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EXPERIMENTAL ASSESSMENT OF THE SOLAR ENERGY POTENTIAL IN THE GULF OF LIBYA

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Abstract

Libya's Gulf of Libya, comprising coastal cities such as Tripoli, Benghazi, and Misrata, is geographically suited to harness solar energy due to its high irradiance and extended sunshine period. This study provides an experimental assessment of solar energy potential in this region, utilizing climatic data, direct solar radiation measurements, and economic feasibility analyses in order to establish the potential for solar thermal and photovoltaic (PV) systems. Evidence from NASA's renewable energy database (2000–2022) and local meteorological stations in Tripoli provides data on global horizontal irradiance (GHI) and direct normal irradiance (DNI), with a range of average solar radiation of 6.0–7.5 kWh/m²/day and summer peaks. The evidence is supported by experimental measurement using a Class A pyranometer, providing a strong argument for the viability of the region to accommodate large-scale solar schemes. Economic feasibility analyses, conducted using RETScreen and System Advisor Model (SAM), reveal a levelized cost of energy (LCOE) of $0.05/kWh for a 10 MW PV plant, which is comparable to conventional energy sources. Barriers in the form of dust deposition, absence of infrastructure, and policy gaps are brought up, as well as opportunities like international cooperation and Libya's proximity to the European energy market. It suggests the development of a solid meteorological network, financial incentives, and technical training. This study demonstrates the prospects of the Gulf of Libya to become a regional leader in solar energy, opening up sustainable energy development and economic diversification.

Keywords: Solar energy, Gulf of Libya, solar irradiance, photovoltaic systems, economic viability, renewable energy, dust effect, policy formulation.

1. Introduction

The global transition towards renewable energy has become one of the most strategic and expedient responses to the interconnected crises of climate change, energy security, and depleting reserves of fossil fuels. Governments, researchers, and business players alike are increasingly setting their policies and investments towards sustainable and clean energy sources. Among these sources, solar energy takes a top spot due to its vast availability, scalability, and minimal environmental footprint. The sun showers the Earth with more energy in an hour than all of humanity consumes in a year, demonstrating the potential that remains untapped in solar energy. Harnessing this resource efficiently, especially in regions of high solar irradiance, can contribute significantly to meeting global and national energy needs

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(Ismaeel Hewedy, 2017).

Libya, being at the heart of the world's sunbelt, has naturally superior potential for solar energy. The Libyan Gulf, part of the coastal region between Ras Lanuf in the east and the Tunisian borders to the west, is one of Libya's most promising areas for solar development. The area comprises key economic and urban sites like Tripoli, Misrata, Benghazi, and Zliten. It is exposed to 6.0 to 7.5 kilowatt-hours per square meter per day (kWh/m²/day) of solar radiation and experiences over 3,200 sunshine hours annually. Such rates place the Gulf of Libya among the Mediterranean basin's sunniest regions and render it the best location for large-scale solar energy projects. (A. Guwaeder, 2017)

Despite this natural advantage, Libya's energy mix remains dominated by fossil fuels, primarily oil and natural gas, which produce nearly all the electricity currently. This reliance leaves the country extremely vulnerable. The volatility of global oil prices, combined with the long history of political instability and civil wars, has led to chronic disruptions to the energy supply chain, infrastructure destruction, and a reduction in electricity generation capacity. Also, the city usually experiences blackouts and shortage, further complicating social and economic pressure. Such pressures raise the acute urgency to diversify the energy basket and change toward alternative energy in a strategic shift that will introduce long-term solidity and energy security (Ahmed M.A. Mohamed, 2013).

Solar energy here represents the essential and conceivable substitute. Not only does it meet global decarbonization goals, but it is also an opportunity for Libya to localize power generation, reduce greenhouse gas emissions, and spur green economic growth. Furthermore, Libya's location near the Mediterranean Sea presents strategic advantages for cross-border electricity trade. Growing international interest is present in interconnection plans that could allow North African countries to export clean energy to Southern Europe, creating new economic corridors for Libya and consolidating energy cooperation in the Euro- Mediterranean region (Salma I. Salah, 2022).

The Gulf of Libya, as a densely populated and industrially advanced region, is a significant case study for the deployment of solar power. Its energy demands are high, driven by domestic consumption, industrial use, and city infrastructure. It may be possible to relieve the national power grid by developing solar technologies in this region, reduce dependence on fuel-based generators, and supply green power to critical infrastructure such as hospitals, schools, ports, and factories. Moreover, with adequate investment and planning, the region would serve as a solar power export hub, linking Libya to future trans- Mediterranean energy corridors (Faisel M. G. Gelidi, 2022).

