International Journal of Computational and Experimental Science and ENgineering (IJCESEN)

Vol. 12-No.2 (2026) pp. 295-304
http://www.ijcesen.com

ISSN: 2149-9144

Research Article

Sizing and optimization of a hybrid photovoltaic-grid system: application to the port of ghazaouet (Algeria)

Fatiha Lassouani[1], Djamila Kherbouche[2], Amina Ghomri[3]*, Imene Lafri[4]

[1]Ecole Supérieure en Sciences Appliquées Tlemcen Algeria
Email: fatih2a@gmail.com - **ORCID:** 0000-0002-1147-7850

[2]Ecole Supérieure en Sciences Appliquées Tlemcen Algeria
Email: djamil2a@gmail.com- **ORCID:** 0000-0002-5247-7330

[3]Ecole Supérieure en Sciences Appliquées Tlemcen Algeria
* **Corresponding Author Email:** ghomrighomri1@gmail.com- **ORCID:** 0000-0002-5247-0050

[4]Centre de recherche en agropastoralisme Djelfa Algeria
Email: imen2e@gmail.com- **ORCID:** 0000-0002-5247-1250

Article Info:

DOI: 10.22399/ijcesen.5201
Received : 01 August 2025
Revised : 10 January 2026
Accepted : 11 January 2026

Keywords

hybrid system
photovoltaics
HOMER Pro sizing
renewable energies
Algeria

Abstract:

This study presents the sizing and techno-economic optimization of a hybrid photovoltaic (PV)-grid system designed for the port of Ghazaouet located in the Tlemcen province Algeria. The main objective is to assess the technical energy and environmental feasibility of integrating photovoltaic energy to reduce dependence on the conventional electrical grid and fossil fuels. The methodological approach involves analyzing local solar potential detailed assessment of the site's energy needs and systematic sizing of system components including the photovoltaic array battery storage system charge controller and inverter. A techno-economic simulation and optimization were subsequently performed using HOMER Pro software enabling comparison of several hybrid configurations and identification of the most cost-effective solution based on life-cycle cost. The results indicate a total annual production of approximately 64207 kWh of which 98.9% is provided by photovoltaic energy confirming the dominant role of solar energy. This study demonstrates that hybrid PV-grid systems significantly reduce CO_2 emissions while ensuring a reliable and continuous power supply confirming their relevance as a sustainable solution for industrial zones in Algeria.

1. Introduction

The global energy transition represents a major challenge in the face of increasing electricity demand and the environmental impacts of conventional energy sources [1 2]. Harnessing renewable energies particularly solar photovoltaic (PV) energy offers an effective solution for reducing dependence on fossil fuels especially in regions with high solar potential such as Algeria.

However the intermittent nature of solar energy limits the exclusive use of standalone photovoltaic systems. Integrating hybrid systems that combine photovoltaics the electrical grid and energy storage improves power reliability and optimizes energy and economic performance [3 4]. Such systems are particularly well-suited to high-consumption industrial applications such as port facilities.

Despite extensive research on hybrid PV systems few studies address their application to Algerian port infrastructure a sector characterized by high and irregular consumption profiles. The specific research gap addressed in this work is the absence of a validated sizing methodology combined with techno-economic optimization for such industrial coastal sites. This study fills this gap by applying a systematic analytical sizing methodology validated through HOMER Pro simulation to the port of Ghazaouet (Tlemcen province). The objective is to evaluate the technical and environmental feasibility of this solution through solar potential analysis energy requirement estimation and software-based optimization in order to identify the most efficient and cost-effective configuration [5].

2. Materials and methods

The methodology adopted in this study follows a two-stage approach: (1) analytical sizing of PV system components based on measured site data and (2) techno-economic optimization using HOMER Pro simulation software. The following subsections detail each stage.

2.1. Site description

The site under study is located at the port of Ghazaouet Tlemcen province Algeria. It benefits from high solar potential with an average annual irradiance of approximately 5 kWh/m²/day making it highly suitable for photovoltaic energy development. Key geographic parameters are: Latitude 35° 6' 00" N Longitude 1° 52' 21" W minimum ambient temperature 13.75°C and maximum ambient temperature 22.03°C.

