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Article

Optimization of a Photovoltaic Power Plant for Electricity Generation and Contribution to Energy Sustainability in the Comoros

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Abstract

Photovoltaic systems are increasingly recognized for their superior energy efficiency and lower carbon footprint compared to conventional fossil fuel sources. A comprehensive investigation was conducted into the architectural and functional variables that maximize the electrical output and overall energy efficiency of solar photovoltaic devices. The analysis specifically focused on performance degradation associated with the photovoltaic cell derating factor, a variable known to significantly impact system efficiency. To facilitate this analysis, a customized MATLAB code was developed to compute various performance metrics. The findings reveal that the optimal operating temperature for the photovoltaic cell is 200 K, resulting in a peak energy efficiency of 15.7% for the photovoltaic power plant. Additionally, it was discovered that the maximum electrical power output reaches 4.34 MW when the derating factor is optimized at 0.7. These insights underscore the critical role of optimizing both thermal conditions and operational parameters to enhance the performance of photovoltaic systems. This research not only contributes to the understanding of photovoltaic technology but also emphasizes its potential for sustainable electricity generation, particularly in remote areas with limited access to conventional energy sources. By enhancing the design and implementation of photovoltaic systems, the potential for wider adoption and utilization in diverse environments is promoted, ultimately supporting the transition to renewable energy solutions. The results of this study highlight the importance of addressing both architectural and functional aspects in the ongoing development of photovoltaic technologies, which can lead to more efficient and eco-friendly energy production methods.

Keywords

Fossil fuels, Electrical power, Energy efficiency, Derating factor, Photovoltaics

Article History

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1. Introduction

Faced with escalating global energy demand and alarming projections of fossil fuel depletion, as well as unprecedented climate impacts resulting from global air pollution and disruption of the Earth's radiation balance. Current research is focusing on the exploitation of alternative energy sources with a low carbon footprint, referred to as renewable or sustainable energies, with a view to mitigating environmental impacts. Indeed, the exploitation of renewable energy resources is becoming increasingly important, in particular the technology of concentrating solar flux, a primordial energy vector, enabling radiative energy to be efficiently converted into electricity via advanced thermodynamic or photovoltaic systems [1]. Recent decades have seen exponential growth in energy demand for industrial and commercial cooling systems. Investigations into solar-powered refrigeration systems have generated considerable interest, particularly in regions with high solar potential and prolonged exposure to solar radiation, in conjunction with photovoltaic and thermal conversion technologies. Concerning hybrid power power device, Ganjei et al. [2] evaluated the universal output of a microgrid combining photovoltaic, wind and diesel power with battery storage, generating 22 kWh/d for a full weight capacity of 2.5 kW in 2022, thus optimizing energy reliability. Employing HOMER software, an analysis of sensitivity was conducted on critical factors like wind velocity, solar radiation, and surface reflectivity. In a comparable study, Alayi and colleagues [3] introduced a solar power setup for a home in Tehran, Iran, in 2020, aimed at lowering peak energy consumption through a detailed technical and economic evaluation, thereby enhancing the energy system's feasibility. A sensitivity evaluation was conducted to examine how fluctuating load patterns influence the ideal configuration of the energy system. The findings of this research indicate that a 422 kW solar power system connected to the grid, paired with battery storage, is the best option for the location analyzed. Additionally, in 2022, Shaikh and colleagues [4] suggested a net metering (NM) system for developing a hybrid microgrid (solar-wind) linked to the grid. Comparative analysis before and after NM implementation demonstrated that this strategy is viable and effective for meeting diversified energy needs, due to its practical results and ability to satisfy energy requirements appropriately. In 2021, Alayi et al. [5] developed a photovoltaic-wind hybrid system model to assess its ability to generate electricity under different weather conditions. With a view to optimizing the efficiency of photovoltaic systems, in 2022 AlMallahi et al. [6] used a multi-criteria decision-making approach (TOPSIS) to compare different methods of cleaning solar panels in Dubai, considering financial, ecological, and social factors. A sensitivity evaluation was perform confirming that the water-based robot cleaning technique was the most efficient. The work carried out by [7] establishes a meticulously elaborated hybrid architecture, integrating a fractional gray model associated with a radial-based neural network for the prediction of hourly load at the general hospital in Yaoundé, Cameroon. This model extracts robust daily trends from a one-year set of data, while the radial-based network adjusts residuals taking into account cyclic temporal characteristics. The gray hybrid model achieved a mean absolute error rate of 4.32% and a mean square error of 2.92, surpassing the benchmarks established for machine learning through a significant reduction in prediction errors in the experimental setting examined. In 2024, Taghezouit et al. [8] reviewed recent advances in modeling and diagnosing anomalies in photovoltaic systems. Guanghua and his team [9] introduced a comprehensive mathematical framework that reflects the relationships among essential solar panel parameters. In 2022, Om Prakash et al. [10] assessed the accessibility, future opportunities, and capabilities of solar energy in India, concluding that over 50% of electricity demands could be satisfied by solar energy by 2040. These studies demonstrate the importance of optimization and modeling to improve the efficiency of renewable energy systems. In 2022, analyzed a combined solar energy system at ten tourist locations in Iran using HOMER software. The findings revealed that 90 to 99% of the generated energy was sourced from solar panels, with estimated pollutant emissions ranging from 33.9 to 277 kg per year [11]. In 2024, Chouay and his team [12] created a sensor utilizing solar photovoltaic cells to monitor incoming radiation and the operating temperature of the PV system. The outcomes indicated strong performance, with a mean absolute percentage error (MAPE) of 1.64% for temperature and 1.45% for radiation. Jamal et al. [13] investigated the impact of shading on photovoltaic systems utilizing PVsyst software. The findings demonstrated a return on investment (ROI) of 145.2 million euros over 8.2 years, achieving an efficiency rate of 145.2%. Chala et al. [14] assessed how cleaning and cooling influence the performance of solar panels in Muscat, Oman. The findings indicated that manual cleaning every three days achieved peak efficiency and power output of 23.6% and 85.6 W, respectively. [15] have proposed a new adaptive model of inverse fractional order accumulation (AWFRAGM) that systematically reinforces the principle of the new priority of information through a multi-layer synergistic architecture. Validation using NASA's B0005 and B0018 battery datasets demonstrates that the AWFRAGM achieves absolute mean percent errors of 0,53% and 0.61%, which corresponds to a reduction of approximately 40-60% in prediction error compared to advanced gray models and hybrid neural network benchmarks. These studies demonstrate the importance of optimization and maintenance in improving the performance of renewable energy systems.

