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Feasibility of a 40kWp Grid-Connected Solar Power Plant in Tiaret, Algeria: Design, Simulation, and Smart Grid Integration

Benameur Afif[1], Mohammed Baghdad[2], Mohammed Berka*[3],
Salah Amhimmid Mohammed Masoud[4], Maamar Yahiaoui[5].

[1,3,5]Faculty of Science and Technology, University Mustapha Stambouli of Mascara, Algeria.
[2]Faculty of Science and Technology, Tissemsilt University, Tissemsilt, Algeria.
[4]Zawia University, Faculty of Science, Al-Ajailat, Libya.

E-***mail:*** [1] b.afif@univ-mascara.dz , [2] baghdad.cut@gmail.com , [3] m.barka@univ-mascara.dz , [4] s. masoud@zu.edu.ly , [5] m.yahiaoui@univ-mascara.dz .

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ABSTRACT

This study evaluates the technical and economic feasibility of a 40kWp grid-connected solar power plant in Tiaret, Algeria. Utilizing comprehensive solar irradiance data and advanced PV system software, we designed and simulated the plant's performance under local conditions. Our analysis incorporates smart grid integration strategies and economic modeling. Results indicate an annual electricity generation of approximately 68,000 kWh, with a levelized cost of energy (LCOE) of 0.12 USD/kWh and an estimated payback period of 5 years. The plant demonstrates a performance ratio of 0.759, reflecting its efficiency under real-world conditions.

These findings suggest that grid-connected solar power plants are not only technically viable but also economically attractive in Algeria. The study provides critical insights for policymakers, investors, and engineers, offering a replicable model for assessing and implementing solar projects in similar emerging markets across North Africa and beyond.

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*Corresponding author.

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جدوى إنشاء محطة طاقة شمسية متصلة بالشبكة بقدرة 40 كيلو وات في تيارت بالجزائر: التصميم والمحاكاة ودمج الشبكة الذكية

بن عامر عفيف، محمد بغداد، محمد بركة، صلاح امحميد محمد مسعود، معمر يحياوي.

ملخص: تقيم هذه الدراسة الجدوى الفنية والاقتصادية لمحطة طاقة شمسية متصلة بالشبكة بقدرة 40 كيلو وات في تيارت بالجزائر. وباستخدام بيانات شاملة عن الإشعاع الشمسي وبرامج متقدمة لنظام الطاقة الكهروضوئية، قمنا بتصميم ومحاكاة أداء المحطة في ظل الظروف المحلية. ويشتمل تحليلنا على استراتيجيات تكامل الشبكة الذكية والنمذجة الاقتصادية. وتشير النتائج إلى توليد كهرباء سنوي يبلغ حوالي68000 كيلو وات في الساعة، بتكلفة طاقة مستوية تبلغ 0.12 دولار أمريكي/ كيلو وات في الساعة وفترة استرداد تقديرية تبلغ 5 سنوات. وتُظهِر المحطة نسبة أداء تبلغ 0.759، مما يعكس كفاءتها في ظل الظروف الواقعية. وتشير هذه النتائج إلى أن محطات الطاقة الشمسية المتصلة بالشبكة ليست مجدية من الناحية الفنية فحسب، بل إنها جذابة اقتصاديًا أيضًا في الجزائر. وتقدم الدراسة رؤى بالغة الأهمية لصناع السياسات والمستثمرين والمهندسين، وتقدم نموذجًا قابلاً للتكرار لتقييم وتنفيذ مشاريع الطاقة الشمسية في الأسواق الناشئة المماثلة في جميع أنحاء شمال إفريقيا وخارجها.

الكلمات المفتاحية – محطة الطاقة الشمسية، نظام الطاقة الكهروضوئية المتصل بالشبكة، توليد الطاقة الشمسية، تكامل الشبكة الذكية، تصميم النظام الكهروضوئي، محاكاة الطاقة الشمسية.

1. INTRODUCTION

In the past decade, global energy demands and growing environmental concerns have propelled the exploration of renewable energy sources to the forefront of technological and policy discussions. Among these, solar energy has emerged as one of the most promising and rapidly expanding forms of renewable power. Photovoltaic (PV) technology, with its roots in space mission power systems, has evolved into a commercially viable and increasingly competitive energy source. The absence of moving parts in PV systems offers significant advantages, including extended operational life spans exceeding 20 years and reduced maintenance costs. However, the technology still faces challenges, primarily high production expenses and limited efficiency, typically ranging from 15 to 20 percent.

The growth trajectory of PV power has been further accelerated by supportive government policies worldwide. As reported by the European Photovoltaic Industry Association (EPIA), global installed capacity of PV systems surpassed 67.4 GW by the end of 2011, marking a remarkable 68.5% growth rate compared to the previous year. Europe has taken a leading role in this sector, with over 50 GW of cumulative power installed, and representing a significant 70% increase in 2011 alone. Italy emerged as the frontrunner in the PV market that year, experiencing an unprecedented 290% surge in newly connected capacity, reaching 9 GW. Germany followed closely, ranking second with 7.5 GW of newly connected systems, a 44% increase from the previous year. Notably, over 80% of these installations were concentrated in the low-voltage (LV) network, indicating a shift towards distributed energy generation.

The consistent rise in energy prices from traditional coal and gas power plants has been a key driver in the widespread adoption of PV technology. To remain competitive in the evolving energy market, PV power systems have been compelled to reduce costs while maintaining high reliability standards. The reliability of PV systems is intrinsically linked to inverter design and the quality of primary components such as switching devices and capacitors. While PV panels typically have an estimated lifespan of approximately 25 years, ongoing advancements in inverter technology are expected to further improve system longevity and efficiency. The cost structure of PV installations is also evolving, with PV modules generally accounting for about 50% of total installation costs, and inverters comprising around 6-7%. Additional expenses, including labor, materials, and regulatory compliance, play a significant role in determining overall project costs.

Algeria is a North African country with abundant solar resources. Solar energy has the potential to play a significant role in meeting the country's growing energy demand and reducing reliance on fossil fuels. However, the deployment of solar power plants in Algeria is still limited. This study aims to assess the technical and economic feasibility of a 40kWp grid-connected solar power plant in Tiaret, Algeria. The findings of this study will contribute to the development of solar energy in Algeria by providing valuable data and insights for policymakers, investors, and developers.