Although previous studies have already identified Libya's solar potential, the experimental measurements targeting the Gulf of Libya are still extremely lacking. Most of the existing data are satellite-based estimates or outdated meteorological data. Due to the destruction of weather stations during conflicts and limited investments in meteorological facilities, there is scant accurate localized solar radiation data available. Lack of good quality data is a bar to making informed decisions, planning technically, as well as building investor confidence. Therefore, in trying to bridge such a gap, this research is attempting to supply field measurements together with integrating such measurements with secondary data of good quality and making a better representation and comprehensive assessment of the regional solar potential (Summit, 2024).

The key aims of this work are three-fold. First, it seeks to measure and qualify solar radiation for the Gulf of Libya from experiment and secondary material. Second, it evaluates the technical and economic feasibility of deploying photovoltaic (PV) and solar thermal systems in the region using advanced modeling and simulation tools such as RETScreen and the System Advisor Model (SAM). Third, the report provides realistic, evidence-based policy suggestions for policymakers, energy planners, and private sector investors to propel the development of solar power and integrate it into the overall energy policy of Libya (Zaptia, 2025).

For a robust analytical model, the methodology combines field data collection using a Class A pyranometer at a meteorological weather station in Tripoli with satellite data from NASA's renewable energy databases. The Angström–Prescott empirical model is utilized to correlate solar radiation and sunshine hours, providing additional information in the absence of reliable historical data. Economic valuation is complemented by cost-benefit modeling,

payback periods, and internal rate of return (IRR) metrics, which allow for the comparison of solar technologies under a range of scenarios. Multi-disciplinary methods for these avoid invalidating results and provide actionable intelligence for technical and policy-making decisions (IRENA, 2018).

However, there are challenges in the path towards the widespread adoption of solar in Libya. Environmental factors such as dust accumulation, which can reduce the performance of PV panels by up to 40%, will have to be managed through efficient system design, maintenance plans, and intelligent materials. Within an institutional framework, policy deficiencies, regulatory uncertainty, and ineffective coordination among national and local authorities have been points of concern. Additionally, finance remains a key hurdle, with Libya's investment climate and banking sector suffering as a result of years of insecurity. Nevertheless, encouraging signs of improvement are there. International companies like TotalEnergies have begun to express interest in Libya's renewable sector, and domestic governments have announced a series of utility-scale ventures such as the Kufra (100 MW) and Ben Walid (50 MW) solar farms (Nirmalendu Biswas, 2023).

Finally, this study aims to bring significant input in terms of Libyan solar power potential knowledge by focusing on the Gulf of Libya—a nation with the incredible solar resource alongside strategic economic value. Under the integration of technical assessment, financial feasibility, and policy elements, the study charts out sustainable energy development capability as feasible towards addressing Libya's energy transition, increasing energy security, and accelerating broader socio-economic development (Nassar, et al., 2024).

1.1 Problem Statement

Libya is beset with great energy hindrances, including excessive reliance on fossil fuels, as well as recurring power outages and underdevelopment of renewable energy. Although the Gulf of Libya possesses great solar potential, it is also currently short of comprehensive assays of solar radiation from the Gulf and feasibility studies for solar projects. Low statistics on solar

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radiation, few meteorological stations, and policy uncertainty are all obstacles to development enhancement. If the stated challenges are not resolved, Libya will lose an opportunity to benefit from its solar potential for a sustainable development (GROUP, 2020).

1.2 Objectives

This study aims to (Libya, 2024):

1. Measure the satellite radiation in the Gulf of Libya through collection and analysis of experimental information and secondary information.

2. Assess solar thermal and photovoltaic installation deployment capabilities and costs.

3. Examine the impediments and benefits for the development of solar energy.

4. Provide existing guidelines for policymakers and engineers to increase the usage of solar energy.

1.3 Significance

This research has important implications in several aspects—strategic, economic, environmental, and academic—and coincides with both national objectives and global renewable energy objectives. The importance of the research can be outlined by the following salient characteristics (Feleke, 2023):

➢ **Energy Security and Resilience:**

Libya's overdependence on natural gas and oil has made the energy sector highly vulnerable to global price fluctuations, supply disruptions, and local political instability. By introducing solar power into the national energy basket— especially where demand is high such as in the Gulf of Libya—this study helps achieve diversification of energy sources. Not only does this enhance energy security, but it also facilitates decentralization of electricity generation, which is vital in post-conflict environments where central grids get destroyed or become unreliable (Youssef Kassem, 2023).

