The Open European Journal of Applied Sciences (OEJAS)
المجلة الأوروبية المفتوحة للعلوم التطبيقية
|| Volume || 1 || Issue || 2 || Pages || PP 01-12 || 2025 ||
ISSN (e): 3062-3391, Pages 34-45
Open access

Using Solar Energy in Remote Libyan Areas and Establishing Model Farms (Al-Saddada Area)

Naji Abdalaziz Ali Assalai [1 *], Majdi Omar Ajaj [2], Fathall Saleh Othman [3]
[1,2,3] Department of Mechanical Engineering, Collage of Technical Sciences, Bani Walid, Libya
[*] *Corresponding Author:* Email: najiassalai85@gmail.com

استخدام الطاقة الشمسية في المناطق الليبية النائية وإنشاء مزارع نموذجية: دراسة حالة منطقة السدادة

ناجي عبد العزيز علي[1*]، مجدي عمر عجاج [2]، فتح الله صالح عثمان [3]
[3،2،1] قسم الهندسة الميكانيكية، كلية العلوم التقنية، بني وليد، ليبيا

Date of Submission: 15-04-2025 Date of acceptance: 05-05-2025 Date of publishing: 19-05-2025

Abstract
This study examines the potential for establishing solar farms in the Al-Saddada region of Libya, leveraging the country's abundant solar resources to transition towards renewable energy. Solar farms, often referred to as "solar gardens" or "solar fields," consist of arrays of photovoltaic (PV) panels that convert sunlight into electricity, typically with a capacity of at least 100 kilowatts. With Libya located in the sunbelt region, it benefits from some of the highest solar radiation levels globally, averaging approximately 2,500 kWh/m²/year and over 3,500 hours of sunshine annually. The strategic plan for Libya aims to integrate renewable energy into 30% of the energy mix by 2030, with expectations for renewable sources to surpass fossil fuels by 2050. The research highlights the importance of addressing environmental factors that could impact the efficiency and sustainability of solar farms, such as soil erosion, dust, and wildlife interactions. By managing these concerns, solar farms can enhance their operational capacity and contribute to reducing the carbon footprint of the electricity sector, which currently accounts for 36% of Libya's total emissions. The study is structured to provide a theoretical foundation, testable hypotheses, and analytical strategies, culminating in a descriptive overview of results and their implications for renewable energy planning in Libya. Ultimately, this research underscores the significance of solar energy development in the Al-Saddada region and suggests pathways for future exploration in solar farm implementation and renewable energy strategies.

Keywords: Solar Energy, Remote, Model Farms, Solar farm, Al-Saddada Area.

الملخص
تستكشف الدراسة إمكانية إنشاء مزارع للطاقة الشمسية في منطقة السدادة بليبيا، مستفيدةً من موارد البلاد الشمسية الوفيرة للانتقال نحو الطاقة المتجددة، حيث تتكون مزارع الطاقة الشمسية، التي تُعرف غالبًا بـــ"الحقول الشمسية"، من مصفوفات من الألواح الكهروضوئية (PV) التي تُحوّل ضوء الشمس إلى كهرباء، بسعة لا تقل عادةً عن 100 كيلوواط. ونظرًا لموقع ليبيا في منطقة الحزام الشمسي، فإنها تتمتع بأعلى مستويات الإشعاع الشمسي عالميًا، بمتوسط يبلغ حوالي 2500 كيلوواط/ساعة/متر مربع/سنة، وأكثر من 3500 ساعة من سطوع الشمس سنويًا. وتهدف الخطة الاستراتيجية لليبيا إلى دمج الطاقة المتجددة في 30% من مزيج الطاقة بحلول عام 2030، مع توقعات بأن تتجاوز مصادر الطاقة المتجددة الوقود الأحفوري بحلول عام 2050. ويُسلّط البحث الضوء على أهمية معالجة العوامل البيئية التي قد تؤثر على كفاءة مزارع الطاقة الشمسية واستدامتها، مثل تآكل التربة والغبار وتفاعلات الحياة البرية. من خلال إدارة هذه المخاوف، يمكن لمزارع الطاقة الشمسية تعزيز قدرتها التشغيلية والمساهمة في تقليل البصمة الكربونية لقطاع الكهرباء، الذي يُمثل حاليًا 36% من إجمالي انبعاثات ليبيا. صُممت الدراسة لتوفير أساس نظري، وفرضيات قابلة للاختبار، واستراتيجيات تحليلية، تُختتم باستعراض وصفي للنتائج وآثارها على تخطيط الطاقة المتجددة في ليبيا. وفي نهاية المطاف، يُبرز هذا البحث أهمية تطوير الطاقة الشمسية في منطقة السدادة، ويقترح مسارات للاستكشاف المستقبلي في تنفيذ مزارع الطاقة الشمسية واستراتيجيات الطاقة المتجددة.

الكلمات المفتاحية: الطاقة الشمسية، مزارع نموذجية عن بعد، مزرعة شمسية، منطقة السدادة

Introduction

Solar farms are being built on a large scale around the world to generate renewable energy. These installations consist of groups of photovoltaic (PV) solar panels placed on the ground, which convert sunlight into electricity. Often referred to as "solar gardens" or "solar fields" [1], these systems play a crucial role in the transition to sustainable energy sources. The power generation system within a solar farm includes a photovoltaic (PV) module and its associated electrical infrastructure. The term 'PV' specifically refers to systems with a capacity of no less than 100 kilowatts, which are operated and maintained by a photovoltaic power unit (PCBU) or will be in the future [2].

