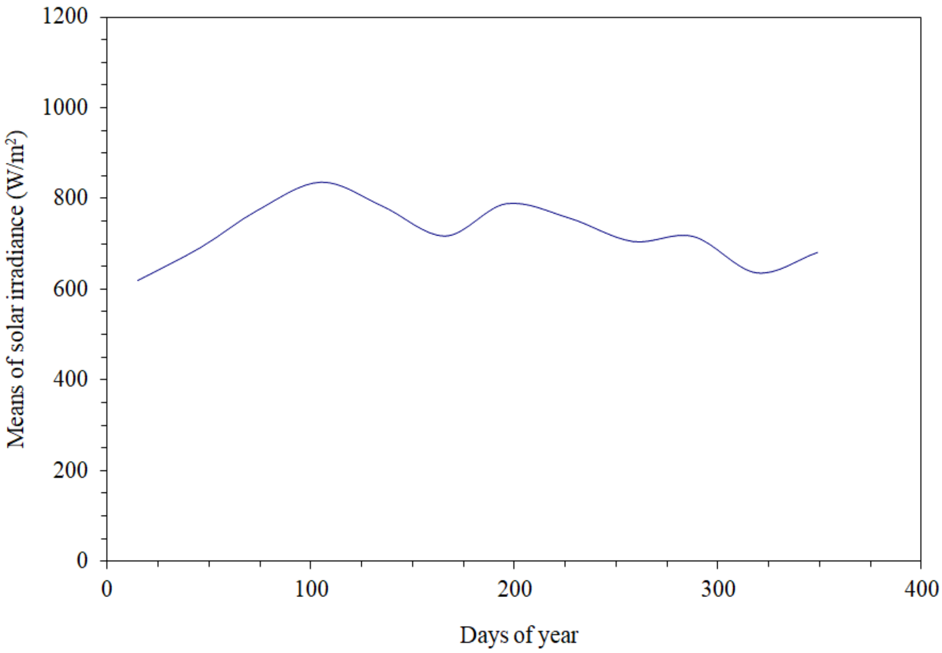

Figure7. Variation of solar irradiance rates along the year.

According to the variance in the amount of incident solar radiation, there were variances in the peak sun hours, which represent the solar fuel as shown in Figure 8. These values are promising for investment in solar energy, especially in the summer, when they reach about 11 hours. The annual peak solar hours were approximately 6 hours.

The provided set of graphs offers a detailed profile of the solar energy availability for a specific location across an entire year. The first two images, which are identical, show the instantaneous Solar Irradiance W/m} ^2 versus Time of Day (hours) for each month. These curves are bell-shaped and centered around noon (12:00 hours), illustrating that the peak intensity occurs in the summer months (June and July), reaching approximately 980\{W/m} ^2, while the lowest intensity is observed in the winter months (December and January), peaking around 860\{W/m} ^2. This seasonal trend is strongly supported by the graph detailing the Number of Sunny Hours versus the Day of the Year (DOY), which shows a minimum of roughly 10 sunny hours near the winter solstice (DOY 0/365) and a maximum of approximately 14 sunny hours near the summer solstice (DOY 180). However, the graph showing the Means of Solar Irradiance (W/m} ^2$) versus DOY exhibits a complex, multi-modal pattern: it has a primary peak around DOY 100 ($\sim 840\text{W/m} ^2$) and secondary peaks around DOY 200 and DOY 270, with dips in between. This deviation from a simple summer maximum, particularly the dip around the summer solstice, likely suggests the significant influence of local atmospheric conditions like increased cloud cover or dust storms during the period of maximum potential solar radiation. Similarly, the Means of Peak Sun Hours versus DOY shows a clear maximum of nearly 12 hours per day around the summer solstice, confirming that summer is the period of longest and strongest sunlight, despite the potential atmospheric interference seen in the mean irradiance data. While Figure 10 show the approximation of Start of Sunlight and End of the case study.