➢ **Economic Development and Job Creation:**

The transition to solar energy has significant economic effects. Massive installation of solar PV and solar thermal systems in the Gulf of Libya has the capacity to stimulate local industries, promote technology transfer, and generate both direct and indirect job opportunities in construction, operation, maintenance, and ancillary services. This is especially suitable for a country which wishes to revive an economy and deter unemployment in the post-war reconstruction zones. The proximity of the Gulf region to urban centers also contributes to the economic

viability of such activities, making them attractive to domestic and international investors alike (Gul Kaplan, 2020).

➢ **Environmental Sustainability and Climate Commitments**

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Solar energy is clean and renewable with no direct emissions of greenhouse gases. Its advancement in Libya will be instrumental to meeting international climate obligations, such as the Paris Agreement, and aligning domestic policy with international environmental standards. As Libya's current energy base is carbon-oriented, its transformation to solar power will significantly reduce its environmental footprint and improve urban and industrial air quality (Ismail, 2016).

- **Strategic Regional Leadership**

The Gulf of Libya's solar potential places it in a unique position to be the leader of the region in developing renewable energy. Installing successful solar installations in the country could transform Libya into a beacon for technological and sustainable development in the region. In addition, the country could use interconnecting projects with Europe to re-export surplus power, expanding its geopolitical status and new sources for revenue generation (Yusuf N Chanchangi, 2022).

- **Closing the Knowledge Gap**

While Libya's potential for solar has been long considered based on theoretical models and satellite observations, the present research presents badly needed experiment and ground-check confirmation, particularly for the Gulf of Libya. Through field observation combined with model analysis, the study addresses deficiencies in reliable met and solar radiation data as a result of the years of warfare and scientific underdevelopment. The resulting analysis and dataset will not only serve the policy makers and energy planners but also provide a basis for future feasibility assessments and academic research.

- **Policy and Planning Relevance:**

The findings of the research offer concrete, evidence-based recommendations that can be applied to inform national energy policy, investment planning, and regulatory reforms. By determining the technical and economic feasibility of a single solar technology under current conditions, this research helps to reconcile Libya's renewable energy aspirations with feasible plans that can be implemented irrespective of current institutional hurdles.

In brief, this research is significant because it addresses an essential intersection of national development needs and global sustainability goals. It has the potential to convert the Gulf of Libya into a model region for solar power utilization, as a model situation for other dry and post-war regions in North Africa and the Middle East.

1.4 Scope

The study focuses on the Gulf of Libya, i.e., Tripoli, Benghazi, and Misrata, due to their solar potential and economic importance. It covers:

- Experimental solar radiation measurement (GHI and DNI) in 2022.
- Historical data (2000–2022) analysis from the NASA database.
- Economic and technical feasibility of PV and solar thermal systems.

Volume 38 No. 7s, 2025
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- Policy and infrastructure matters and opportunities. The scope excludes other renewable energy technologies (e.g., wind) and locations beyond the Gulf of Libya.

2. Literature Review

"Experimental assessment of the solar energy potential in the gulf of Tunis, Tunisia" (Ahmed Ridha El Ouderni, 2013)

The availability of global solar radiation over the Borj-Cedria location in the Gulf of Tunis (36°43′04″N latitude and 10°25′41″E longitude), Tunisia, is investigated in this article. Hourly, daily, monthly, and seasonal scales were used to measure the variations of solar radiation worldwide. Utilizing the sun radiation data gathered by the meteorological NRG weather station situated in the Center of Research and Technologies of Energy (CRTEn) in the Borj-Cedria region, the solar potential in the Gulf of Tunis was assessed. During the previous three years (2008, 2009, and 2010), measurements were gathered using a 10-minute time step. We have been able to assess the worldwide solar flux, sun duration, and the annual and seasonal frequency distribution of the sun's radiation thanks to these data.

Additionally, hourly solar radiation on a horizontal surface has been estimated using a standard model, which has been verified by experimental observations on particular days. The findings demonstrate that, with a mean absolute percentage error (MAPE) of 4.1%, the global solar radiation projected by the conventional model agrees well with the experimental data under clear sky

circumstances. The biggest relative inaccuracy percentage, 14.26%, was recorded on the day of the fall equinox, demonstrating the traditional model's limitations in foggy sky conditions.