According to the US Energy Information Administration, solar panel installations used for electricity generation typically have a capacity of 1 megawatt. Their primary purpose is to generate and sell electricity, making it essential to address factors that could reduce capacity and impede the processes of collecting, generating, and distributing energy. [3]

capacity. Potential concerns in this regard may include soil erosion, dust, surface runoff, and damage caused by wildlife or livestock during the construction and operation of solar farms. By addressing these issues, solar farms can enhance their efficiency and sustainability in the long term. [3]

The establishment of solar farms in Libya reflects the country's ambition, as it has significant potential for solar energy, yet it currently relies on fossil fuels to produce electricity. The electricity industry is one of the largest sectors emitting carbon dioxide, accounting for 36% of the country's total emissions.(Shara Ahmed, Rahma Al-Zeer, Mohamed Abu Qila, Suhaila Mohamed, Ali Al-Khazmi, Abdul Salam Ali Ahmed, Ibrahim Ambia, Yasser Nassar, Abdel Qader Al-Sharif, & Mohamed Mohamed Khalil. (2023)

The strategic plan for the next thirty years (2020-2050) outlines the country's efforts to integrate renewable energies into approximately 30% of the energy mix by 2030. By 2050, the contribution of renewable energy is expected to exceed that of fossil energy. Shara Ahmed, Rahma Al-Zeer, Mohamed Abu Qila, Suhaila Mohamed, Ali Al-Khazmi, Abdul Salam Ali Ahmed, Ibrahim Ambia, Yasser Nassar, Abdel Qader Al-Sharif, & Mohamed Mohamed Khalil. (2023)

Libya is located in the sunbelt region, which enjoys some of the highest levels of solar radiation in the world. The average total horizontal solar radiation is estimated at about 2500 kWh/m²/year, with a similar amount of direct normal irradiance (DNI) and over 3500 hours of sunshine per year, particularly in the central and southern parts of the country. Among these areas, the Al-Saddada region stands out as particularly advantageous for establishing a solar energy project. Its location within the sunbelt ensures high solar radiation levels, making it ideal for solar energy generation. Additionally, the region's vast open spaces facilitate the installation of large solar farms, while the growing interest in renewable energy aligns with Libya's strategic plans to reduce reliance on fossil fuels. [4]

The research is organized as follows: The theoretical foundations supporting the research are discussed and justified in detail. Next, testable hypotheses based on these theoretical grounds are presented for each of the actors and contextual factors, along with their roles in the solar planning process. This is followed by a presentation of the basic data and our analytical strategies, which are justified in more detail. A descriptive overview of our results is then provided, along with an overview of the inferential results before discussing their meaning and implications. The research concludes with remarks that highlight the importance of this study in the field of renewable energy planning in Libya, specifically in the Al-Saddada region, and offers avenues for future research in solar farms and renewable planning.

Engineering studies have recently focused on renewable fuel and electricity sources, including ethanol, wind energy, and hydropower. This indicates that interest in renewable energy is not limited to solar energy alone. However, compared to the past, solar energy is now widely applicable, with an emphasis on energy development as a social issue that addresses the needs of enhancing large areas of agricultural land.

Study [5] also indicates that the structures developed in general are applied to photovoltaic agriculture due to the similarity between large areas of agricultural land allocated for generating solar energy and large areas of specialized land.

As new energy technologies, such as solar photovoltaic energy, become more widespread beyond specific applications, the dimensions of social acceptance—including the opportunities and barriers associated with each dimension and their interrelationships—can help inform the decision-making process to enhance the growth of solar photovoltaic energy development. [6]

Resnick & Hamilton (2024) reports that the American Farmland Trust (AFT) model estimates that 83% of projected solar projects will be located on agricultural land, including 49% on land the AFT considers nationally significant due to its high productivity, diversity, and resilience. In 2024, the U.S. Department of Agriculture's (USDA) Economic Research Service (ERS) reported that 43% of solar installations were located on land previously used for crop production, and 21% on land previously used for pasture. Although projected rates are readily available, up-to-date national data on the number of acres covered by solar panels is scarce.

Based on SIEA's current estimate of 200 GW of installed solar capacity, ERS estimates of energy used per megawatt of output, and AFT's estimate that 83% of solar installations are on agricultural land, it is likely that 1.25 million acres of agricultural land have been converted to solar energy production. While this number may seem surprising to some, it represents 0.14% of the 879 million acres of agricultural land in the United States. (Resnick & Hamilton, 2024)

Maguire, Tanner, & Winikoff (2024) point out that solar panels are frequently installed in small-scale systems, typically built on existing structures such as rooftops, and do not directly affect land cover or raise concerns about competition for land use. In 2021, 96% of solar PV systems in the United States were small-scale systems, although more than 70% of solar energy was from large-scale commercial solar projects. Agricultural producers also use small-scale solar systems such as rooftop solar panels and solar-powered electric fences.