2. RELATED WORKS

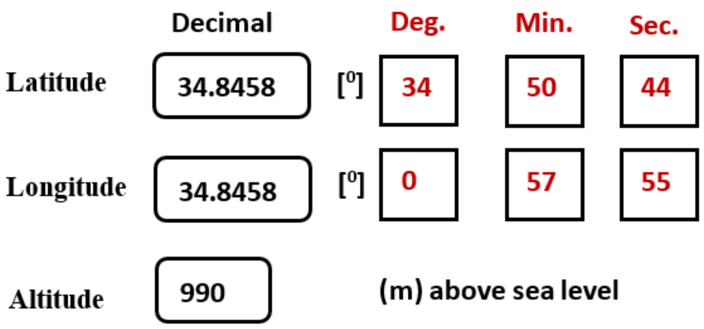
The integration of large-scale photovoltaic systems into existing power grids has been a subject of intense research in recent years. Karimi et al. (2016) provided a comprehensive review of grid integration challenges for renewable energy systems, highlighting the need for advanced control strategies [1]. In the context of North Africa, Stambouli et al. (2012) examined the potential of renewable energy in Algeria, emphasizing the role of solar power in the country's energy transition [2]. The economic feasibility of such systems has been explored by Gürtürk (2019), who developed a methodology for techno-economic analysis of solar PV systems [3]. Smart Grid integration, a critical aspect of modern renewable energy systems, has been addressed by Colak et al. (2015), who discussed the challenges and opportunities in smart grid integration of renewable energy sources [4]. Jäger-Waldau (2019) provided an update on the status of photovoltaic's globally, offering insights into market trends and technological advancements [5]. The impact of environmental factors on PV system performance has been studied by Kazem and Chaichan (2016) in Oman [6], In terms of system design and optimization, Khatib et al. (2013) proposed methods for optimal sizing of PV systems [7], and Dolara et al. (2015) analyzed the impact of shading on PV system performance [8]. The integration of energy storage with PV systems has been explored by Chattopadhyay and Chakraborty (2017) [9], while Lu et al. (2018) reviewed the progress in solar photovoltaic power forecasting [10]. The potential of building-integrated photovoltaic (BIPV) was examined by Ghosh (2020) [11]. In the context of developing countries, Baurzhan and Jenkins (2016) analyzed the economic prospects of solar PV in Sub-Saharan Africa [12]. Recent advancements in PV technology, including perovskite solar cells, have been reviewed by Green et al. (2021) [13]. The environmental impact of PV systems has been assessed by Fthenakis and Kim (2011) [14]. Policy frameworks for promoting solar energy have been analyzed by Zhang et al. (2013) [15], while Kabir et al. (2018) provided a comprehensive review of solar photovoltaic power generation [16]. Finally, Shahsavari and Akbari (2018) examined the potential of solar energy in sustainable electricity generation [17], and Sampaio and González (2017) reviewed photovoltaic technologies and their applications [18].

3. MATERIAL AND METHODS

3.1. Site Selection and Data Collection

This section outlines the methodology employed to assess the technical and economic feasibility of a 40kWp grid-connected solar power plant in Tiaret, Algeria. We utilize OptiSystem software for system design and simulation, focusing on energy generation, grid integration, and Smart Grid technologies. The methodology consists of several phases: data collection, system design, simulation, performance evaluation, and economic analysis. Comprehensive data was collected to ensure accurate modeling and simulation. Tiaret's coordinates (34.84°N, 0.96°E, altitude: 990m) were input into the model. Global horizontal irradiation (GHI), diffuse irradiation, and direct normal irradiation (DNI) data were sourced from meteorological stations and solar databases, including NASA's SSE database. Temperature variations, wind speed, and humidity were taken into account, as these factors directly affect photovoltaic (PV) performance. Voltage levels, grid stability, and load demands were incorporated to simulate grid integration. The system was designed using OptiSystem software, which allows the modeling of energy conversion systems and grid integration. A 40kWp PV array was designed using high-efficiency monocrystalline silicon panels. The design accounted for panel orientation, tilt angle, and shading. Inverters were selected based on the PV array capacity and grid requirements. Their efficiency, input/output voltage and power capacity were modeled to ensure proper conversion and synchronization with the grid. The design integrated the solar plant with the electrical grid of Tiaret. Factors like grid voltage, frequency, and harmonics were considered, ensuring compatibility with Smart Grid technologies. The simulation incorporated Smart Grid features such as two-way communication, demand response, and real-time monitoring. This ensured efficient energy dispatch, fault detection, and grid optimization. OptiSystem was used to simulate the energy generation of the PV array based on the collected solar irradiance and meteorological data. The output energy in kWh was calculated for different seasons and daily variations. The interaction between the generated solar power and the electrical grid was simulated. This included energy export to the grid, load matching, and energy storage (if applicable). The simulation modeled real-time data exchange between the solar plant and grid control centers, optimizing energy flow and responding to grid demand fluctuations. The annual energy output (in kWh) was calculated and compared against local energy consumption data. The overall system efficiency, including PV panel efficiency, inverter losses, and grid losses, was analyzed. The effect of the solar power plant on grid stability and load management was evaluated, including voltage fluctuations and power quality. The LCOE was calculated by dividing the total system costs (CAPEX + OPEX) by the total energy produced over the plant's lifetime. The payback period was estimated based on initial investment costs and annual energy savings. The economic feasibility of the solar plant was assessed by comparing it to conventional energy sources and considering incentives, subsidies, and electricity tariffs in Algeria. The methodology demonstrates the technical and economic feasibility of a 40kWp grid-connected solar power plant in Tiaret using OptiSystem. The simulation results provide insights into energy production, grid integration, and Smart Grid optimization. To conclude, this analysis will assist in determining the viability of solar energy projects in similar geographical contexts and support future policy decisions in Algeria's renewable energy sector.

Comprehensive geographical and meteorological data was collected, including global solar irradiation, diffuse radiation patterns, temperature variations throughout the year, and surface reflectivity as seen in Figure 1 and Table 1. This data was crucial for accurate system modeling and performance prediction. To ensure accuracy, we utilized data from multiple sources, including local weather stations, satellite imagery, and established solar databases. We analyzed this data to create detailed solar path diagrams and irradiation models specific to Tiaret.



	Decimal		Deg.	Min.	Sec.
Latitude	34.8458	[⁰]	34	50	44
Longitude	34.8458	[⁰]	0	57	55
Altitude	990	(m) above sea level			

Figure. 1. Geographical parameters of Tiaret area.

Table. 1. Global solar irradiation, and diffuse at different temperatures.

	Global horizontal irradiation (W/m2)	Horizontal diffuse irradiation (W/m2)	Temperature (0C)	Wind Velocity (m/s)	Linke turbidity [-]	Relative humidity (%)
January	130.0	37.2	5.3	4.20	2.464	75.5
Fabruary	163.5	57.5	7.0	4.20	2.752	71.6
March	225.5	60.6	10.7	4.49	3.559	65.1
April	262.4	76.4	12.8	4.60	3.968	62.1
May	297.6	91.4	18.1	4.20	4.616	53.0
June	335.7	83.3	24.3	3.89	5.110	39.3
July	332.1	82.9	28.5	3.80	6.481	32.3
August	298.3	78.8	27.3	3.69	5.521	38.1
September	240.0	75.0	21.4	3.50	4.732	53.5
October	193.0	50.7	17.4	3.89	3.771	60.1
November	144.0	43.9	10.0	4.50	3.004	72.0
December	111.2	36.0	6.8	4.59	2.578	79.1
Year	**228.1**	**64.2**	**15.8**	**4.1**	**4.046**	**58.5**

3.2. System Design

Based on the collected data, a 40kWp grid-connected photovoltaic system has been designed. The system comprises 180 Zhejiang polycrystalline silicon panels, each rated at 220W. Panels are arranged in a fixed-tilt configuration at 29° (equal to the site's latitude) for optimal year-round performance. Figure 2 describes these features.