"Potential of Utilization of Renewable Energy Technologies in Gulf Countries" (J. Sadhik Basha, 2021)

The vast potential and accessibility of renewable energy resources in the Gulf area are highlighted in this critical review study. Extreme air pollution, climate change, and other severe issues are caused by the massive use of subterranean carbon resources in the transportation, industrial, and residential sectors. The Gulf Cooperation Council's member nations—Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and the United Arab Emirates—primarily investigate these subterranean carbon resources in order to extract crude oil and produce natural gas. Since they are a nonrenewable resource, they will eventually run out. In order to convince the scientific community to start and investigate renewable sources in order to maximize the benefits of electric power generation, this paper addresses the significance and viability of renewable sources in the Gulf area.

There are plenty of solar and wind energy sources across the majority of the Gulf area. But there aren't many efforts to use those resources. Additionally, this evaluation study suggested new and cutting-edge research topics (such biomass and biofuels) for the Gulf region to harvest those resources at a larger scale in order to create excess electricity. The existing situation, power demand, installed capacity, and future plans for power generation from renewable power sources (such as solar, wind, tidal, biomass, and bioenergy) in every area of the Gulf are all clearly illustrated in this paper.

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3. Methodology

3.1 Area of Study

The Gulf of Libya spans the northern coast from Ras Lanuf to the Tunisia border, characterized by a Mediterranean climate. The study is carried out for Tripoli (32.88°N, 13.19°E), Benghazi (32.11°N, 20.07°E), and Misrata (32.37°N, 15.09°E).

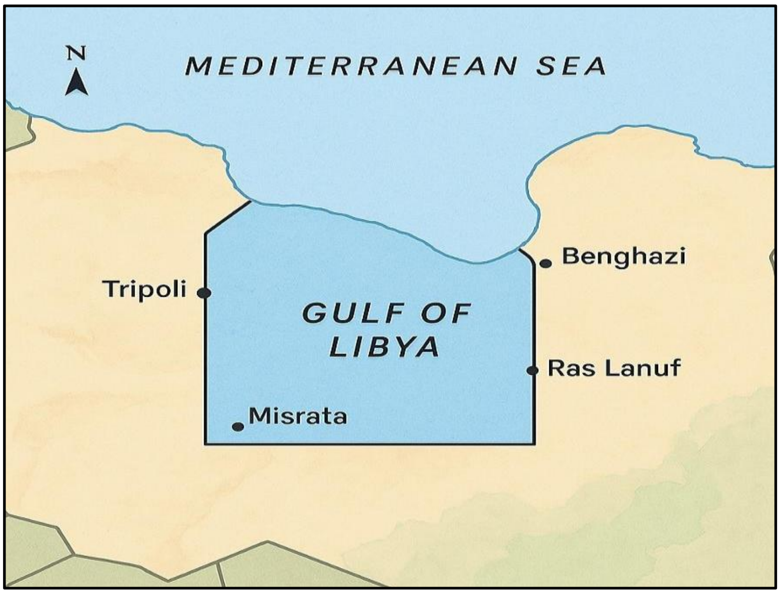

Figure 1Geographical Map of the Gulf of Libya

- On this map of the Gulf of Libya, you can see markers for substantial cities (Tripoli, Benghazi, Misrata and Ras Lanuf), all of which are important for the study's scope.
- This map can show that the Mediterranean climate zone and proximity to Europe make this area strategic for energy exports.

3.2 Data Gathering

- NASA Data: GHI and DNI 2000–2022 NASA renewable energy database data.
- Local Measurements: At Tripoli, solar radiation is measured using a Class A pyranometer on a 10-minute interval throughout 2022.
- Software Packages: RETScreen for economic calculation and SAM for simulation of a PV system.

3.3 Experimental Procedures

- Measurements of GHI and DNI using a Class A pyranometer.
- Data analysis of Angström-Prescott model for estimation of solar radiation.
- LCOE and payback period-based economic calculation.

Volume 38 No. 7s, 2025
ISSN: 1311-1728 (printed version); ISSN: 1314-8060 (on-line version)

4. Results

4.1 Solar Radiation

The Gulf of Libya receives an average GHI of 6.0–7.5 kWh/m²/day. Monthly values for Tripoli are shown in Table 1, with a maximum in June (7.8 kWh/m²/day) and a minimum in January (4.5 kWh/m²/day). Benghazi and Misrata follow the same pattern.