2.2. Consumption assessment

Monthly electricity consumption data for the slipway facility at the port were collected for the year 2022. Tab. 1 summarizes the power consumption and associated costs for each month. The average daily energy consumption was determined to be 33222 Wh/day which serves as the primary input for the sizing calculations.

2.3. Optimal tilt angle for the PV panels

The optimal tilt angle for a solar panel depends on the latitude of its location and the season. To maximize annual solar energy production [11] the panel tilt angle is set equal to the site latitude minus 10° in summer and plus 10° in winter [12]. Standard pitched roofs typically present angles of 30° to 45° which provide efficient year-round performance in many regions [13 14]. For the port of Ghazaouet at latitude 35° 05' 38" N the optimal winter tilt angle is 45° and the optimal summer tilt angle is 25°.

2.4. Photovoltaic field sizing

The peak power required from the PV array is calculated using the daily energy consumption (Ec = 33222 Wh/day) the correction factor (k = 0.65) and the average daily irradiance (Ir = 5 kWh/m²/day):

$$P_{ch} = E_c / (k \times I_r) = 33222 / (0.65 \times 5) = 10222 \text{ Wp} \quad (1)$$

The selected photovoltaic module is the Condor CEM200M-72 with a peak power of 200 Wp utilizing 72 multicrystalline silicon cells. Its electrical and mechanical characteristics are presented in tab. 2 and tab. 3 respectively.
Based on the peak power requirement and the module specifications the array operating voltage is set at Vch = 96 V. The number of modules is determined as follows:

$$N_p = P_{ch} / P_{module} = 10222 / 200 = 51.1 \approx 52 \text{ modules} \quad (2)$$

$$N_{ps} = V_{ch} / V_{module} = 96 / 45.6 = 2.1 \approx 3 \text{ (modules in series)} \quad (3)$$

$$N_{pp} = N_p / N_{ps} = 52 / 3 = 17.3 \approx 17 \text{ (modules in parallel)} \quad (4)$$

The final array configuration is 3 modules in series × 17 strings in parallel = 51 modules total. The total array surface area is:

$$S = N_{ps} \times N_{pp} \times S_{module} = 3 \times 17 \times 1276.64 \text{ cm}^2 = 65108 \text{ cm}^2 \approx 65.1 \text{ m}^2 \quad (5)$$

2.5. Battery storage system sizing

The battery bank is sized to provide an autonomy of N = 0.5 days with a permissible depth of discharge (DoD) D = 0.8 at the system operating voltage U = 96 V. The required battery capacity is:

$$C_{ch} = (E_c \times N) / (D \times U) = (33222 \times 0.5) / (0.8 \times 96) = 216.3 \text{ Ah} \approx 217 \text{ Ah} \quad (6)$$

The selected battery model is CROWN 12CRV100 AGM Deep Cycle (12 V 107 Ah). The battery bank configuration is:

$$N_{bats} = V_{ch} / V_{bat} = 96 / 12 = 8 \text{ (batteries in series)} \quad (7)$$

$$N_{batp} = C_{ch} / C_{bat} = 217 / 107 = 2.03 \approx 3 \text{ (batteries in parallel)} \quad (8)$$

The total battery bank thus comprises 24 units (8 series × 3 parallel) with a total nominal capacity of 321 Ah at 96 V providing the required 217 Ah minimum with an adequate safety margin.

2.6. Charge controller sizing

The charge controller is sized based on the total PV array power and the system voltage. The array output current is calculated as:

$$P_{array} = P_{module} \times N_{ps} \times N_{pp} = 200 \times 3 \times 17 = 10200 \text{ W} \quad (9)$$

$$I_{controller} = P_{array} / V_{ch} = 10200 / 96 = 106.25 \text{ A} \approx 107 \text{ A} \quad (10)$$

The selected charge controller is rated at 96 V / 107 A.

2.7. Inverter selection

The inverter must handle both the active power load and the reactive power demand. Assuming a power factor of cos φ = 0.8 (sin φ = 0.6):

$$P_r = P_{ch} \times (\sin\varphi / \cos\varphi) = 33222 \times (0.6 / 0.8) = 24916.5\ VAR \quad (11)$$

$$P_{ond} = \sqrt{P^2 + P_r^2} = \sqrt{33222^2 + 24916.5^2} = 41527.5\ VA \approx 41\ kVA \quad (12)$$

The OG 66 kVA TL UL static converter was selected providing sufficient capacity with a safety margin.