Previous studies, such as those by Praene et al. [16], have highlighted the specific technological and economic challenges facing the country in developing sustainable energy solutions. However, these studies have not sufficiently explored how technical optimization of photovoltaic installations could improve the efficiency of electricity production. Furthermore, recent initiatives have begun to explore the sociopolitical aspects of the energy transition, but there remains a lack of studies targeting energy optimization and management mechanisms through models adapted to local conditions [17].

This study therefore aims to fill this gap by proposing a systematic approach to optimizing a photovoltaic power plant, taking into account the specific characteristics of the Comoros. Based on theoretical models combined with practical simulations, he will explore how to maximize electricity production while promoting energy sustainability. Through this research, the hope not only to contribute to the existing literature, but also to provide practical recommendations for policymakers and investors in the energy sector.

1.1 Energy Context of the Comoros

The Union of the Comoros, composed of three main islands (Grande Comores, Anjouan and Mohéli), has one of the lowest electricity access rates in sub-Saharan Africa, with coverage estimated at 62% in urban areas and less than 20% in rural areas [18]. The nation depends predominantly on imported fossil fuels, accounting for 42% of its energy consumption and biomass (56%), for its electricity production, which makes it vulnerable to fluctuations in oil prices and exposes its public finances to significant energy subsidies [19]. The electrical infrastructure is aging, thermal power plants obsolete, and frequent power outages. The low reliability of the network hinders socio-economic development, particularly in the health, education and industry sectors [20]. Reforms have been undertaken since 2018, notably with the creation of National Electricity Company of Comoros (SONELEC) which replaces Comorian Water and Electricity Company (MaMWE), which produces and distributes electricity in an integrated manner, but with very large technical losses and a failure to meet demand, particularly on the Ngazidja Islands, Ndzouani and Moheli. To meet these challenges, the Comorian government relies on its technical and financial partners to develop renewable energy development projects, including the construction of photovoltaic power plants and storage batteries, allowing to better guarantee the reliability of the electrical system, diversify the energy mix and reduce dependence on fossils.