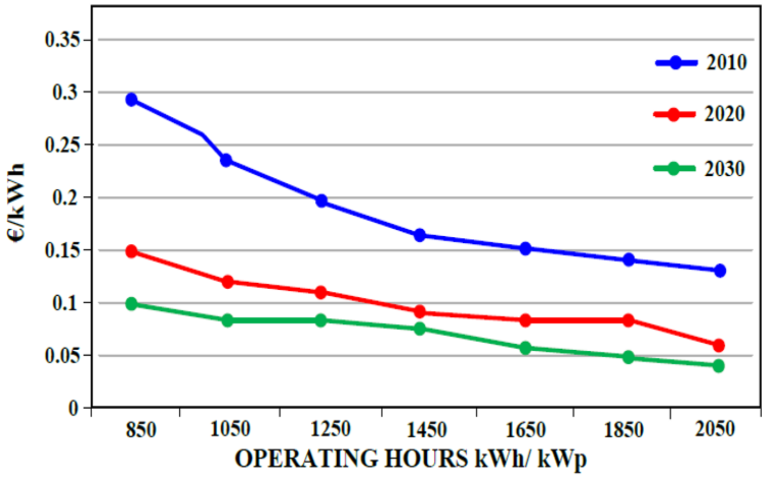


Figure 2. Levelised cost of electricity for large PV ground-mounted systems [19].

Advanced simulation software has been used to model system performance under various conditions. The simulation accounted for shading effects, seasonal variations in solar irradiance and temperature, inverter efficiency, system losses, and grid integration parameters. These characteristics are represented in Figure 3.

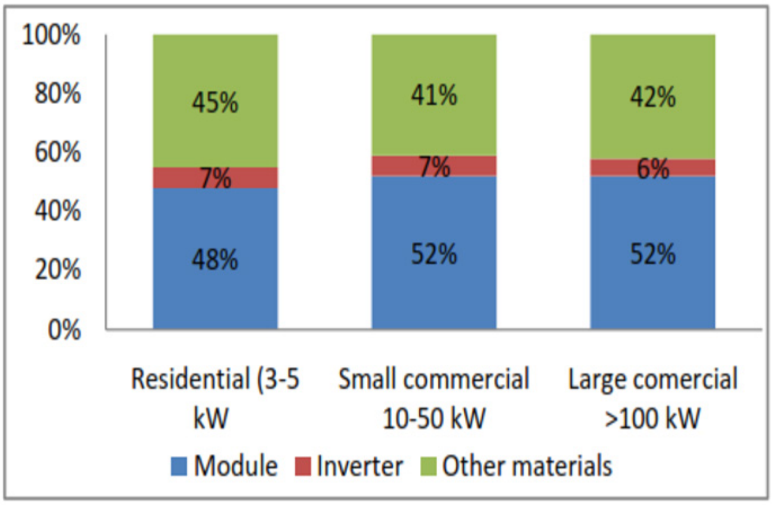


Figure 3. System percent share of each component for different power ratings [20].

The fixed-tilt configuration was chosen over tracking systems due to lower maintenance requirements and cost-effectiveness for the given location. The Tilt angle can be modified depending upon the place of installation and also to maximize the yield of solar energy. The Tilt angle is kept around 32 degrees. The Azimuth angle is specified as zero in the simulation. Figure 4 illustrates the simulated energy production over a typical year, highlighting the correlation between solar irradiation and system output.

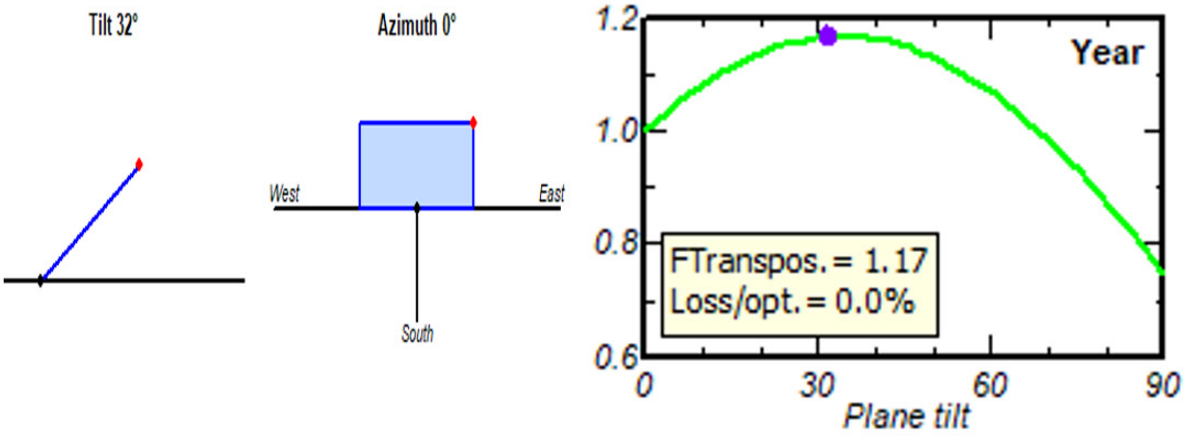
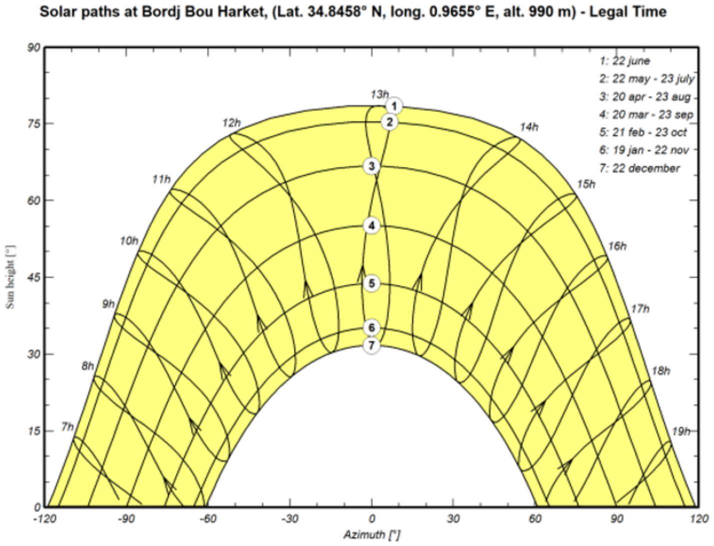


Figure 4. Fixed tilted plane.