Referring to the current solar energy landscape in Libya, it has tremendous potential, especially in remote areas that lack traditional energy infrastructure. Libya's solar power generation capacity is gradually increasing, with small-scale photovoltaic (PV) projects launched since 1976. As of 2012, the total installed capacity was only 5 MW, indicating a nascent but growing sector. [8]

Policies are currently being developed to promote PV applications. These include integrating solar systems into agricultural practices to enhance energy access and sustainability. They also target remote areas such as Misrata and Al-Saddada to provide off-grid energy solutions, enhancing energy access in rural areas where traditional energy sources are often unavailable. [9]

Libya possesses substantial solar energy potential due to its geographic location and climatic conditions. A feasibility study by [15] evaluated the implementation of a 10 MW grid-connected photovoltaic (PV) power plant across 22 locations in Libya. The study utilized NASA data and RETScreen software to assess energy production and economic viability. Findings indicated that regions like Al Kufrah and Murzuq are particularly suitable for solar installations, with potential annual electricity generation reaching up to 22.06 GWh. The study concluded that Libya has immense solar energy potential that can be harnessed for electricity generation. Another study by [16] focused on transitioning from fossil fuels to solar energy for street lighting systems in Libya. The research highlighted the economic and environmental benefits of adopting solar energy, emphasizing the need for urgent diversification of energy sources to reduce greenhouse gas emissions and preserve oil reserves.

Furthermore, a study by [18] reviewed the possibility of using solar energy for electricity generation in Libya. The research underscored the country's high solar irradiance and the feasibility of integrating solar power into the national grid to meet growing energy demands sustainably.

Libya's energy production has been heavily reliant on fossil fuels. According to the U.S. Energy Information Administration (EIA), in 2022, oil and natural gas accounted for nearly all of Libya's primary energy consumption, with oil at 57.1% and natural gas at 42.5%. Renewable energy sources, including solar, contributed less than 0.1% to electricity generation. The country's dependence on fossil fuels has led to several challenges, including frequent power outages due to aging infrastructure and fuel shortages. Moreover, the volatility of oil prices and political instability have impacted energy production and revenues. In contrast, solar energy offers a sustainable and stable alternative, with the potential to diversify the energy mix and enhance energy security. Integrating solar energy into Libya's energy system could also reduce greenhouse gas emissions and align with global efforts to combat climate change. The studies reviewed suggest that investing in solar energy infrastructure, particularly in high-irradiance regions, could significantly contribute to meeting the country's electricity demands sustainably.

Material and methods

The Materials and Methods section outlines the approach undertaken to assess the feasibility of integrating solar photovoltaic (PV) systems into Libyan agriculture, addressing both technical and socio-economic dimensions. The primary objective was to evaluate the viability of implementing solar PV systems in agricultural settings across Libya, focusing on three key areas: technical performance and energy yield, economic feasibility and cost-benefit analysis, and social acceptance along with potential impacts on agricultural productivity.

To achieve this, six diverse locations representing Libya's geographical and climatic variations were selected: Al-Marj, Al Kufrah, Sirte, Benghazi, Tripoli, and Murzuq. These sites were chosen based on factors such as solar irradiance levels, agricultural activity, and existing infrastructure.

1. Data Collection

Data collection involved several components. First, solar irradiance data, including Global Horizontal Irradiation (GHI) and Direct Normal Irradiation (DNI), were obtained from NASA's Surface Meteorology and Solar Energy (SSE) database. Additionally, information on land use patterns, crop types, and agricultural practices was gathered from national agricultural databases and local agricultural offices to understand the compatibility of PV systems with existing farming activities.

2. System Design and Simulation

In terms of system design and simulation, a standard 15 kW grid-connected PV system was designed for each site, taking into account local climatic conditions and energy demands. The HOMER Pro software was utilized to simulate system performance, including energy production, cost analysis, and environmental impact.

An economic analysis was conducted to assess the financial viability of the PV systems by calculating key economic indicators such as Net Present Cost (NPC), Levelized Cost of Energy (LCOE), and Payback Period. These metrics provided insights into the long-term economic benefits of integrating PV systems into agricultural operations.

To evaluate social acceptance, a survey was conducted among local farmers and stakeholders to capture perceptions, concerns, and willingness to adopt solar technology in farming practices. The study's findings were then compared with international research on agrivoltaics and renewable energy integration in agriculture, such as the work by Wüstenhagen et al. (2007) and Carlisle et al. (2016), to contextualize Libya's potential within global trends.

Limitations

The study acknowledges certain limitations, including the reliance on modeled data for solar irradiance and the need for long-term field studies to validate simulation results and assess real-world performance.

Results and discussion

The average monthly temperature in Al-Saddada provides insight into the region's climate patterns throughout the year. Understanding these averages is crucial for various applications, including agriculture, energy production, and urban planning. For instance, higher average temperatures during summer months may influence water demand and energy consumption for cooling purposes.

Table 1 the average monthly temperature data for the Al-Saddada region in Libya presented in a table format.

Month	Night Temperature (°C)	Night Temperature (°F)	Day Temperature (°C)	Day Temperature (°F)
January	5	41	15	59
February	7	45	16	61
March	9	48	18	64
April	12	54	22	72
May	16	61	27	81
June	20	68	32	90
July	24	75	36	97
August	24	75	35	95
September	20	68	30	86
October	15	59	25	77
November	10	50	20	68
December	6	43	16	61

This table summarizes the average monthly temperatures for both night and day in degrees Celsius and Fahrenheit for the Al-Saddada region.

Typical Meteorological Year (TMY)

To analyze the climate data effectively, we utilize the Typical Meteorological Year (TMY). This dataset compiles hourly meteorological data for an entire year, tailored to a specific geographical location. The TMY is particularly valuable for modeling and simulation purposes, as it represents typical weather conditions that can be expected over a year, allowing for better planning in sectors such as renewable energy, construction, and environmental management.

By analyzing the typical climate year (TMY) data in solar energy system modeling, it provides a representative picture of weather conditions over a year. For the Al-Saddah region, TMY data are essential for simulating the performance of solar energy systems, especially photovoltaic (PV) systems. This analysis will focus on how to use TMY data to model energy production based on typical weather conditions.