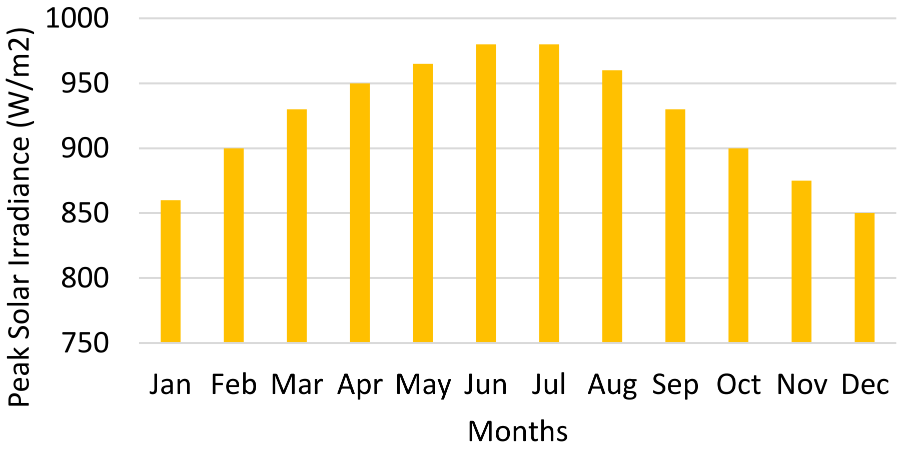

Figure 8. Variation peak sun hours along the year.

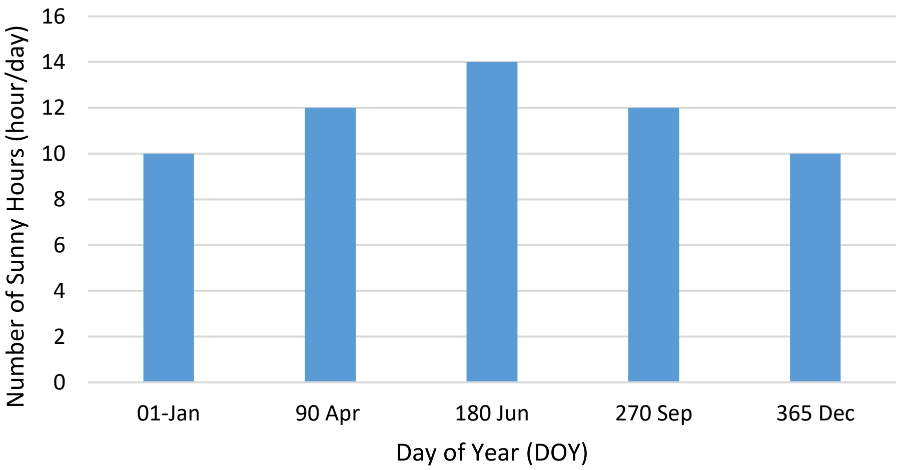

Figure 9: Number of Sunny Hours (hour/day).