2.8. Cable sizing

Cable cross-sections are determined based on a permissible voltage drop of 2% of the system voltage. Given V_{ch} = 96 V:

$$\Delta U = 96 \times 0.02 = 1.92\ V \quad (13)$$

The maximum current from 3 parallel-connected modules (I_{max} = 5.42 A per module × 3 = 16.26 A):

$$R = \Delta U / I_{max} = 1.92 / 16.26 = 0.118\ \Omega \quad (14)$$

$$S = \rho \times L / R = 1.6 \times 10^{-8} \times 3 / 0.118 = 4.07 \times 10^{-4}\ m^2 \approx 4.07\ mm^2 \quad (15)$$

A standard 6 mm² copper cable is recommended for practical installation. Tab. 4 summarizes all sizing results.

2.9. HOMER Pro simulation setup

For the optimization stage the hybrid PV-grid system was modeled in HOMER Pro software using real-world data on load profiles and solar radiation obtained from the National Renewable Energy Laboratory (NREL) database [5]. The system architecture includes the PV array battery bank static converter and grid connection as illustrated in fig. 2.

The monthly solar radiation profile at the site is shown in fig. 3 exhibiting marked seasonal variations with a maximum irradiance in June–July and a minimum in December confirming the annual average of 5 kWh/m²/day used in the sizing calculations.

The grid electricity purchase price was set at 5600 DA/kWh and the feed-in tariff at 10.00 DA/kWh to model bidirectional energy exchange with the national grid. Component costs used in the economic model are: PV module (Condor CEM200M-72): 22230.00 DA/unit; Battery (CROWN 12CRV100): 400.00 DA/unit; Static converter (OG 66 kVA TL UL): 9090.00 DA.

3. Results

HOMER Pro simulated several dozen feasible system configurations by varying the number of PV modules battery units and converter capacity within the defined search space. For each configuration the software computed the net present cost (NPC) over a 25-year project lifetime and verified compliance with the minimum reliability constraint. The simulation results ranked all viable architectures by increasing NPC clearly identifying the hybrid PV-battery-grid configuration as the least costly option. The grid-only solution incurred the highest long-term operational cost due to sustained dependence on purchased electricity at 5600 DA/kWh and generated the greatest CO_2 emissions. Standalone PV configurations required oversized battery banks driving their NPC above that of the hybrid solution. The hybrid architecture achieved the lowest NPC by exploiting the complementarity between the PV array the battery bank and the grid . The selected optimal configuration — 51 PV modules (10200 Wp) 24 batteries (321 Ah at 96 V) and a 66 kVA converter — therefore represents the best techno-economic compromise for the port of Ghazaouet.

3.1. PV production and system consumption

Figs. 4 and 5 present the monthly electricity production and the energy breakdown of the system respectively. Renewable (PV) sources account for 98.9% of total production with the grid supplying the remaining 1.1% primarily during nighttime hours when PV generation is unavailable.

3.2. Load profile analysis

The annual and daily load profiles are presented in figs. 6 to 8. A recurring consumption peak is observed before noon attributed to operational activity at the port (loading/unloading equipment). Consumption remains relatively stable throughout the remainder of the day.

3.3. Converter performance

Fig. 9 presents the inverter power output. The inverter input and output energies are 60967.7 kWh/year and 64207.1 kWh/year respectively yielding a converter efficiency of approximately 94.9%. Energy injections into the grid vary according to seasonal solar irradiance with peak exports occurring in summer months.

3.4. Battery performance

The battery bank (8 series × 3 parallel 96 V) maintains a stable state of charge (SoC) throughout the year as shown in fig. 10. The average daily throughput of 0.00945 hours indicates minimal cycling stress suggesting a long operational lifetime for the chosen battery model. The stable SoC confirms that the battery sizing (section 2.5) is adequate for the site's consumption pattern.

3.5. PV field performance

Fig. 11 illustrates the average daily power delivered by the PV generators. PV production commences between 06:00–07:00 in autumn/winter and between 05:00–06:00 in spring/summer. During periods of zero PV production (nighttime and early morning) power demand is met by the battery bank and when necessary by the grid.