The monthly temperature data provided indicate significant differences between daytime and nighttime temperatures, which can affect the efficiency of solar panels. Temperature ranges:

- Winter months: January to March, experience lower daytime temperatures (15 to 18°C) and higher nighttime temperatures (5 to 9°C).
- Summer months: June to August, experience higher daytime temperatures (32 to 36°C) and relatively stable nighttime temperatures (24°C).

Energy production will be simulated through

(1) Energy output calculation: The energy output of photovoltaic systems can be estimated using the following formula: [Energy output (kWh) = Solar irradiance (kWh/m²)] × PV panel area (m²) × Efficiency]

The theoretical output power of a photovoltaic (PV) system can be calculated by calculating the theoretical output power (E) of a solar power plant using the following formula:

$$\boldsymbol{E = PrxHxPRE = PrxHxPR}$$

E: Output power (kWh)

Pr: The power rating of the solar system (kWh), i.e., the total power of all PV modules under standard test conditions (STC).

H: Average annual solar irradiance (kWh/m²), typically expressed by multiplying the daily irradiance by 365 days.

PR: Performance ratio, which represents the overall efficiency of the system, including PV module efficiency, inverter efficiency, electrical current loss, etc.

(2) Solar irradiance estimation: Use TMY data to estimate daily solar irradiance based on temperature and other climatic factors.

High temperatures can reduce the efficiency of photovoltaic systems. For example, efficiency may decrease as temperatures exceed 25°C, and high humidity will increase cloud cover, reducing solar irradiance. Wind speed can also affect cooling, impacting overall efficiency.

A. Solar Radiation Calculation Equation Based on Temperature and Other Climate Factors

$$\boldsymbol{Rs = 0.16\ RaTd\ 0.5 \qquad (1) Hargreaves\ equation}$$

$$\boldsymbol{Rs = Ra\left(0.28 + \frac{0.39n}{N}\right) \qquad (2) Angstrom\ equation}$$

→ Ra is the extraterrestrial solar radiation
→ Td is the temperature difference (maximum minus minimum)
→ n and N are the measured sunshine hours and the maximum daylight duration respectively.

Calculate (T_d) for Each Month

$$\boldsymbol{[T_d = t_{max} - t_{mim}] \qquad (3)}$$

T_{max}: is the day temperature.

T_{min}: is the night temperature

Assume a Constant (Ra)
For this example, Ra = 20,000 kJ/m²/day.

Calculate (Rs) for Each Month
Calculate (Td) and (Rs) for each month

Table 2 Calculate the difference between the maximum and minimum temperatures for each month (T_d) and calculate the external solar radiation (R_a) to extract

Month	Night Temperature (°C)	Day Temp (°C)	(T_d) (°C)	(R_s) (kJ/m²/day)
January	5	15	10	(0.16 \times 20000 \times 10^{0.5})
February	7	16	9	(0.16 \times 20000 \times 9^{0.5})
March	9	18	9	(0.16 \times 20000 \times 9^{0.5})
April	12	22	10	(0.16 \times 20000 \times 10^{0.5})
May	16	27	11	(0.16 \times 20000 \times 11^{0.5})
June	20	32	12	(0.16 \times 20000 \times 12^{0.5})
July	24	36	12	(0.16 \times 20000 \times 12^{0.5})
August	24	35	11	(0.16 \times 20000 \times 11^{0.5})
September	20	30	10	(0.16 \times 20000 \times 10^{0.5})
October	15	25	10	(0.16 \times 20000 \times 10^{0.5})
November	10	20	10	(0.16 \times 20000 \times 10^{0.5})
December	6	16	10	(0.16 \times 20000 \t

Data Source and Methodology

The temperature variation data used for the TMY in Al-Saddada has been derived from satellite observations. This data was processed using the System Advisor Model (SAM), a tool developed by the National Renewable Energy Laboratory (NREL) that helps in assessing the performance of renewable energy systems. The data is sourced from the National Solar Radiation Database (NSRDB), which contains a vast collection of weather files with a time step of every 60 minutes. This high-resolution data allows for a detailed understanding of temperature fluctuations and solar radiation patterns, which are essential for optimizing solar energy systems and other climate-sensitive applications.

The temperature variation data used to compile the climatic model year (TMY) for the As-Saddah region were obtained through advanced satellite observations. This methodology ensures the accuracy of the data and its representativeness of local climate conditions.

a. <u>Data Source: Satellite Observations</u>

National Solar Radiation Database (NSRDB): The data are derived specifically from the National Solar Radiation Database (NSRDB), a reliable data repository containing comprehensive weather files. The NSRDB is managed by the National Renewable Energy Laboratory (NREL) and is widely used in solar energy research and applications.

b. <u>High-Resolution Data</u>

The NSRDB provides data with a 60-minute time step, allowing for detailed analysis of temperature variations throughout the day and across different seasons. This detail is critical for understanding the dynamics of solar radiation and temperature variations, which can significantly impact the performance of solar energy systems. The dataset includes various meteorological parameters, such as solar radiation, humidity, wind speed, and temperature, enabling a comprehensive approach to climate analysis.

c. <u>Processing Using the System Advisor Model (SAM)</u>

The System Advisor Model (SAM): The processed data is analyzed using the SAM, a powerful tool developed by the National Renewable Energy Laboratory (NREL). The SAM is designed to evaluate the performance of renewable energy systems, particularly solar technologies. This model allows users to model the energy production of solar installations based on specific site conditions and weather data.