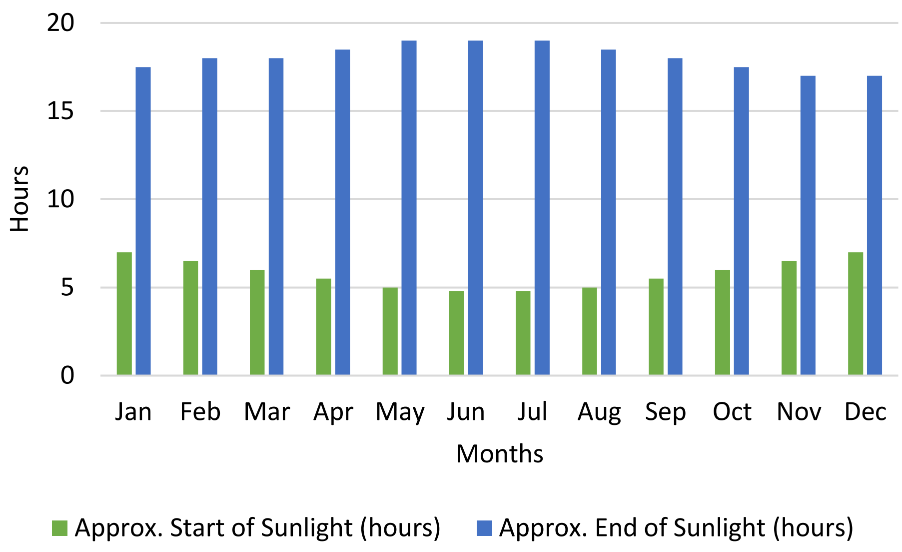

Figure 10: Approximation of Start of Sunlight and End**.**

The comprehensive analysis of the solar data for Bani Walid, Libya, firmly establishes the region as having an outstanding solar resource, which is ideal for large-scale photovoltaic (PV) power generation. The graphs detailing the instantaneous Solar Irradiance (W/m2) versus Time (Images 1, 7, 9) confirm that the peak intensity reaches approximately 980 W/m2 during the midday hours of the summer (June/July), with even the winter months maintaining a strong peak of around 860 W/m2. This high intensity is complemented by a remarkably long duration of solar activity, as evidenced by the Number of Sunny Hours graph (Image 3), which demonstrates a clear seasonal cycle peaking at approximately 14 hours of sunlight per day around the summer solstice. Furthermore, the Means of Peak Sun Hours graph (Images 2, 6) reinforces this quality, showing a high annual average that peaks near 12 hours/day, indicating consistently strong and useful sunlight. However, the graph showing the Means of Solar Irradiance (W/m2) versus Days of Year (Image 8) reveals a critical operational nuance: the curve exhibits a noticeable dip in average irradiance during the middle of the summer (Day 150-250), despite this being the period of longest sun exposure. This suggests that while Bani Walid is theoretically superb for solar energy, the actual energy harvest is frequently affected by local atmospheric conditions such as dust storms or increased cloud cover, a factor that must be addressed through maintenance protocols in any large-scale PV plant design. Figure 11 show the situation of Solar Azimuth of Bani Walid. While Figure 12 presented the Average hourly profiles of Solar irradiation of Bani Walid.