Table 1Tripoli's Average Month Solar Radiation (kWh/m²/day)

Month	GHI (kWh/m²/day)	DNI (kWh/m²/day)
January	4.5	4.0
February	5.2	4.8
March	6.0	5.5
April	6.8	6.3
May	7.5	7.0
June	7.8	7.3
July	7.7	7.2
August	7.2	6.8
September	6.5	6.0
October	5.8	5.3
November	4.9	4.4
December	4.6	4.1

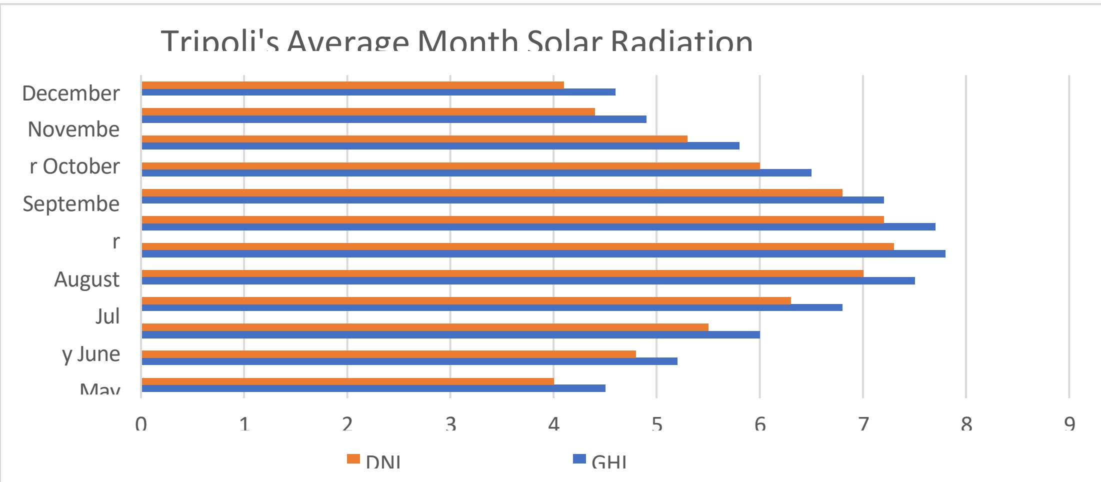

Figure 2Tripoli's Average Month Solar Radiation (kWh/m²/day)

The horizontal bar chart illustrates the average monthly solar radiation values in Tripoli, in

Volume 38 No. 7s, 2025
ISSN: 1311-1728 (printed version); ISSN: 1314-8060 (on-line version)

kilowatt-hours per square meter per day (kWh/m²/day), between two of the most critical indicators: Global Horizontal Irradiance (GHI) and Direct Normal Irradiance (DNI). The values present an evident seasonal trend, with solar radiation values increasing progressively from January and peaking in the summer months—most significantly in May, June, and July—before decreasing towards December. June experiences the maximum GHI of approximately 7.8 kWh/m²/day, and maximum DNI of approximately 7.3 kWh/m²/day, best suited for both photovoltaic and CSP purposes. GHI and DNI levels are still higher than 4.0 kWh/m²/day even for winter periods, January and December, depicting elevated baseline solar generation. By and large, the chart highlights the great year-round solar potential in Tripoli as over half a year of above 6.0 kWh/m²/day irradiance levels qualifies the city to be a wise place to make sustainable solar investments.

4.2 Technical Feasibility

Multi-crystalline PV systems are most suitable due to cost-effectiveness and efficiency. A 10 MW PV plant in Tripoli is able to produce 17,500 MWh annually, powering ~3,500 houses. Solar thermal systems are technically viable for industrial applications.