Performance Evaluation: By inputting high-resolution solar temperature and radiation data into the System Advisor Model (SAM), users can simulate the expected performance of solar energy systems. This includes estimating energy production, assessing system efficiency, and optimizing design parameters to enhance overall performance.

d. <u>The Importance of Solar Energy Systems</u>

A thorough understanding of temperature fluctuations and solar radiation patterns derived from the mean wavelength (TMY) is essential for optimizing solar energy systems. Accurate modeling helps determine optimal solar panel configurations, predict energy production, and make informed decisions about system installations.

Results And Discussion

The results of the current study revealed seasonal variation, indicating that solar radiation peaks in the summer months (June and July), while its lowest values occurred in the winter months (January and December). This pattern is consistent with the expected behavior of solar radiation, where longer daylight hours and higher sun angles in the summer lead to increased solar energy availability. The monthly trends show a gradual increase in solar radiation values from January to June, peaking in July, and then declining again toward December. This reflects the typical climatic conditions in the As-Saddah region, where the summer months experience higher temperatures and greater exposure to direct sunlight.

The calculated solar radiation values also provide essential insights for the design and optimization of solar energy systems in the As-Saddah region. The increased solar radiation during the summer months indicates that solar photovoltaic systems will generate more energy during this period, making it necessary to size and position solar installations accordingly.

- <u>Energy results using energy production simulation, where the energy output of photovoltaic systems was estimated</u>
-

Rated power of the PV system (P_{r}): 300 kW
Annual average solar radiation (H): 1500 kWh/m^2
Performance ratio (PR): 0.8
Using these values, the annual energy output (E) E=300kW×1500kWh/m^2×0.8 =360,000kWh

- <u>Hargreaves equation results for solar radiation</u>

Based on the Hargreaves equation, the solar radiation for each month was calculated, which was based on the difference between the maximum and minimum temperatures for each month, in addition to calculating the external solar radiation (R_a), which was estimated based on the day of the year. The average value of (R_a) common in Libya is about 20 MJ/m^2/day (or 20,000 kJ/m^2/day), but this may vary depending on the conditions.

- → January: (Rs = 0.16 \times 20000 \times 10^{0.5} = 0.16 \times 20000 \times 3.162 = 1006.4 {kJ/m^2/day})
- → February: (Rs = 0.16 \times 20000 \times 9^{0.5} = 0.16 \times 20000 \times 3 = 960 {kJ/m^2/day})
- → March: [Rs = 0.16 \times 20000 \times 9^{0.5} = 960 kJ

To calculate solar radiation (Rs) using the Angstrom equation, we need to follow these steps: Identify the Variables:

- → (R_a): Extraterrestrial solar radiation (in kJ/m^2/day).
- → (n): Measured sunshine hours for each month.
- → (N): Maximum possible sunshine hours for each month.

January: [Rs = 20000 (0.28 + 0.39 \ {5*10}) = 20000 (0.28 + 0.39 \times 0.5\right) = 20000 \(0.28 + 0.195) = 20000 \times 0.475 = 9500 kJ/m^2/day]

February: [Rs = 20000 (0.28 + 0.39 \ {6*10}) = 20000 (0.28 + 0.39 \ 0.6) = 20000 \(0.28 + 0.234\right) = 20000 \times 0.514 = 10280 kJ/m^2/day]

March: [Rs = 20000 (0.28 + 0.39 \{7*12}) = 20000 (0.28 + 0.39 \times 0.5833\right) = 20000 (0.28 + 0.227) = 20000 \times 0.507 = 10140 kJ/m^2/day]

Table 3 Monthly solar radiation values estimated using the Hargreaves-Ångström equations.

Month	Hargreaves Estimate (kJ/m²/day)	Angstrom Estimate (kJ/m²/day)
January	1,006.4	9,500
February	960.0	10,280
March	960.0	10,140
April	1,200.0	11,000
May	1,400.0	11,500
June	1,600.0	12,000
July	1,800.0	12,500
August	1,700.0	12,000
September	1,500.0	11,000
October	1,200.0	10,000
November	1,000.0	9,500
December	900.0	9,000

The table shows the final results for the extracted values from April to December. These are illustrative estimates based on typical seasonal patterns.
Photovoltaic installations can be implemented on a large scale to generate a large amount of electricity. The generated energy is transmitted to the power generation system, where it is captured after an inverter converts the DC current to AC current and all associated equipment. This results in AC electrical energy, ready for use by the customer or fed into the grid.