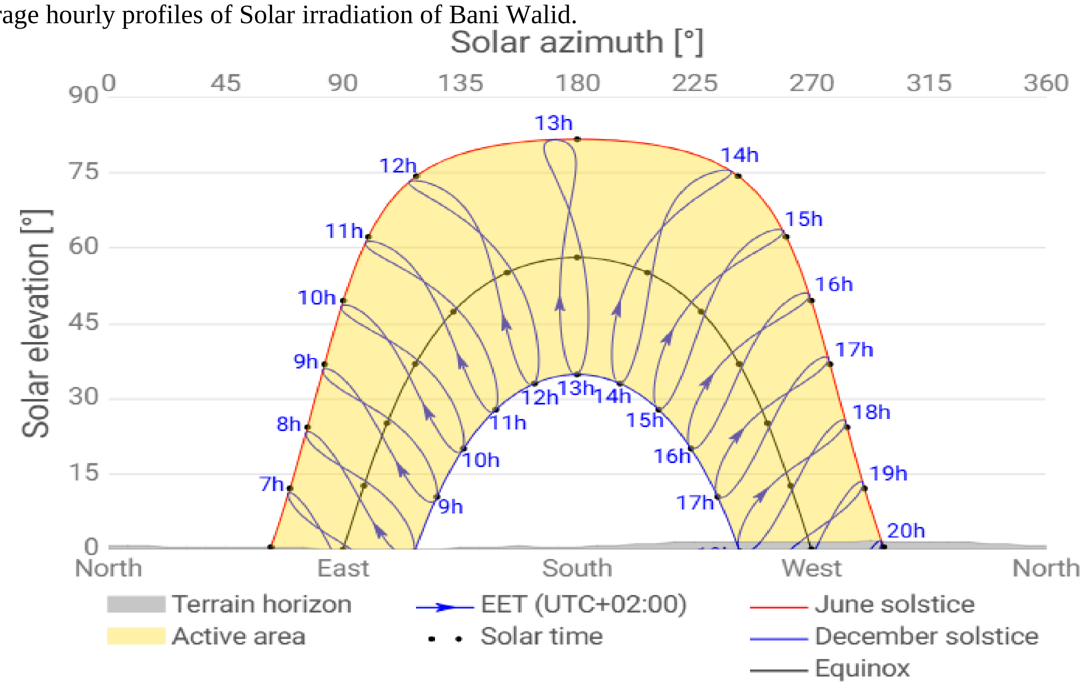

Figure 11: Solar Azimuth of Bani Walid.

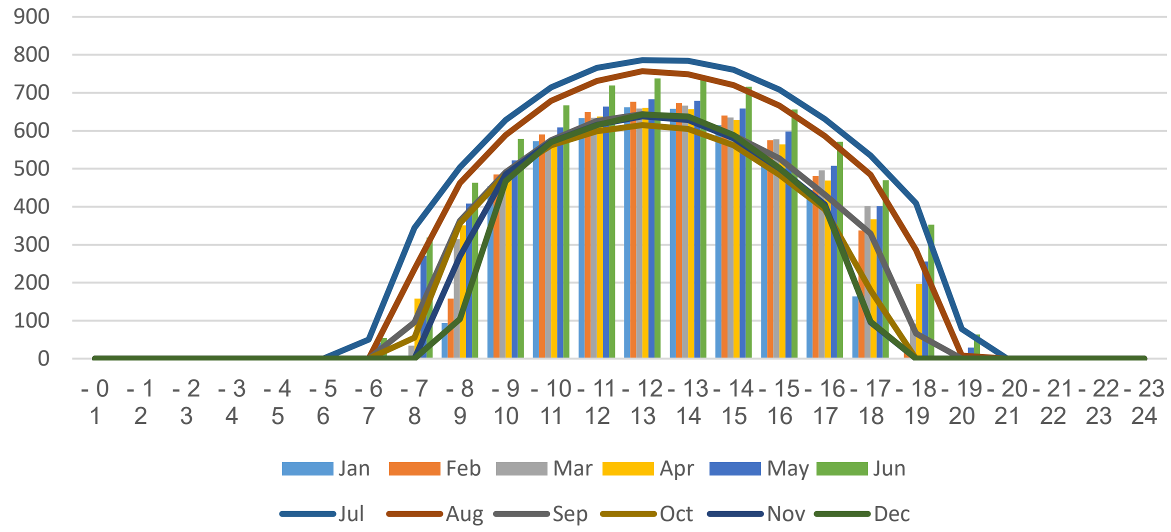

Figure 12: Average hourly profiles of Solar irradiation of Bani Walid.

4. Conclusions

The theoretical study of solar radiation in Bani Walid confirms the town possesses an exceptional solar resource profile, making it highly suitable for large-scale photovoltaic (PV) development. The analysis demonstrates a long solar activity period, extending for over fourteen hours during the summer, which significantly enhances the potential daily energy yield. This prolonged exposure, coupled with favorable intensity levels, strongly supports the recommendation for building huge solar energy stations and subsequently integrating their output into the national grid. Moving forward, the focus should shift from theoretical assessment to actionable implementation. Future studies must prioritize ground-truthing the data using measured irradiance values, performing a detailed techno-economic feasibility study to determine optimal system designs and cost-effectiveness, and modeling the specific effects of local atmospheric conditions, such as dust and cloud cover, on long-term PV performance to ensure sustained efficiency and maximize the return on investment.

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