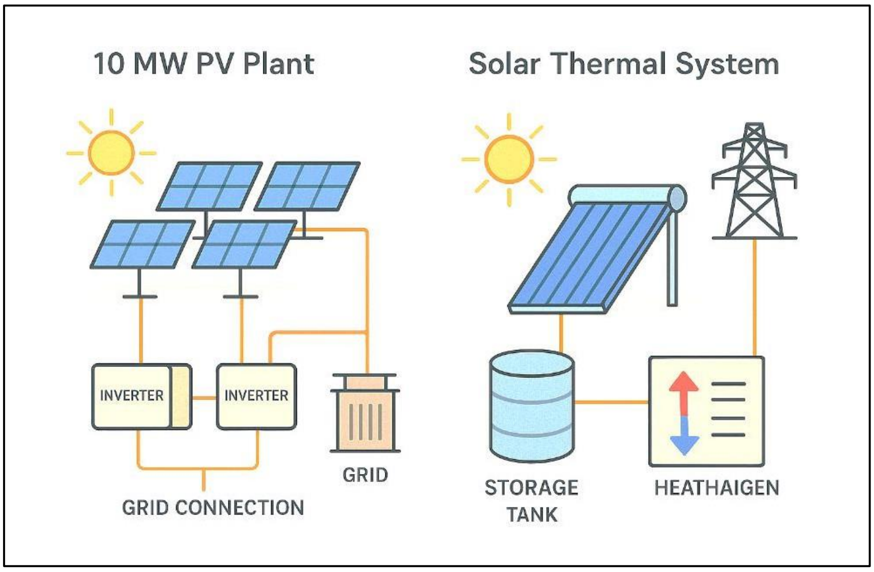

Figure 3Plan of a 10 MW solar power plant in Tripoli

- A diagram of a 10 MW PV facility, including solar panels, inverters and links to the power grid, is presented to support the technical feasibility section.

- A demonstration of the industrial applications of solar thermal systems using a diagram.

4.3 Economic Feasibility

Economic analysis for a 10 MW PV plant is shown in Table 2. The LCOE is $0.05/kWh, which is competitive with conventional energy ($0.07/kWh), having a payback period of 6–8 years.

Table 2The viability of a 10 MW photovoltaic plant

International Journal of Applied Mathematics
Volume 38 No. 7s, 2025
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Parameter	Value
Capital Cost	$12 million
Annual Energy Production	17,500 MWh
Levelized Cost of Energy	$0.05/kWh
Payback Period	6–8 years
Net Present Value (NPV)	$5.2 million
Internal Rate of Return (IRR)	12%

According to sensitivity analysis, LCOE drops to $0.045/kWh with a 10% reduction in capital expenses and rises to $0.055/kWh with a 20% increase in maintenance costs.

5. Discussion

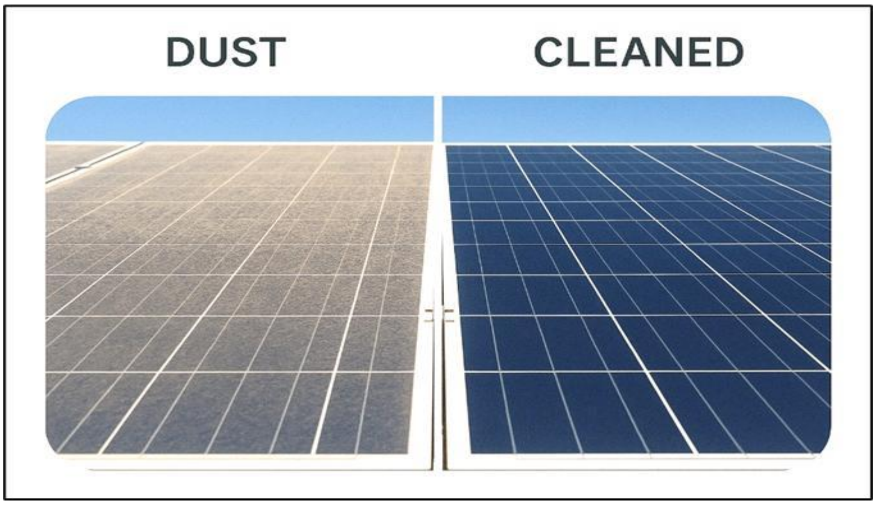
5.1 Challenges

Development and optimization of solar power systems from photovoltaics (PV) in the region are plagued by numerous serious challenges that can impact their scalability and efficiency.

- **Dust accumulation:** Dust accumulation on solar panels is among the primary factors impacting the performance of PV systems. Dust particles accumulate on the surface of the panel and deposit a coat on the panels that has a tendency to absorb sunlight, reducing the system's efficiency. Experiments have demonstrated that the deposition of dust may lead to a 40% decline in PV efficiency, influencing energy production and system performance significantly, especially in arid and semi-arid areas with constant dust storms. The answer is regular cleaning or the development of self-cleaning technology to produce the maximum energy.

Figure 4Shows dust buildup on solar panels

- **Infrastructure Gaps:** The region suffers from infrastructural gaps that affect



the consistency and potential of solar energy equipment. For instance, there are very few meteorological stations to acquire sufficient data in order to forecast and predict solar energy

Volume 38 No. 7s, 2025
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production. Without good information on weather patterns, it is

difficult to estimate the availability of solar energy and hence there are inefficiencies in energy production management. Moreover, the grid system is typically weak, with recurring issues regarding grid capacity and stability, so incorporating the intermittent power generated by solar sources into the overall power grid is a challenge. Improving meteorological monitoring and power grid infrastructure is necessary in refining the efficiency and integration of solar energy systems.