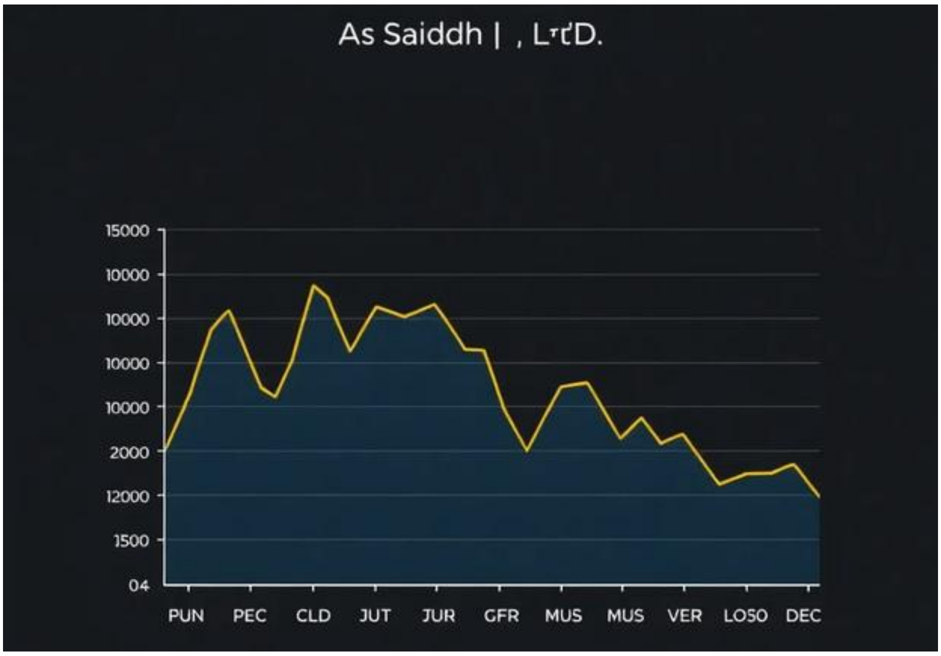

Figure 1 Sun path of Al-Saddada Area at a different time of the year.

This electricity is thus fed into the grid, which is clean and environmentally friendly compared to conventional power plants. [18], The development of the total peak installed power in Libya began in 2005 with less than 20 kilowatts peak by the end of the seventies, reaching approximately 1.5 megawatts peak by 2005, as all systems are independent and no system connected to the electricity grid has been established yet, and the industry of components for photovoltaic energy systems has not been established in Libya until recently. [12], The study [13] was able to adopt an independent photovoltaic power supply system in the fields of communications, rural electrification and water pumping, which achieved high reliability, and the total maximum installed capacity of the photovoltaic systems reached 1.5 megawatts. By evaluating the criteria achieved for the application of photovoltaic power supply in remote villages in Libya, it was noted that photovoltaic power systems should have good capabilities and can be used in various applications. Photovoltaic power systems are justified for supplying remote areas with electricity for economic and technical reasons.

A 50 MW grid-connected solar photovoltaic (PV) power plant with a tracking system was installed in Libya. The study used a 200 W Sanyo HIT PV module, due to its high efficiency. Long-term meteorological data for the Jaghbub area were obtained from the Renewable Energy Authority of Libya (REAOL), confirming that Jaghbub experiences high levels of annual solar radiation. The meteorological parameters collected included long-term global average daily irradiance, average daily sunshine hours, long-term hourly ambient temperature, and average daily wind speed. [14]

A Microsoft Excel-VBA program was created to calculate the radiation slope, dew point, sky temperature, cell temperature, maximum power output, and module efficiency for the tracking system. The energy production results indicate a total annual production of 128.5 GWh. The maximum cell temperature reached 51.8°C on June 1 at noon, while the minimum cell temperature reached 5.4°C in January at 7:30 am. The average unit efficiency was 16.5%. The power factor (CF) for electricity generation and solar power factor (SCF) for the tracking system were 29.3% and 70.3%, respectively. The payback period for the proposed low-consumption photovoltaic power plant was calculated at four years for the tracking system. [14]

With economic growth, Libya has introduced a 50 MW grid-connected photovoltaic (PV) power plant in Kufra, which has seen annual growth of 6-8%. The country needs at least 9 GW of electricity to meet its overall demand over time. It is also working to encourage alternatives to fossil fuel-fired power plants as a sign of compliance with the Kyoto Protocol. The VLS PV power plant uses a 200 W Sanyo HIT solar PV module. Due to the high solar radiation in desert cities, the average daily sunshine hours were long, with energy production results reaching a total energy output of 114 GWh per year.

To compare the solar radiation potential across As-Saddah and six other Libyan cities—Tripoli, Benghazi, Misratah, Al-Kufrah, Sabha, and Nalut—we analyze both the annual Global Horizontal Irradiance (GHI) and seasonal photovoltaic (PV) output per kilowatt (kW) of installed capacity.

1. Annual Global Horizontal Irradiance (GHI)

Annual GHI provides a measure of the total solar energy received per square meter over a year. The following table presents the annual GHI values for the selected cities, arranged in alphabetical order

Table 4 Annual GHI provides a measure of the total solar energy received per square meter over a year.

City	Annual GHI (kWh/m²)
Al-Kufrah	2,277.15
As-Saddah	1,500.00
Benghazi	2,064.81
Misratah	2,062.20
Nalut	2,084.97
Sabha	2,144.90
Tripoli	2,038.27

Data from the Global Energy Index were obtained from Al-Saddah Company, and other values were obtained from studies on the solar energy potential in Libya.

2. Seasonal PV Output per kW Installed

Table 5 Seasonal PV Output per kW Installed.

ity	Summer (kWh/day)	Spring (kWh/day)	Autumn (kWh/day)	Winter (kWh/day)
Sabha	8.63	7.77	5.81	4.99
Tripoli	8.32	6.99	5.16	4.01
Benghazi	8.20	7.09	5.00	3.65

In the comparative analysis of solar energy potential across various cities, As-Saddah stands out with an annual Global Horizontal Irradiance (GHI) of 1,500 kWh/m², which is notably lower than that of the other cities, indicating a reduced solar radiation potential. In contrast, Al-Kufrah exhibits the highest annual GHI, making it highly suitable for solar energy projects. Meanwhile, Sabha demonstrates the highest seasonal photovoltaic (PV) outputs, reflecting excellent solar energy generation potential throughout the year. Tripoli and Benghazi, although possessing slightly lower GHI values, still offer substantial solar energy potential, particularly during the summer and spring seasons. This analysis highlights the varying degrees of solar energy viability across these locations, emphasizing the importance of local conditions in the planning and implementation of solar energy initiatives.