3.6. Grid interaction

Fig. 12 presents the grid power flow indicator. Excess photovoltaic energy is fed into the national grid with maximum exports occurring during summer months (June to August) due to high solar irradiance. The grid acts as a backup source primarily in the evening hours ensuring continuous electricity supply when PV production drops.

3.7. Environmental impact – emissions

Fig. 13 quantifies the gaseous emissions associated with the hybrid system. The significant reduction in CO_2 emissions compared to a fully grid-powered baseline results directly from the displacement of fossil fuel-based electricity by solar energy. The near-elimination of CO_2 SO_2 and NO_x emissions underscores the environmental sustainability of the proposed configuration.

Figure 1. *Location of port of Ghazaouet Tlemcen province Algeria*

Table 1. *Monthly power consumption and cost of the slipway facility (2022)*

Month	Power Consumption (kWh)	Cost of Consumption (DA)	Month	Power Consumption (kWh)	Cost of Consumption (DA)
January	1116.21	14510.82	July	804.77	13357.33
February	1014.79	16452.98	August	888.49	13369.40
March	1056.95	16727.95	September	1100.75	20148.48
April	834.28	16532.93	October	1170.29	19924.56
May	835.41	17976.88	November	1129.35	15746.13
June	794.46	15263.19	December	1214.19	16730.40
Average Daily Consumption			**33222 Wh/day**		

Table 2. *Electrical characteristics of the Condor CEM200M-72 PV module*

Parameter	Value
Peak power (Wp)	200
Open-circuit voltage Voc (V)	45.6
Short-circuit current Isc (A)	5.78

Voltage at max. power Vmp (V)	36.8
Current at max. power Imp (A)	5.44
Module efficiency (%)	15.67
Power tolerance (%)	±3

Table 3. *Mechanical characteristics of the Condor CEM200M-72 PV module*

Parameter	Value
Dimensions (mm)	1580 × 808 × 40
Weight (kg)	17.5
Number of cells	72
Cell type	Multicrystalline silicon

Table 4. *Summary of sizing results*

Parameter	Sub-Parameter	Value
Installation Voltage (V)	–	96 V
Number of PV Modules (200 W)	Total	51 (3 × 17)
	In Series	3
	In Parallel	17
Battery Bank	Total Capacity (Ah)	217 Ah (min.)
	Total Number	24 (8 × 3)
	Type	12 V / 107 Ah
Charge Controller	–	96 V / 107 A
Inverter Power	–	41 kVA (66 kVA selected)
Cable Cross-Section	–	≥ 4.07 mm² (6 mm² recommended)