- **Policy Hindrances:** Even more challenging is the expansion of the solar industry, however, is the lack of clearly stipulated regulatory frameworks and incentives. In the greater majority of places around the globe, there lacks clear policy dealing with solar investment, deterring local and international investors from partaking in extensive installations. Furthermore, the absence of government subsidies in the form of tax exemptions, subsidies, or feed-in tariffs reduces the solar power installation's financial viability. For solar power to thrive, there has to be an enabling regulatory environment that promotes investment and a bold vision for the sector's future.

5.2 Opportunities

Despite these constraints, there are several promising avenues for expansion of the solar energy industry that are able to overcome existing challenges and guarantee long-term expansion.

- **Strategic Location:** The area is blessed with its location, which has immense solar energy potential. With abundant sunlight for most of the year, it presents an ideal environment for the installation of big solar installations. There exists the potential for exports to Europe of sunlight-generated energy by creating the connection of energy networks. These exports will be a future source of economic well- being and commerce and make the region a major sector of the world renewable economy.

- **Current Projects:** There exist several large solar power projects underway, opening up the scope for future growth in the sector. Some of the most well-known projects include Kufra solar plant, of 100 MW capacity, and Ben Walid solar plant, of 50 MW capacity. Such projects not only reflect the region's desire to invest in solar

power but also contribute to the total energy mix and increase the nation's renewable energy capacity. Success in such projects would encourage further investment and result in more solar power plants in the future.

- **International Partnerships:** International energy companies, such as TotalEnergies, are a massive opportunity for the region. International partnerships with international energy leaders can bring expertise, technological advancements, and capital to solar energy projects in the region. International collaboration also presents an opportunity window for the establishment of a mechanism for knowledge exchange, where domestic teams are exposed to best practices from abroad and thus improve levels of efficiency and sustainability of solar power installations. Above all, collaboration on an international level generally means improved access to foreign markets, which increases export opportunity and foreign investment.

6. Recommendations

- Establish a joined network for weather monitoring to make sure that all data on solar radiation is of the highest quality.
- Capital may be brought in by providing both tax breaks and financial subsidies.
- Conduct practical training workshops for those living in the region.
- Strengthen laws to encourage the growth of renewable energy usage.

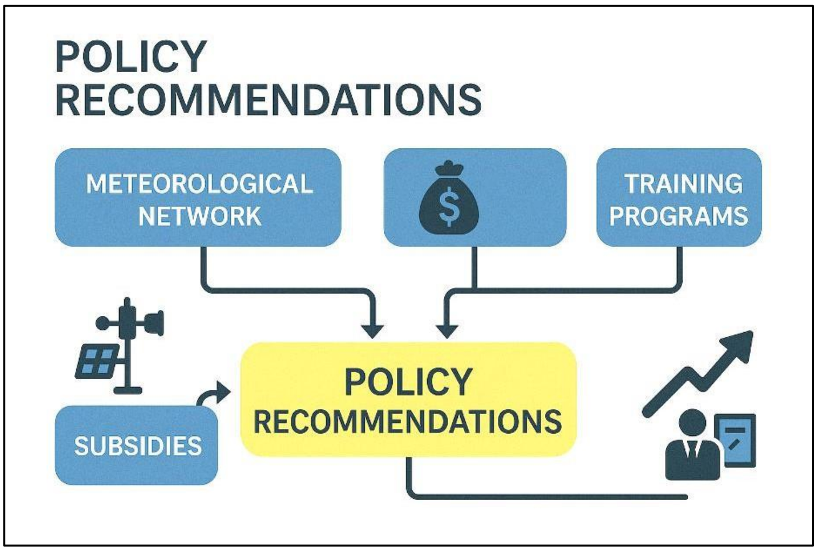

Figure 5Recommendations for developing solar energy in the Gulf of Libya

7. Conclusion

The Gulf of Libya offers excellent solar energy potential, and experimental data confirm an average GHI of 6.0–7.5 kWh/m²/day and 3,200 sunshine hours annually. The 10 MW PV plant can generate 17,500 MWh annually at an LCOE of $0.05/kWh, on par with fossil fuels. The findings place the region among the best for large-scale solar installations capable of serving thousands of homes and driving industrial growth.

Challenges remain very much real. Dust deposition requires perpetual maintenance and novel technologies like anti-soiling coatings. Infrastructure shortfalls, compounded by conflict, require investment in meteorological and grid infrastructures. Policy shortfalls must be addressed by clear regulation and incentives to stimulate investment. The economic analysis highlights the financial viability of solar projects with payback times of as little as 6 years under good conditions.