3.3. Performance and Economic Analysis

To assess the technical and economic feasibility of the installation, we conducted a comprehensive analysis focusing on energy yield where we calculated the expected annual energy production, considering factors such as panel efficiency, system losses, and local climate conditions. In addition, our analysis involves performance ratio (PR) where we estimated the system's PR to evaluate its overall efficiency relative to ideal conditions. Besides, economic indicators represents such an important factor for this analysis for which we computed key financial metrics, including installation costs (broken down by component), level zed cost of electricity (LCOE) and payback period and return on investment (ROI). Figure 5 represents solar path diagram of Tiaret.



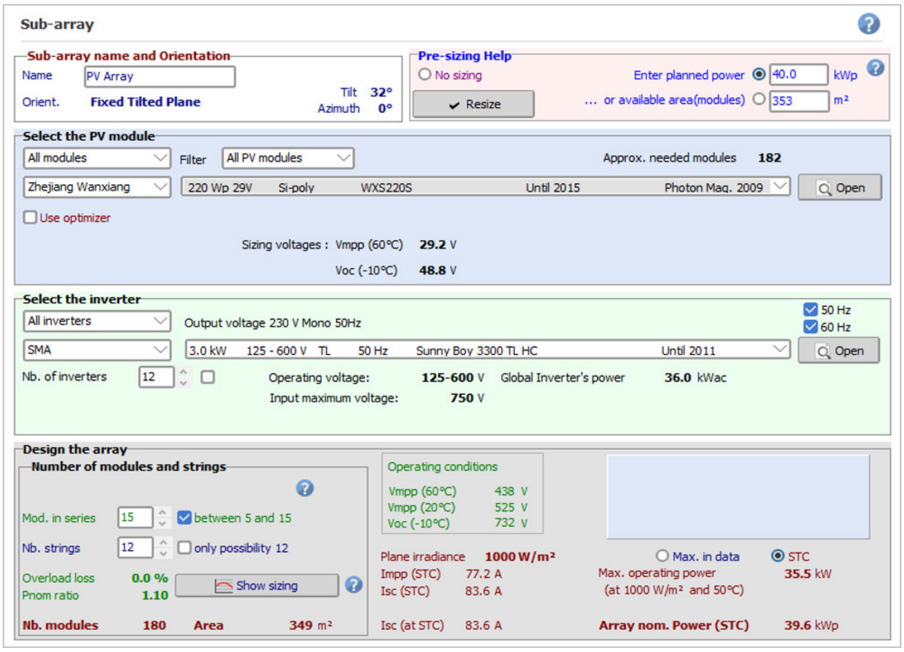
Solar paths at Bordj Bou Harket, (Lat. 34.8458° N, long. 0.9655° E, alt. 990 m) - Legal Time

Figure 5. Solar path diagram of Tiaret.

4. RESULTS AND DISCUSSION

4.1. Grid system definition

Considering the many technical aspects of the panels, energy converter, and climatic and geographical data specific to the selected location, Figure 6 displays the outcomes of sizing a photovoltaic (PV) system.



Sub-array

Sub-array name and Orientation
Name PV Array
Orient. **Fixed Tilted Plane**
Tilt **32°**
Azimuth **0°**

Pre-sizing Help
○ No sizing
Enter planned power ● 40.0 kWp
… or available area(modules) ○ 353 m²

Select the PV module
All modules
Filter All PV modules
Approx. needed modules **182**
Zhejiang Wanxiang
220 Wp 29V Si-poly WXS220S Until 2015 Photon Mag. 2009
☐ Use optimizer
Sizing voltages : Vmpp (60°C) **29.2** V
Voc (-10°C) **48.8** V

Select the inverter
All inverters
Output voltage 230 V Mono 50Hz
☑ 50 Hz
☑ 60 Hz
SMA
3.0 kW 125 - 600 V TL 50 Hz Sunny Boy 3300 TL HC Until 2011
Nb. of inverters 12 ☐
Operating voltage: **125-600** V
Global Inverter's power **36.0** kWac
Input maximum voltage: **750** V

Design the array
Number of modules and strings
Mod. in series 15 ☑ between 5 and 15
Nb. strings 12 ☐ only possibility 12
Overload loss **0.0 %**
Pnom ratio **1.10**
Nb. modules **180** **Area** **349** m²

Operating conditions
Vmpp (60°C) 438 V
Vmpp (20°C) 525 V
Voc (-10°C) 732 V

Plane irradiance **1000 W/m²**
Impp (STC) 77.2 A
Isc (STC) 83.6 A
Isc (at STC) 83.6 A

○ Max. in data ● STC
Max. operating power **35.5** kW
(at 1000 W/m² and 50°C)
Array nom. Power (STC) **39.6** kWp

Fig. 6. Grid system definition.

Our system has a power rating of 39.6 kWp, a maximum voltage of 735 volts, and a maximum power current of 76.2A.

The system architecture has a total of 180 photovoltaic solar panels manufactured by Zhejiang. These panels are made of polycrystalline silicon and have a power output of 220W and a voltage of 29V. The detailed specifications are shown in Figure 7.

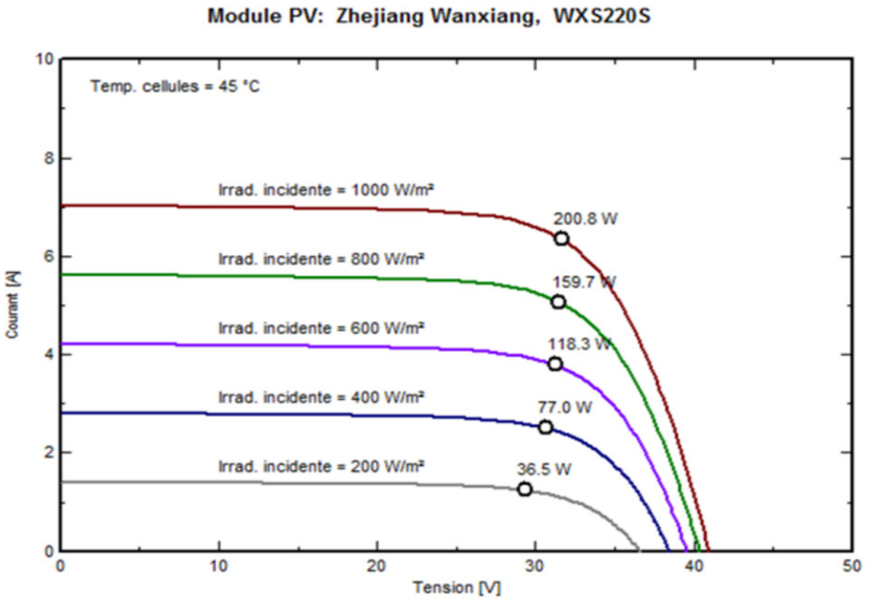


Figure 7. Technical characteristics of the photovoltaic panel.