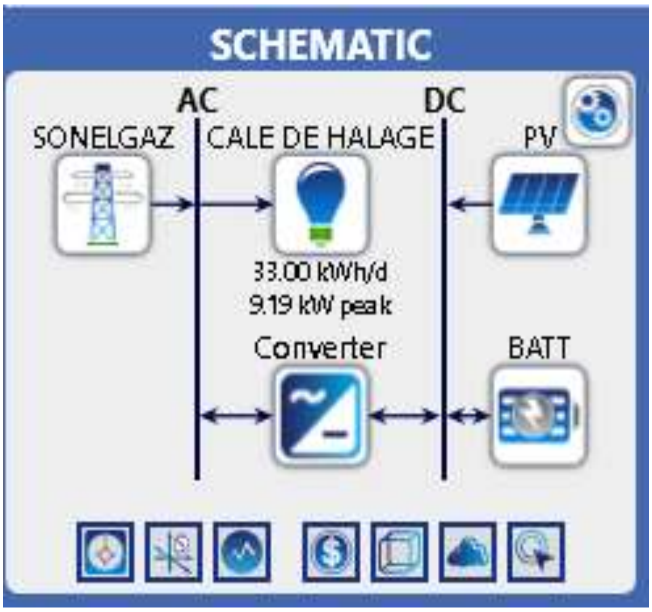


Figure 2. *Configuration of the hybrid PV-grid system modeled in HOMER Pro*

Figure 3. *Monthly solar radiation profile at the port of Ghazaouet*

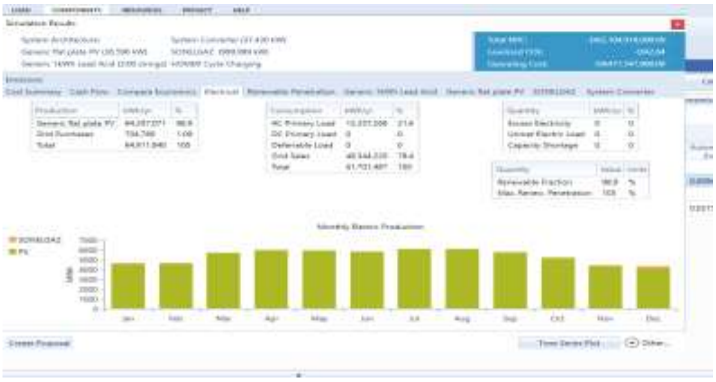


Figure 4. *Total monthly electricity production of the hybrid system*

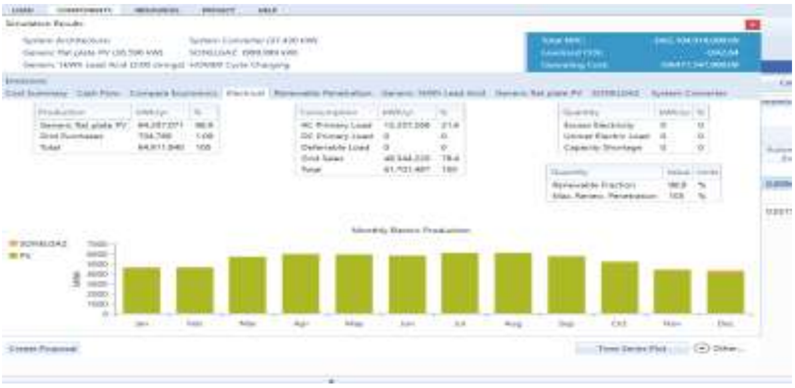
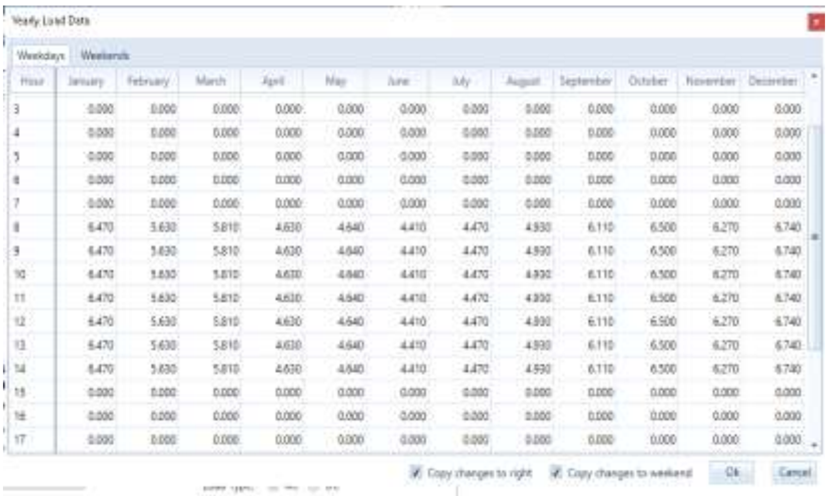


Figure 5. *Electrical energy share by source (PV vs. grid)*



Hour	January	February	March	April	May	June	July	August	September	October	November	December
3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
7	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
8	6.470	5.630	5.810	4.630	4.640	4.410	4.470	4.930	6.110	6.500	6.270	6.740
9	6.470	5.630	5.810	4.630	4.640	4.410	4.470	4.930	6.110	6.500	6.270	6.740
10	6.470	5.630	5.810	4.630	4.640	4.410	4.470	4.930	6.110	6.500	6.270	6.740
11	6.470	5.630	5.810	4.630	4.640	4.410	4.470	4.930	6.110	6.500	6.270	6.740
12	6.470	5.630	5.810	4.630	4.640	4.410	4.470	4.930	6.110	6.500	6.270	6.740
13	6.470	5.630	5.810	4.630	4.640	4.410	4.470	4.930	6.110	6.500	6.270	6.740
14	6.470	5.630	5.810	4.630	4.640	4.410	4.470	4.930	6.110	6.500	6.270	6.740
15	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
16	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
17	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Figure 6. *Total annual energy consumption profile*