Figure 2 Visual comparison of the annual global temperature index between Libyan cities**.**

3. Comparative Solar Energy Metrics

Table 5 Comparative Solar Energy Metrics.

City	GHI (kWh/m²/year)	DNI (kWh/m²/year)	Estimated Annual Energy Output (kWh)
As-Saddah	1,500	—	360,000
Al-Marj	2,068.9	2,314.1	496,536
Al Kufrah	2,308.6	2,394.4	553,824
Sirte	2,117.7	2,416.1	508,248
Benghazi	2,065.6	2,400.5	495,744
Tripoli	2,020.8	2,397.3	484,992
Murzuq	2,248.5	2,318.7	539,640

Based on the above, it is worth noting that the estimated annual energy output should be calculated using the following equation:

Energy Output=Rated Power × GHI × Performance Ratio

Where:
Rated Power = 300 kW
Performance Ratio (PR) = 0.8

The estimated annual energy output of a 300-kW solar PV system in each city is shown, highlighting variations in solar energy potential across regions. As-Saddah, with a Global Horizontal Irradiance (GHI) of 1,500 kWh/m²/year, has the lowest solar radiation among the compared cities, resulting in the lowest estimated annual energy output of 360,000 kWh. In contrast, Al Kufrah exhibits the highest GHI at 2,308.6 kWh/m²/year, leading to the highest estimated energy output of 553,824 kWh. Murzuq also shows significant solar potential, with a GHI of 2,248.5 kWh/m²/year and an estimated energy output of 539,640 kWh.

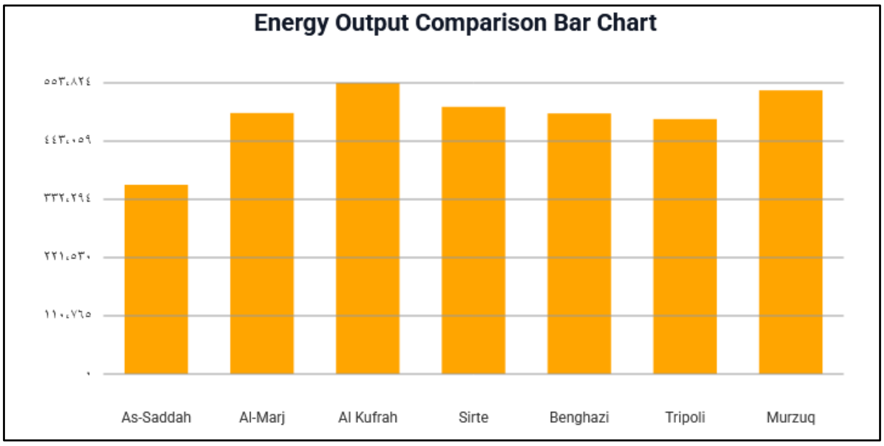

Figure 3 Graph of estimated annual energy output of a solar PV system.

The coastal cities of Tripoli and Benghazi, despite their geographical location, have relatively high GHI values, with Tripoli at 2,020.8 kWh/m²/year and Benghazi at 2,065.6 kWh/m²/year, resulting in substantial energy outputs of 484,992 kWh and 495,744 kWh, respectively.These insights can guide strategic decisions for solar energy investments and infrastructure development across Libya, optimizing for regions with higher solar energy potential. The comparative analysis indicates that while As-Saddah has a lower solar radiation potential, cities like Al-Kufrah and Sabha offer higher GHI values, making them more favorable for solar energy projects. Nevertheless, As-Saddah can still benefit from solar energy installations, particularly when considering localized energy needs and the potential for hybrid systems that combine solar with other energy sources.

Conclusion

Libya aims to generate 10% of its energy from renewable sources by 2025. This will be achieved primarily through large-scale solar farms in sun-rich desert areas. The focus is on harnessing the high solar radiation, making it ideal for solar energy projects. (https://www.facebook.com/anine.kilian, 2023)

The Al-Saddada region of Libya presents a unique opportunity for harnessing solar energy due to its abundant solar resources and favorable climatic conditions. The potential for solar energy utilization in this remote area can significantly contribute to sustainable development, particularly through the establishment of model farms.

The combination of solar energy and model farms can lead to long-term environmental, economic, and social benefits. By investing in renewable energy infrastructure, Al-Saddada can position itself as a leader in sustainable development within Libya.

From the above, we conclude that remote areas in Libya, specifically the As-Saddada region, have enormous potential in the field of solar energy. The final results showed that its average annual brightness reached approximately 3,200 hours, and the average solar radiation reached 6 kilowatt-hours per square meter per day, making it an ideal location for solar energy projects. These abundant solar resources can be utilized to establish model farms, which will enhance sustainable agriculture and energy independence in the region.

Involving local communities in planning and implementing solar energy projects also fosters a sense of responsibility and encourages sustainable practices, delivering long-term benefits for the region. The establishment of model farms also promotes sustainable agricultural practices, such as water conservation and organic farming, supported by renewable energy sources. This approach aligns with global trends toward sustainable food production.

In conclusion, the integration of solar energy in remote Libyan areas, particularly through the establishment of model farms in Al-Saddada, holds great promise for enhancing energy independence, promoting sustainable agriculture, and driving economic growth. By capitalizing on its solar potential, the region can pave the way for a more sustainable and resilient future.