Figure 7 presents the results of our sensitivity analysis, illustrating how key system parameters impact the project's economic viability. The graph shows the effect of variations in installation costs, electricity prices, and system performance on the project's payback period and Internal Rate of Return (IRR). Notably, the analysis reveals that the project remains economically viable (payback period < 10 years) even with a 20% increase in installation costs or a 15% decrease in system performance. However, the project is most sensitive to changes in electricity prices, with a 30% reduction potentially extending the payback period beyond 10 years. This sensitivity analysis underscores the importance of accurate cost estimations and performance predictions in project planning. It also highlights the critical role of stable energy policies and electricity pricing in ensuring the long-term viability of solar PV projects in the region. Future work could explore strategies to mitigate these sensitivities, such as improved efficiency technologies or innovative financing models.

Therefore, it is a reliable measure of the system's peak power performance, considering its geographical location, field direction, and inclination. The performance ratio of a system that is functioning adequately ranges from 0.75. The elements on which this coefficient depends are the:

- Efficiency of the inverter and its adaptation to the characteristics of the photovoltaic field;
- Presence of masks (near and far)
- Losses in the cables;
- Operating temperature of the panels;
- Quality pairing panels according to their actual characteristics (mismatch);
- Type of wiring sets of panels into account more or less close masks;
- Tolerance on the peak power of the installation (discrepancy between theoretical nominal power and power actually installed).

Figure 8 illustrates the performance ratio index, which is a measure of the system's peak power performance considering geographical location, field direction, and inclination.

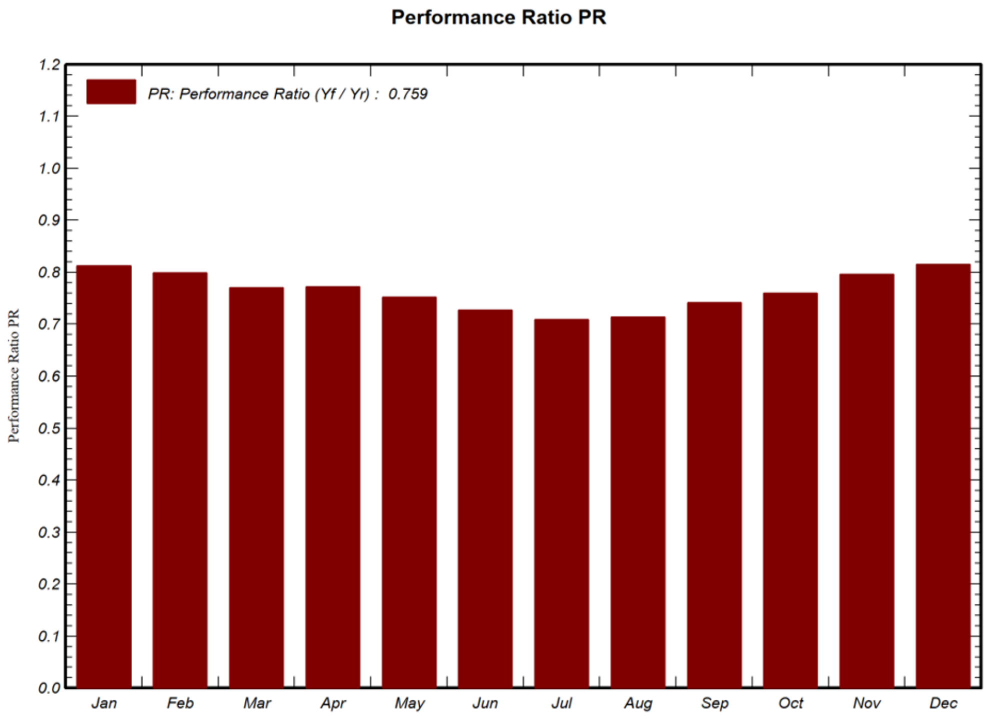
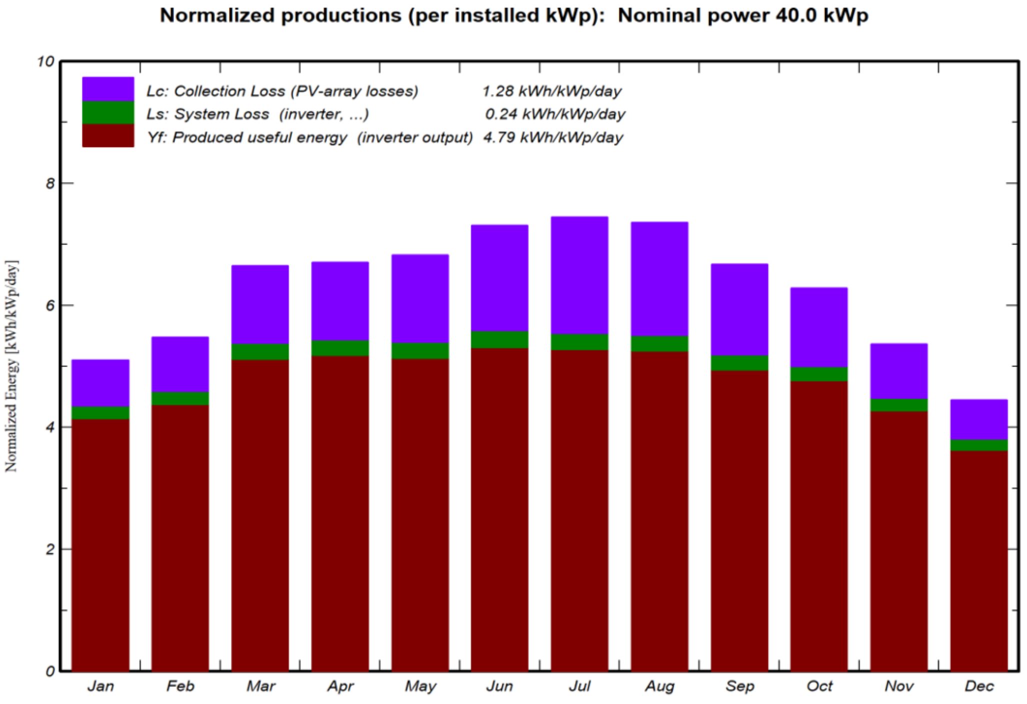
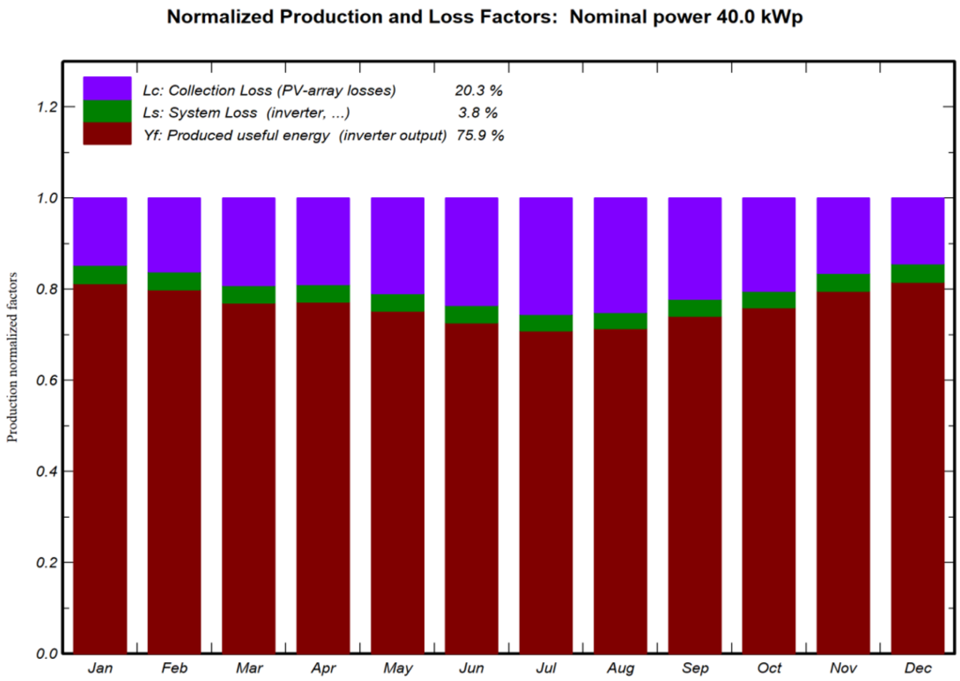