Figure 7. *Daily load profile of the facility*

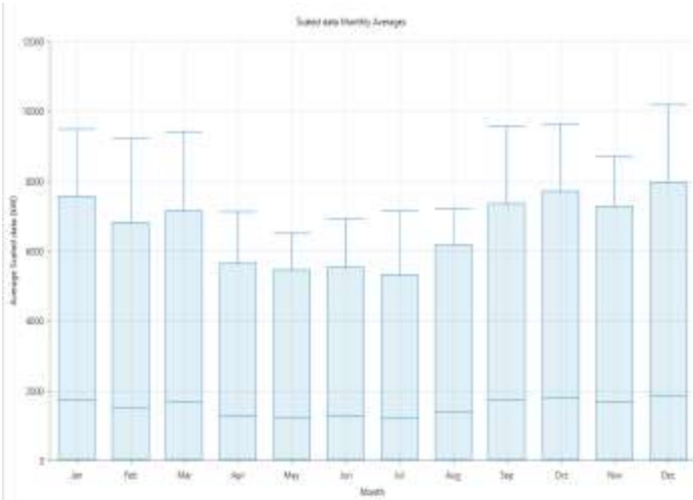


Figure 8. *Annual load profile variation*

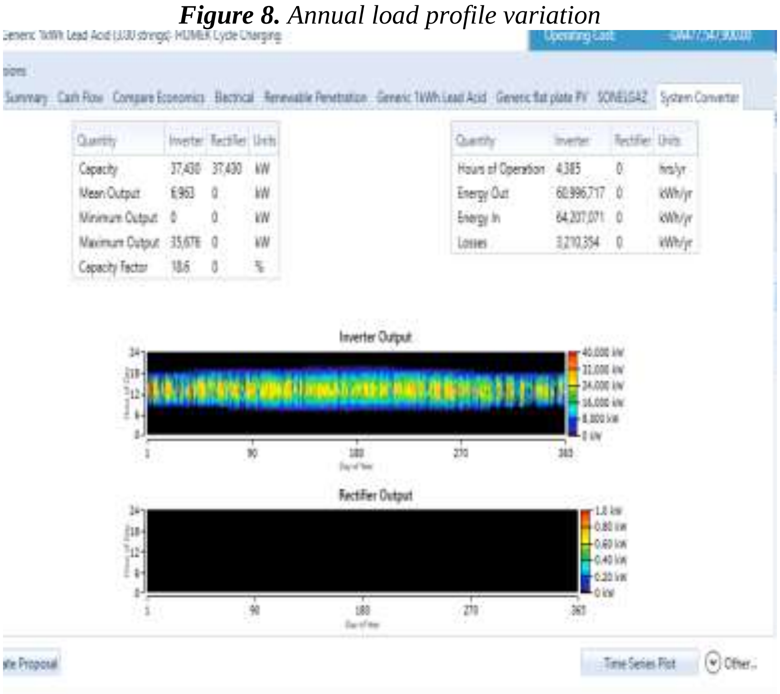


Figure 9. *Monthly inverter power output profile*

Figure 10. *Average daily and monthly state of charge of the battery bank*

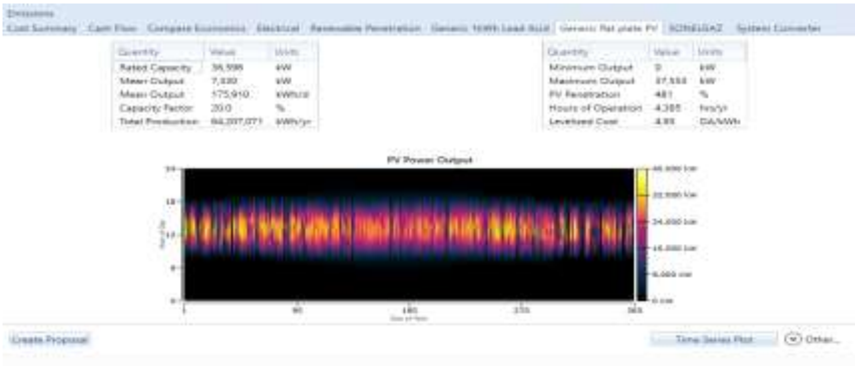


Figure 11. *Average daily power delivered by the PV generators*

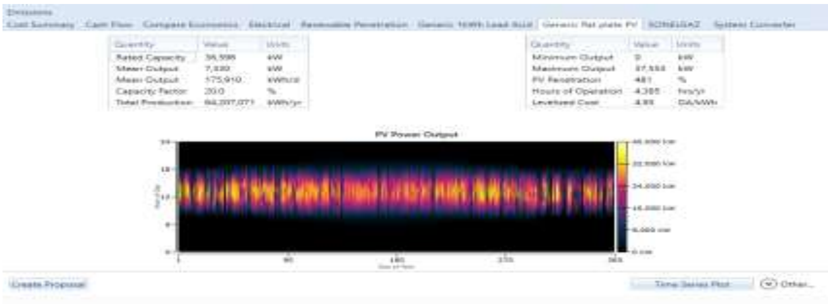


Figure 12. *Grid power interaction indicator (import/export profile)*

Quantity	Value	Units
Carbon Dioxide	445,414	kg/yr
Carbon Monoxide	0	kg/yr
Unburned Hydrocarbons	0	kg/yr
Particulate Matter	0	kg/yr
Sulfur Dioxide	1,931	kg/yr
Nitrogen Oxides	944	kg/yr

Figure 13. *Gaseous emissions from the hybrid PV-grid system*

4. Discussion

The results demonstrate that the proposed hybrid PV-grid system is both technically viable and economically attractive for the port of Ghazaouet. The analytical sizing methodology yielded a 51-module PV array at 96 V with a 217 Ah battery bank which the HOMER Pro simulation confirmed as capable of supplying 98.9% of the facility's annual electricity demand from renewable sources.

The high renewable fraction (98.9%) is consistent with the site's favorable solar resource (5 kWh/m²/day annual average) and compares favorably with similar PV-grid hybrid studies conducted in North African contexts [3 4]. The stable battery SoC profile indicates that the chosen storage capacity is adequate and avoids both deep discharge events (which would shorten battery lifetime) and unnecessary oversizing (which would inflate capital costs).

The charge controller current rating (107 A at 96 V) is consistent with the array output current calculation. The grid interaction analysis reveals an important economic benefit: excess summer PV production is exported to the grid at the feed-in tariff partially offsetting the system's operational costs. This net-billing mechanism is a key financial driver for the economic feasibility of the hybrid system in the Algerian context.