1.2 Potential of Renewable Energies in the Archipelago

The Comoros possesses substantial solar potential, featuring an average annual irradiance ranging from 5.0 to 5.5 kWh/m²/day [21]. Despite favourable conditions, this resource remains underutilized. Renewable alternatives, such as hydroelectricity, are constrained by geomorphology and volcanic topography [22]. Photovoltaic development appears as a relevant opportunity to valorize local energy resources.

1.3 Objectives of This Study

The archipelago of Comoros is facing major energy challenges, including a dependence on imported fossil fuels and irregular electricity production, leading to frequent blackouts and energy insecurity. Faced with these constraints, the exploitation of solar energy appears as a credible solution, given the abundance of the resource on the territory. The development of photovoltaic power plants could improve the security of electricity supply, stabilize distribution and reduce maintenance costs. This project is part of a transition strategy towards a more reliable, sustainable energy system adapted to the specific needs of Comoros, aiming at reducing energy vulnerability and promoting a more sustainable development.

2. Material and Methods

2.1 Technical Study of the Photovoltaic Project

The system studied is an autonomous photovoltaic power plant and represented by Figure 1. The solar panels used in this system facilitate the transformation of solar energy into steady electrical power. The inverter serves as a device that changes direct electrical energy into alternating electrical energy. The regulator controls and adjusts the voltage to maintain a desired value or range of acceptable values. While the battery allows to store electrical energy.

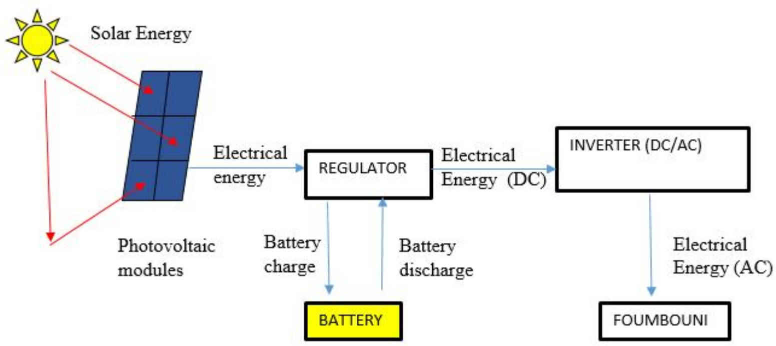

Figure 1. More detailed photovoltaic system.

2.1.1 System Sizing

(1) The Power of the Photovoltaic Field

The simplified calculation of the power of the PV field takes into account the overall horizontal insolation of the site, the efficiency of the installation that is to say the result of the effectiveness of the PV field, the performance of the batteries, that of the inverter and also of the regulator if the latter does not also ensure this function. The power of the photovoltaic system is given by Equation (1) [23,24]. The energy efficiency of a photovoltaic system refers to the ability of this system to convert sunlight into electricity and is given by Equation (2) [25]. The annual energy production E (in kWh) of a photovoltaic system refers to the total amount of electricity generated by this system over a period of one year can be estimated according to Equation (3) [26,27] and PR is the Performance Ratio (generally between 0.75 and 0.85) [28]. The number of modules in series and in parallel are symbolized by Equations (4) and (5) respectively:

$$P_C = \frac{CJT}{\eta \cdot E_j} \quad (1)$$

$$\eta = \eta_{Bat} \cdot \eta_{inv} \cdot \eta_{PV} \quad (2)$$

$$E = P_C \cdot H_{solar} \cdot PR \quad (3)$$

$$N_S = \frac{U_C}{U_{\text{mod}}} \quad (4)$$

$$N_P = \frac{U_C}{N_S \cdot P_{Inv}} \quad (5)$$

(2) Batteries and Storage Systems

For stand-alone installations, the batteries ensure power supply outside periods of sunshine. The sizing depends on the daily consumption (in Wh), the desired autonomy (days without sun), the allowed discharge depth, the system efficiency. The capacity in ampere-hours (Ah) is the total amount of energy it can store and deliver and is given by the Equation (6) [29]:

$$C_{Ah} = \frac{E_{daily} \cdot J}{V \cdot DoD \cdot \eta} \quad (6)$$

(3) Sizing of the Cables

The essential condition is that the voltage drop in the cables must not exceed 3%. The percentage voltage drop is obtained by calculating the percentage of the voltage at the terminals of the cable in question. It is given by the Equation (7) [30]:

$$S = \frac{\rho \cdot L \cdot P_{\max}}{\varepsilon \cdot U^2} \quad (7)$$

With: Imax the maximum operating current of the circuit, L the length of the cable (m), P the power (W), U the nominal voltage (V). The charts also allow to graphically determine the section of the cable to be used for our study.