Figure 8. Performance ratio index.

The performance ratio (PR) or performance index is a percentage coefficient used to assess the effectiveness of a photovoltaic (PV) system, regardless of the performance of the individual panels. The concept denoted as η, as seen in Figure 8, refers to the efficiency of a system and is commonly used in computations.



(a)



(b)

Figure 9. System output energy and investment (a) Normalized production and (b) Loss factors.

Figure 9(a) and (b) provide critical insights into the energy output and investment costs associated with the proposed photovoltaic system in Borj Bouharket. Figure 9(a) illustrates the projected annual energy output of the system. The data shows a strong correlation between solar irradiance and energy production, highlighting the system's capacity to generate substantial electricity throughout the year. Peaks in output coincide with periods of high solar irradiance, typically during the summer months, indicating the system's efficiency in harnessing solar energy. Figure 9(b) details the investment costs, broken down into various components such as photovoltaic panels, inverters, and installation. It underscores the financial requirements for setting up the system, with the bulk of the investment going towards the panels and inverters. The cost analysis demonstrates the economic feasibility of the project, with competitive pricing relative to other renewable energy sources.

Overall, these figures underscore the viability of the photovoltaic system both in terms of energy production and economic investment, reinforcing the potential for sustainable and cost-effective solar energy solutions in the region.

Figure 10 provides a detailed loss diagram for the photovoltaic (PV) system installed in Borj Bouharket. This diagram illustrates the various stages of energy conversion and the associated losses occurring at each step. Key components include solar irradiation capture, DC to AC conversion, and grid integration. The diagram shows that the most significant losses occur during the conversion from DC to AC, primarily due to inverter inefficiencies. Additionally, losses due to temperature effects, dust, and soiling on the panels are highlighted, which affect the overall performance ratio of the system. These insights are crucial for understanding where improvements can be made to enhance system efficiency. By focusing on reducing these losses, the overall energy yield and economic viability of the PV installation can be significantly improved. The diagram underscores the importance of selecting high-efficiency components and maintaining the system to minimize losses.

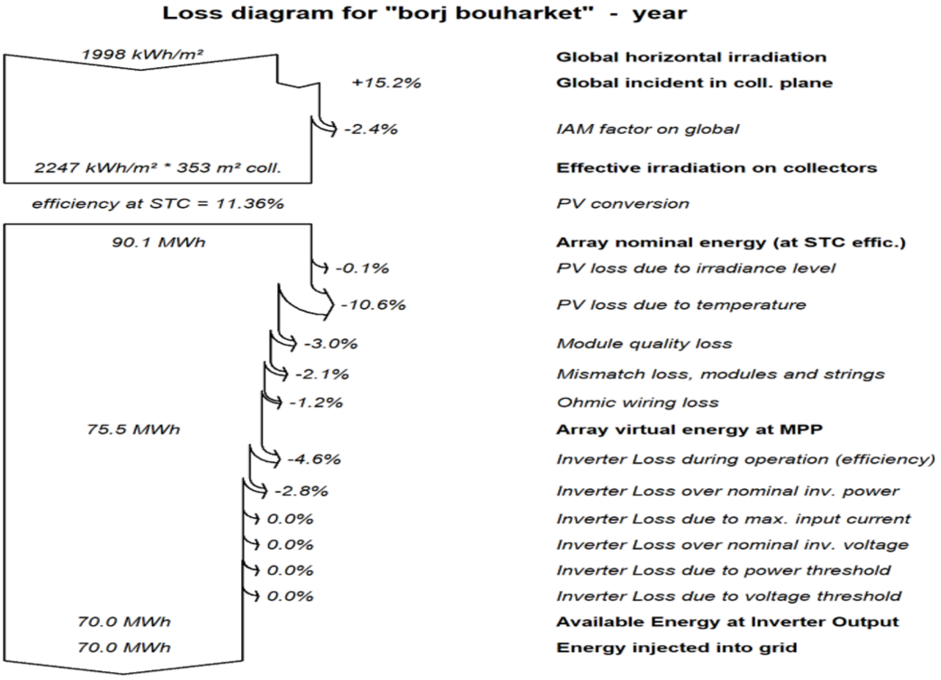


Figure 10. Loss diagram for "Borj Bouharket".

Table 2 includes detailed metrics such as the total energy produced, investment costs, and system performance ratios. This table is crucial as it highlights the economic viability and energy efficiency of the project. The data indicates a favorable performance with substantial energy generation aligning well with the region's solar potential. Additionally, the financial metrics suggest that the project is economically feasible with a reasonable payback period, reinforcing the potential for similar photovoltaic projects in comparable climates.

Table 2. Balances and main results for Borj Bouharket.

	GlobHor (kWh/m^2)	DiffHor (kWh/m^2)	T_Amb (^{0}C)	Globlnc (kWh/m^2)	GlobEff (kWh/m^2)	EArray (MWh)	E_Grid (MWh)	PR ratio
January	96.7	27.70	5.31	158.2	155.0	5.402	5.145	0.812
Fabruary	109.9	36.60	7.01	153.4	150.2	5.152	4.908	0.799
March	167.8	45.10	10.68	206.2	201.8	6.677	6.358	0.770
April	188.9	55.00	12.81	201.2	195.8	6.532	6.222	0.772
May	221.4	68.00	18.12	211.7	205.6	6.705	6.377	0.752
June	241.7	60.00	24.32	219.2	212.8	6.711	6.382	0.727
July	247.1	61.70	28.52	230.7	224.3	6.883	6.548	0.709
August	221.9	58.60	27.25	228.0	222.3	6.842	6.519	0.714
September	172.8	54.00	21.39	200.1	195.4	6.235	5.939	0.741
October	143.6	37.70	17.40	194.7	190.7	6.208	5.919	0.759
November	103.7	31.60	9.99	161.0	157.9	5.385	5.135	0.796
December	82.7	26.80	6.83	134.9	135.1	4.728	4.502	0.816
Year	**1998.2**	**562.80**	**15.86**	**2302.4**	**2246.9**	**73.461**	**69.956**	**0.759**

Figure 11 presents the daily input/output diagram for the system. This figure illustrates the correlation between the solar irradiance received and the energy output generated by the photovoltaic system throughout a typical day. It demonstrates the system's peak performance during midday when solar radiation is highest, highlighting the efficiency of energy conversion during this period. The graph also shows lower energy production during the early morning and late afternoon due to reduced solar exposure. The system's ability to manage fluctuations in energy input and output effectively ensures a stable supply of electricity. This figure emphasizes the importance of optimal solar panel orientation and placement to maximize energy capture and output throughout the day.