Limitations of this study include the use of typical meteorological year data rather than multi-year measured irradiance records and the absence of a detailed grid tariff sensitivity analysis. Future work should incorporate uncertainty analysis on the solar resource and investigate the effect of battery technology alternatives (e.g. lithium-ion) on the system's lifetime cost.

5. Conclusions

This study presented a systematic sizing methodology and techno-economic optimization of a hybrid photovoltaic-grid system for the port of Ghazaouet Algeria. The analytical sizing stage determined an array of 51 PV modules (Condor CEM200M-72 200 Wp) a 24-unit battery bank (96 V / 217 Ah) a 96 V / 107 A charge controller and a 66 kVA inverter all configured at a 96 V system voltage.

HOMER Pro simulation validated this configuration and confirmed that the optimal system supplies 98.9% of the facility's annual electricity demand (64207 kWh/year) from solar energy with only 1.1% from the grid. The battery state of charge remains stable throughout the year indicating reliable operation without excessive cycling stress.

From an environmental perspective the integration of the PV system leads to a significant reduction in CO_2 and other greenhouse gas emissions compared to a fully grid-powered baseline. These findings confirm that hybrid PV-grid systems are a technically sound economically viable and environmentally sustainable solution for supplying industrial port facilities in Algeria's high-solar-potential regions. The methodology developed is transferable to other industrial sites with similar load and resource characteristics.

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
- **Conflict of interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

- **Acknowledgement:** The authors thank the port authorities of Ghazaouet for providing the electricity consumption data used in this study. No external funding was received for this research.