(4) Criteria Required for the Regulator

Regulator power > Installed field power; Regulator voltage = generator voltage (field); Allowable input > Imax of module; Regulator output current > Max power / generator voltage.

2.1.2 System Performance

(1) PV System Output Power

The power output of the solar system in relation to the derating factor is expressed by Equation (8) [31,32]:

$$P_{PV}(t) = f_v \times P_{pv-rated} \times \left(\frac{I(t)}{I_{ref}} \right) \times \left[1 + K_T \left(T_{cel}(t) - T_{ref} \right) \right] \quad (8)$$

Where f_v (in %) is the depreciation factor that adjusts the rated power to reflect actual operating losses. This factor takes into account losses from wiring, soiling, shading, etc. Its value, generally between 0.6 and 0.9 [33], allows estimating the actual energy production of photovoltaic systems taking into account real operating conditions. $P_{pv\text{-}rated}$ is the nominal power at reference conditions, I (in W/m^2) is solar radiation, I_{ref} is solar radiation at reference conditions (I_{ref} = 1000 W/m^2).

T_{cel} is the temperature of the cell under the reference conditions (T_{ref} = 25°C), K_T is the temperature coefficient of maximum power K_T = -0.4%/°C) and T_{cel} is the temperature of the cell which is determined by Equation (2) [26,34].

$$T_{cel}(t) = T_{ref} + \left(\frac{NOCT - 20}{800} \right) I(t) \quad (9)$$

(2) PV System Efficiency

The yield of the PV system is given by Equation (3) [35]:

$$\eta_{PV}(t) = \frac{P_{PV}(t)}{I(t) \cdot A_{pv}} = \eta_{ref}\left[1 - \beta_{ref}\left(T_{cel}(t) - T_{ref}\right)\right] \quad (10)$$

2.2 Study Area

Located on the island of Grande Comores, Foumbouni is a city that is part of the Comoros archipelago, in the Indian Ocean. More precisely on the west side, 30 km south of Moroni, the capital of the Comoros. The city enjoys a tropical maritime climate, with high temperatures throughout the year. On any scale, the average value of the normal global component per available hour varies from 8 to 8.7 kWh/m^2 for the unpleasant month; from 14.8 to 14.9 kWh/m^2 for the pleasant month and according to an investigation conducted on the prediction of the global component of solar radiation [36,37]. Figure 2 illustrates the map of the city of Foumbouni obtained from the geographical coordinates that were introduced in the PVGis software.

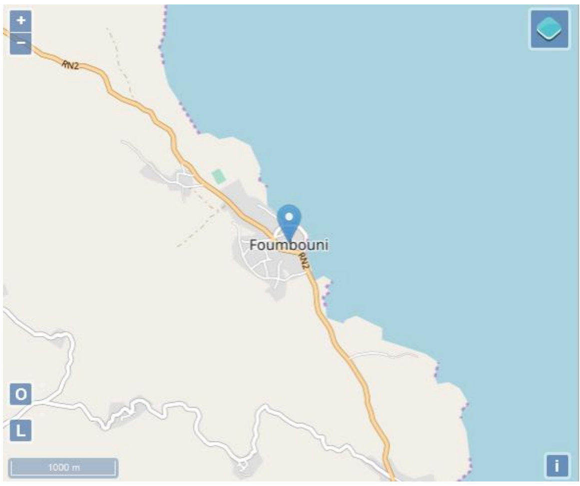

Figure 2. Map of Foumbouni.

2.3 Power Balance

(1) Calculation of Electrical Needs

The inventory above made it possible to draw up a power and energy balance represented by Table 1. The nominal power is 4.345 MW, the maximum starting power: 4.705 MW; the daily consumption averages: 25 MWh/day and the inverter's capacity is greater than or equal to the power output of the loads.

Table 1. Power balance.

Designations of Receptors	Unity Power (MW)	Number	Total Power (MW)	Overall Daily Consumption (MWh)
Foumbouni	4.345	1	4.345	25

(2) Evaluation of the Solar Deposit

The solar field depends on the location of the photovoltaic module installation site, but also on their orientations. Table 2 characterizes the geographical coordinates of the study site. Monthly irradiation is represented by Table 3.