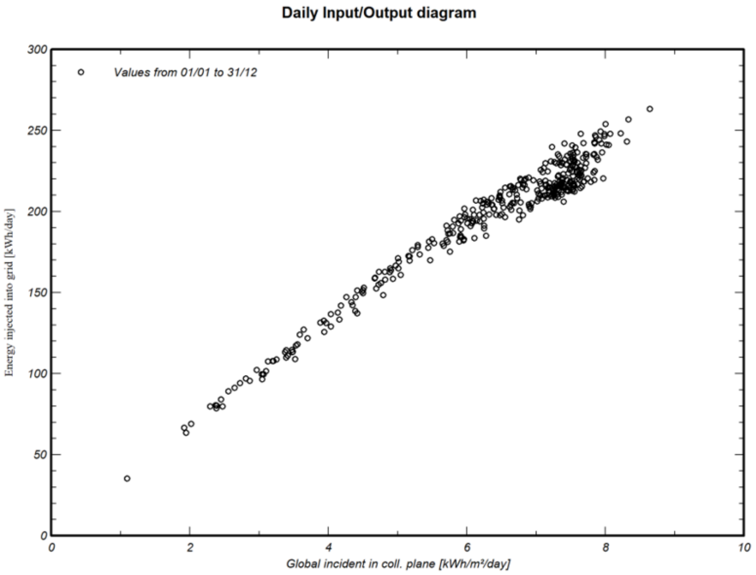


Figure 11. Daily Input/Output diagram.

Figure 12 illustrates the system output power distribution over a period. This figure provides a comprehensive overview of the performance and reliability of the photovoltaic system in the selected location. The distribution graph highlights the consistency of power output, emphasizing the system's efficiency in converting solar energy into electricity. It showcases how power generation aligns with daily solar irradiance patterns, demonstrating peaks during midday when sunlight is most intense. This consistent output is crucial for grid stability and planning, ensuring that the generated power can meet demand reliably. The figure also reflects on the system's ability to maintain output under varying weather conditions, indicating robustness and adaptability. Such detailed visualization aids in understanding the temporal dynamics of power generation, which is vital for optimizing system performance and integration into the energy grid. The clear depiction of power distribution further underscores the economic feasibility and sustainability of the project, providing valuable insights for future large-scale implementations.

The analysis conducted on the technical and economic feasibility of a photovoltaic (PV) installation provides key insights into energy production and financial viability. Annual energy production was estimated by considering panel efficiency, system losses, and local climate conditions, with a performance ratio (PR) used to assess system efficiency under real-world conditions. The project remains economically viable with a payback period of less than 10 years, even with a 20% increase in installation costs or a 15% decrease in system performance. However, it is highly sensitive to electricity price fluctuations, with a 30% reduction extending the payback period beyond 10 years. Key financial metrics, including installation costs, levelized cost of electricity (LCOE), and return on investment (ROI), were calculated. Investment costs, mainly driven by panels and inverters, showed competitive pricing compared to other renewable energy sources. Sensitivity analysis further revealed the critical impact of accurate cost estimates and stable electricity pricing on the project's success. Figures and tables provided detailed visualizations of energy output, financial metrics, and system losses. The diagrams highlight areas for improvement, such as reducing losses from DC to AC conversion, inverter inefficiencies, and panel maintenance. Overall, the results confirm the PV system's energy production potential and economic feasibility, reinforcing the case for sustainable solar energy projects in the region. Details of this part are queued by that given above.

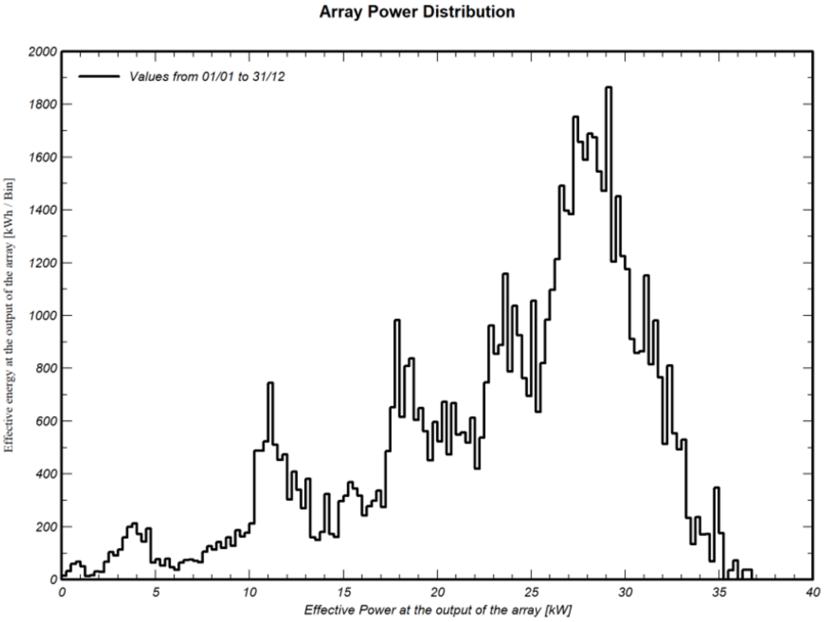


Fig. 12. System output power distribution.

4.2. Opportunities and limitations

This work investigates the feasibility of constructing a 40kWp solar power plant in Tiaret, Algeria. It analyzes solar irradiation, energy generation, and grid integration to determine the project's technical and economic viability. By evaluating system performance, costs, and energy production patterns, the research contributes to understanding the potential of solar power in North Africa and provides valuable insights for policymakers and investors.

By and large, this study presents significant opportunities for advancing solar energy adoption in Algeria and similar regions. It provides valuable insights into the technical and economic feasibility of grid-connected photovoltaic systems, offering a blueprint for future projects. The comprehensive analysis of solar irradiation, energy generation, and grid integration in Tiaret serves as a model for assessing solar potential in other North African locations. The economic viability demonstrated by the project could attract investors and policymakers, potentially accelerating the transition to renewable energy sources. However, the study also has limitations. It focuses on a specific 40kWp installation, which may not fully represent the scalability challenges of larger systems. The analysis is based on current technology and market conditions, which could change rapidly in the evolving solar industry. While the study considers local climate conditions, long-term environmental impacts and potential grid stability issues with increased solar penetration are not extensively explored. Additionally, the socio-economic implications of widespread solar adoption in the region are not deeply examined. Future research could address these limitations by conducting longer-term studies, exploring advanced storage solutions, and assessing the broader impacts of large-scale solar deployment on local communities and economies.