- **Author contributions:** The authors declare that they have equal right on this paper.

- **Funding information:** The authors declare that there is no funding to be acknowledged.

- **Data availability statement:** The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.
- **Use of AI Tools:** The author(s) declare that no generative AI or AI-assisted technologies were used in the writing process of this manuscript.

Nomenclature.

C_ch – required battery capacity [Ah]	P_array – total PV array power [W]
D – depth of discharge [–]	P_ch – peak power required [Wp]
E_c – daily energy consumption [Wh/day]	P_ond – apparent power (inverter) [VA]
I_controller – charge controller rated current [A]	P_r – reactive power [VAR]
I_r – average daily solar irradiance [kWh/m²/day]	R – cable resistance [Ω]
k – system correction factor [–]	S – cable cross-section [mm²]
N – battery autonomy [day]	U – system operating voltage [V]
N_batp – number of batteries in parallel [–]	V_bat – battery nominal voltage [V]
N_bats – number of batteries in series [–]	V_ch – array operating voltage [V]
N_p – total number of PV modules [–]	N_ps – number of modules in series per string [–]
N_pp – number of PV strings in parallel [–]	

Greek symbols

ΔU – permissible voltage drop [V]
φ – power factor angle [°]
ρ – copper resistivity [Ω·m]

Abbreviations

AGM – Absorbent Glass	NPC – Net Present Cost

Mat	
DoD – Depth of Discharge	NREL – National Renewable Energy Laboratory
HOMER – Hybrid Optimization Model for Electric Renewables	PV – Photovoltaic
SoC – State of Charge	

References

[1] Saleh S. H. Hassan A. The Challenges of Sustainable Energy Transition: A Focus on Renewable Energy Applied Chemical Engineering 7 (2024) 2 p. 2084

[2] Kabeyi M. Olanrewaju O. Sustainable Energy Transition for Renewable and Low Carbon Grid Electricity Generation and Supply Frontiers in Energy Research 9 (2022) 743114

[3] Yin K. et al. Review of Photovoltaic-Battery Energy Storage Systems for Grid-Forming Operation Batteries 10 (2024) 8 p. 288

[4] Adekanmi M. et al. Advancements in Hybrid Energy Storage Systems for Enhancing Renewable Energy-to-Grid Integration Sustainable Energy Research 11 (2024) p. 26

[5] Lambert T. HOMER® Energy Modeling Software Software Database U.S. Department of Energy – National Renewable Energy Laboratory (NREL) 2024

[6] Li S. et al. An Energy Storage System Configuration Strategy of Public Buildings for PV Local Consumption and Three-Phase Unbalance Management Frontiers in Energy Research 12 (2024) 1374122

[7] León Gómez J. et al. A Review of Hybrid Renewable Energy Systems: Architectures Battery Systems and Optimization Techniques Eng 4 (2023) 2 pp. 1446-1467

[8] Bajpai P. Dash V. Hybrid Renewable Energy Systems for Power Generation in Stand-Alone Applications: A Review Renewable and Sustainable Energy Reviews 16 (2012) 5 pp. 2926-2939

[9] Faranda R. et al. The Optimum PV Plant for a Given Solar DC/AC Converter Energy 57 (2013) pp. 601-608

[10] Ghomri A. Kherbouche D. Conceptual Density Functional Theory [DFT] Study of Some Organic Dyes for Their Use as Sensitizers in Molecular Photovoltaics Journal of Fundamental and Applied Sciences 12 (2020) 1s pp. 245-254

[11] Yang Y. Blaabjerg F. Overview of Single-Phase Grid-Connected Photovoltaic Systems Electric Power Systems Research 133 (2016) pp. 107-115

[12] Quansah D. et al. Optimal Tilt Angles and Orientations for Solar Photovoltaic Systems in Northern Europe Solar Energy 191 (2019) pp. 356-370

[13] Reda I. Andreas A. Solar Position Algorithm for Solar Radiation Applications Solar Energy 76 (2004) 5 pp. 577-589

[14] Hansen A. et al. Comparison of Measured and Predicted Solar Irradiance on Tilted Surfaces at Seven U.S. Stations Solar Energy 85 (2011) 4 pp. 718-725