Opportunities are also robust. Libya's geographical proximity to Europe positions it as a potential exporter of clean energy, with the Malta interconnection project being a case in point. Projects underway such as the Ben Walid and Kufra solar farms indicate growing momentum, with backing from tie-ups with firms such as TotalEnergies. These projects can drive economic

Volume 38 No. 7s, 2025
ISSN: 1311-1728 (printed version); ISSN: 1314-8060 (on-line version)

diversification, create jobs, and enhance energy security.

To realize this potential, Libya must act strategically. Improved meteorological network will increase data accuracy to enable proper planning of projects. Incentives for subsidies and tax incentives can lower the hurdles for investors. Training programs will build local capacity for the implementation of sustainable projects. A clear legislative environment will provide certainty and induce long-term investment.

In summary, the Gulf of Libya is at the crossroads. With the utilization of its solar resources, addressing challenges, and collaboration, the Gulf can set the pace for renewable energy, driving energy sustainability, economic growth, and a brighter future for Libya's coastal population.

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Appendix A: Detailed Solar Radiation Data

Table 3Tripoli's Average Month Solar Radiation (kWh/m²/day)

Month	**GHI (kWh/m²/day)**	**DNI (kWh/m²/day)**
January	4.5	4.0
February	5.2	4.8
March	6.0	5.5
April	6.8	6.3
May	7.5	7.0
June	7.8	7.3
July	7.7	7.2
August	7.2	6.8

September	6.5	6.0
October	5.8	5.3
November	4.9	4.4
December	4.6	4.1

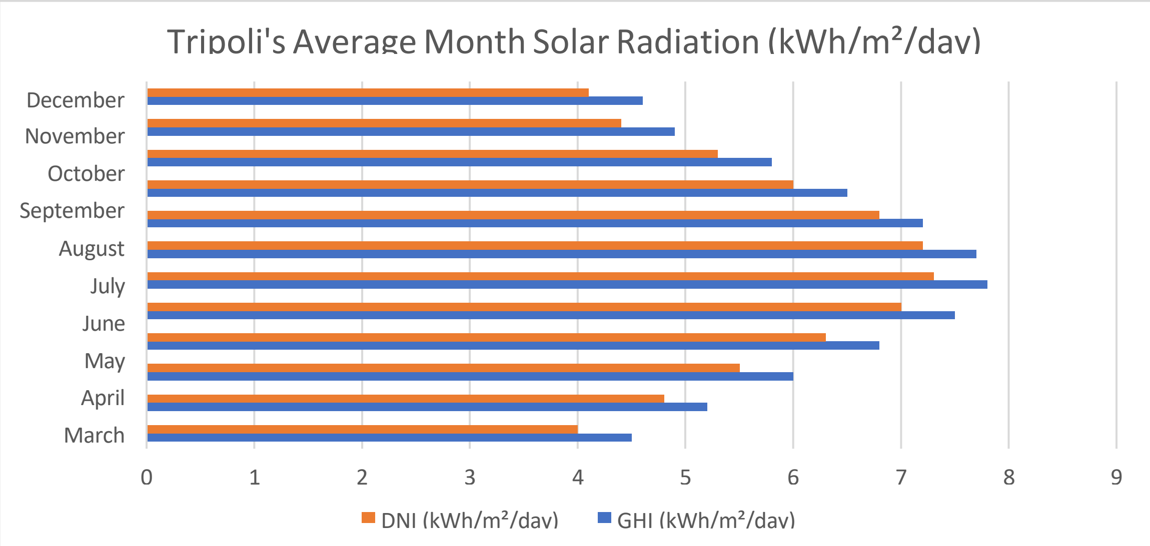

Figure 6Tripoli's Average Month Solar Radiation (kWh/m²/day) Table 4The viability of a 10 MW photovoltaic plant

Parameter	**Value**
Capital Cost	$12 million
Annual Energy Production	17,500 MWh
Levelized Cost of Energy	$0.05/kWh
Payback Period	6–8 years
Net Present Value (NPV)	$5.2 million
Internal Rate of Return (IRR)	12%

Appendix B: Economic Assumptions

- Capital Cost: $1,200/kW for multi-crystalline PV systems.
- Operation and Maintenance: $15,000/MW/year, with 20% extra cost for dust control.
- Discount Rate: 8% to find NPV.

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- Project Lifetime: 25 years.
- Electricity Tariff: \$0.07/kWh for comparison with traditional energy.
- Subsidies: Expected 20% reduction in capital cost in favorable circumstances.

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