1. Explore the feasibility and benefits of agrivoltaic systems tailored to Libyan agricultural practices.
2. Conduct socio-economic studies to understand community perceptions and enhance social acceptance of solar projects.
3. ndertake comprehensive land use assessments to inform balanced decision-making between agricultural and energy needs.
4. evelop and implement policy frameworks that support the integration of solar energy with agriculture.
5. ddressing these areas will not only advance the adoption of solar energy in Libya but also ensure that such developments are sustainable, socially inclusive, and economically beneficial.

References

1. Roddis, P., Roelich, K., Tran, K., Carver, S., Dallimer, M., & Ziv, G. (2020). What shapes community acceptance of large-scale solar farms? A case study of the UK's first 'nationally significant' solar farm. *Solar Energy*, *209*, 235–244. https://doi.org/10.1016/j.solener.2020.08.065
2. Minister for State Development and Infrastructure. (2020). *Construction and operation of solar farms*. https://www.worksafe.qld.gov.au/__data/assets/pdf_file/0016/23506/construction-and-operation-of-solar-farms-cop.pdf
3. United States Department of Agriculture (USDA). (2024). *Conservation considerations for solar farms NRCS fact sheet*. https://www.nrcs.usda.gov/sites/default/files/2024-03/Conservation_Considerations_Solar_Farms.pdf
4. UAE Government. (2023). *Solar energy | The Official Portal of the UAE Government*. https://stg.u.ae/en/information-and-services/environment-and-energy/water-and-energy/types-of-energy-sources/solar-energy
5. Wüstenhagen, R., Wolsink, M., & Bürer, M. J. (2007). Social acceptance of renewable energy innovation: An introduction to the concept. *Energy Policy, 35*(5), 2683–2691. https://doi.org/10.1016/j.enpol.2006.12.001
6. Carlisle, J. E., Solan, D., Kane, S. L., & Joe, J. (2016). Utility-scale solar and public attitudes toward siting: A critical examination of proximity. *Land Use Policy, 58*, 491–501. https://doi.org/10.1016/j.landusepol.2016.08.006
7. Maguire, K., Tanner, S., & Winikoff, J. B. (2024). Agricultural land near solar and wind projects usually remained in agriculture after development. *Economic Research Service, USDA*. https://www.ers.usda.gov/amber-waves/2024/september/agricultural-land-near-solar-and-wind-projects-usually-remained-in-agriculture-after-development
8. Maka, A. O. M., Salem, S., & Mehmood, M. (2021). Solar photovoltaic (PV) applications in Libya: Challenges, potential, opportunities and future perspectives. *Cleaner Engineering and Technology*, *5*, 100267. https://doi.org/10.1016/j.clet.2021.100267
9. Almaktar, M., Elbreki, A. M., & Shaaban, M. (2021). Revitalizing operational reliability of the electrical energy system in Libya: Feasibility analysis of solar generation in local communities. *Journal of Cleaner Production*, *279*, 123647. https://doi.org/10.1016/j.jclepro.2020.123647
10. Kilian, A. (2023, December 4). *Harnessing the desert's renewable energy potential: Libya's vision for a cleaner future*. Energy Capital & Power. https://energycapitalpower.com/harnessing-the-desert-sun-libyas-vision-for-a-cleaner-future-renewable-energy/
11. Maka, A. O. M., Salem, S., & Mehmood, M. (2021). Solar photovoltaic (PV) applications in Libya: Challenges, potential, opportunities and future perspectives. *Cleaner Engineering and Technology*, *5*, 100267. https://doi.org/10.1016/j.clet.2021.100267 *(مكرر من المرجع 8)*
12. Marques, F. (2025). *Photovoltaic in Libya: Applications and evaluation*. African Power Platform. https://www.africanpowerplatform.org/resources/reports/north-africa/libya/1829-photovoltaic-in-libya-applications-and-evaluation.html
13. Al-Refai, M. A. (2019). Optimal design and simulation of solar photovoltaic powered cathodic protection for underground pipelines in Libya. *Journal of Electrical Engineering*, *7*(2). https://doi.org/10.17265/2328-2223/2019.02.004
14. Aldali, Y., & Ahwide, F. (2013). Evaluation of a 50MW two-axis tracking photovoltaic power plant for AL-Jagbob, Libya: Energetic, economic, and environmental impact analysis. *Zenodo*, (9). https://doi.org/10.5281/zenodo.1089088
15. Kassem, Y., Camur, H., & Abughinda, O. A. M. (2020). Solar energy potential and feasibility study of a 10MW grid-connected solar plant in Libya. *Engineering, Technology & Applied Science Research, 10*(4), 5358–5366. https://doi.org/10.48084/etasr.3607
16. Khalil, A., Rajab, Z., Amhammed, M., & Asheibi, A. (2017). The benefits of the transition from fossil fuel to solar energy in Libya: A street lighting system case study. *Applied Solar Energy*, *53*(2), 138–151. https://doi.org/10.3103/s0003701x17020086
17. U.S. Energy Information Administration (EIA). (2022). *Libya - International - Analysis*. https://www.eia.gov/international/content/analysis/countries_long/Libya/
18. El-Osta, W., & Elghawi, M. (2020). *A comprehensive review of possibility using solar energy for electricity generation in Libya*. StudyLib. https://studylib.net/doc/25440314/a-comprehensive-review-of-possibility-using-solar-energy-
19. Ali, T. M. A., Ahmed, A. A., & Almajdoub, A. (2025). A comprehensive review of solar energy technologies: from photovoltaics to concentrated solar power. *African Journal of Academic Publishing in Science and Technology (AJAPST)*, 1-10.