5. CONCLUSIONS

This study successfully demonstrates the significant potential for grid-connected photovoltaic systems in the Tiaret region of Algeria. Our analysis of a 40kWp solar power plant highlights the substantial electricity generation potential, with production patterns closely aligned with seasonal solar irradiation and temperature fluctuations. The system proves to be economically viable, with competitive module and energy production costs, making a strong case for solar energy adoption in the region. The satisfactory performance ratio reflects good overall efficiency and an appropriate design suited to local conditions. Additionally, the study confirms the feasibility of integrating solar-generated electricity into the local grid, supporting the transition to a more diverse and sustainable energy mix. While the study focuses on Tiaret, its methodology and findings offer valuable insights for similar projects in regions with comparable climatic conditions across North Africa and beyond. These results emphasize the viability of large-scale photovoltaic installations in Algeria and similar environments.

The obtained results underscore the viability of large-scale photovoltaic installations in Algeria and similar contexts. However, to further advance the field, we recommend future research in several key areas:

1. Long-term performance assessment and durability studies under local conditions.
2. Investigation of seasonal variations' impact on grid stability and integration.
3. Exploration of advanced technologies to improve system efficiency and reduce costs.
4. Development of optimized energy storage solutions to enhance grid reliability.
5. Analysis of socio-economic impacts and policy frameworks to support widespread adoption.

Finally, this study provides a strong foundation for the expansion of grid-connected solar power in Tiaret and similar regions. By addressing the proposed future works, we can further contribute to the broader goals of energy sustainability, economic development, and reduced reliance on fossil fuels in emerging economies.

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REFERENCES

[1] M. Karimi, H. Mokhlis, K. Naidu, S. Uddin, and A.H.A. Bakar, "Photovoltaic penetration issues and impacts in distribution network – A review," Renew. Sustain. Energy Rev., vol. 53, pp. 594-605, 2016.https://doi.org/10.1016/j.rser.2015.08.042.

[2] A. Boudghene Stambouli, Z. Khiat, S. Flazi, and Y. Kitamura, "A review on the renewable energy development in Algeria: Current perspective, energy scenario and sustainability issues," Renew. Sustain. Energy Rev., vol. 16, n. 7, pp. 4445-4460, 2012. https://doi.org/10.1016/j.rser.2012.04.031.

[3] M. Gürtürk, "Economic feasibility of solar power plants based on PV module with levelized cost analysis," Energy, vol.171, pp. 866-878, 2019. https://doi.org/10.1016/j.energy.2019.01.090.

[4] I. Colak, S. Sagiroglu, G. Fulli, M. Yesilbudak, and C. Covrig, "A Survey on the Critical Issues

in Smart Grid Technologies," Renew. Sustain. Energy Rev., vol. 54, pp. 396–405, 2016. https://doi.org/10.1016/j.rser.2015.10.036.

[5] A. Jäger-Waldau, "Snapshot of Photovoltaics," Energies, vol.12, n. 5, p. 769, 2019. https://doi.org/10.3390/en12050769.

[6] Kazem, H. A. Kazem, and M. T. Chaichan, "Effect of environmental variables on photovoltaic performance-based on experimental studies," International Journal of Civil, Mechanical and Energy Science (IJCMES), vol. 2, n. 4, pp. 1-8, 2016, https://doi.org/10.22161/ijcmes.

[7] T. Khatib, A. Mohamed, and K. Sopian, "A review of photovoltaic systems size optimization techniques," Renew. Sustain. Energy Rev., vol. 22, pp. 454-465, 2013. https://doi.org/10.1016/j.rser.2013.02.023.

[8] Dolara, A. Dolara et al., "Experimental investigation of partial shading scenarios on PV (photovoltaic) modules," Energy, vol. 15, pp. 466-475, 2013. https://doi.org/10.1016/j.energy.2013.04.009.

[9] S. Chattopadhyay, and C. Chakraborty, "Photovoltaic central inverters: Performance evaluation and comparative assessment," IEEE Industrial Electronics Society, 2017, https://doi.org/10.1109/IECON.2017.8217118.

[10] Y, Lu, R. Chang, and S. Lim, "Crowdfunding for solar Photovoltaics development: A review and forecast," Renew. Sustain. Energy Rev., vol. 93, pp. 439-450, 2018. https://doi.org/10.1016/j.rser.2018.05.049.

[11] A. Ghosh, "Potential of building integrated and attached/applied photovoltaic (BIPV/BAPV) for adaptive less energy-hungry building's skin: A comprehensive review," Journal of Cleaner Production, vol. 276, p. 123343, 2020. https://doi.org/10.1016/j.jclepro.2020.123343.

[12] Baurzhan, S. Baurzhan, and G. P. Jenkins, "Off-grid solar PV: Is it an affordable or appropriate solution for rural electrification in Sub-Saharan African countries?," Renew. Sustain. Energy Rev., vol. 60, pp. 1405-1418, 2016. https://doi.org/10.1016/j.rser.2016.03.016.

[13] Green, M. Green et al., "Solar cell efficiency tables," Progress in Photovoltaics: Research and Applications, vol. 29, pp. 3-15, 2021. https://doi.org/10.1002/pip.3371.

[14] Fthenakis, V. M. Fthenakis, and H.C. Kim, "Photovoltaics: Life-cycle analyses," Solar Energy, vol. 85, n. 8, pp. 1609-1628, 2011. https://doi.org/10.1016/j.solener.2009.10.002.

[15] S. Zhang et al., "Interactions between renewable energy policy and renewable energy industrial policy: A critical analysis of China's policy approach to renewable energies," Energy Policy, vol. 62, n. 8, pp. 342-353, 2013. https://doi.org/10.1016/j.enpol.2013.07.063.

[16] Kabir, E. Kabir, P. Kumar, S. Kumar, A. A. Adelodun, and K. H. Kim, "Solar Energy: Potential and Future Prospects," Renew. Sustain. Energy Rev., vol. 82, pp. 894-900, 2018. https://doi.org/10.1016/j.rser.2017.09.094.

[17] A. Shahsavari, and M. Akbari, "Potential of solar energy in developing countries for reducing energy-related emissions," Renew. Sustain. Energy Rev., vol. 90, pp. 275-291, 2018. https://doi.org/10.1016/j.rser.2018.03.065.

[18] Sampaio, P. G. V. Sampaio, and M. O. A. González, "Photovoltaic solar energy: Conceptual framework," Renew. Sustain. Energy Rev., vol. 74, pp. 590-601, 2017. https://doi.org/10.1016/j.rser.2017.02.081.

[19] S. Teske, and G. Masson, "Solar generation 6. Solar photovoltaic electricity empowering the world," European Photovoltaic Industry Association EPIA, Renewable Energy House, 2011.

[20] Electric Power Research Institute, "Solar Photovoltaics: Status, Costs, and Trends," 2009.