Table 2. The location's geographic information.

Position Studied	Latitude (°)	Longitude (°)	Altitude (m)	Climate	Albédo	Inclination On the Horizontal	Orientation
Foumbouni	11.87°S	43.495°E	1000	mousson	0.2	15°	Geographical North (azimut = 0°)

Table 3. Irradiation depending on the month.

Month	JAN	FEV	MAR	AVR	MAI	JUI	JUI	AOUT	SEPT	OCT	NOV	DEC
Irradiation (W/m^2)	269.69	250.23	378.73	382.55	459.66	428.87	411.27	461.28	407.91	402.53	415.65	372.02

After indicating the location (Foumbouni) as well as the inclination (15°) and azimuth orientation 0 in PVgis. Thus the values of solar irradiation in the form of a monthly table are obtained. The characteristics of the photovoltaic studied are visualized in Table 4.

Table 4. Technical specifications.

PV System	Virtus II Monocristallin [33]
η_{ref} (%)	16.5
k_t (%/°C)	0.04
P_T (W)	260
T_pv	45 °C
Imx	8.55 A
Umx	30.4 V
CT	156 mm × 156 mm
t_{PV}	20 years

2.4 Objective Functions, Optimization Parameters and Limitations

Earlier research typically focuses on optimizing specific energy efficiencies. Thus, in this study, each objective function is either maximized. It should be noted that these priorities are based on the needs sought by the designer. The objective functions are given by Equations (9) and (10).

Three optimization factors related to the geometric design and functioning of the PV were chosen to enhance the solar photovoltaic system. They are outlined as Equations (11)-(13).

$$100W.m^{-2} \le I \le 1500W.m^{-2} \quad (11)$$

$$293K \le T_{cel} \le 353K \quad (12)$$

$$0.7 \le f_v \le 0.9 \quad (13)$$

The objective functions are formulated by Equations (8) and (10).

To identify the ideal parameters of the system, a simulation program was created using MATLAB software and implemented with a genetic algorithm method. The algorithm will maximize the electrical power and energy yield of the photovoltaic system.

2.5 Genetic Algorithm Configuration

The genetic algorithm used to optimize photovoltaic systems consists of an initial population of 50 to 100 solutions, each representing architectural and functional configurations. Solutions are evaluated on the basis of electrical power output and energy efficiency. A selection mechanism, such as tournament selection, chooses the best individuals who will reproduce by crossover and mutation to create a new generation. Key parameters include population size, crossover rate (0.6 to 0.9) and mutation rate (0.01 to 0.05). This iterative process aims to maximize energy production and efficiency, while taking into account critical factors such as temperature and degradation factor.

2.6 Numerical Resolution Procedure and Computational Details

After developing the mathematical model, the various components were combined, and the solution was derived through numerical analysis, utilizing MATLAB's computational power. After the development of the mathematical model, the resolution was numerical to obtain the results, thanks to the digital programming technique in MATLAB. The mathematical model of the PV is introduced. The entire process undertaken by the different operations performed is described in Figure 3.

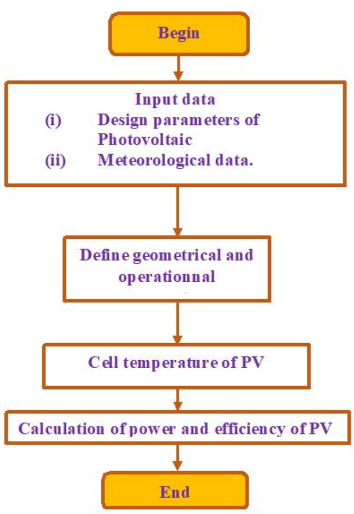

Figure 3. Flowchart of the algorithm for addressing the mathematical model.

To guarantee that simulations can be replicated, it's crucial to include specifics about the hardware setup and details regarding the software used.

(1) Hardware Specifications

CPU: Intel Core i7 or similar, with a minimum speed of 3.0 GHz.

Memory: 16 GB or greater to manage intensive computing tasks.

Storage: 512GB solid-state drive (SSD) for fast retrieval of files and simulation outcomes.

Operating system: Windows 10 or Linux (Ubuntu 20.04 or newer) for best compatibility with MATLAB.

(2) Simulation Execution Time

The execution duration fluctuates based on the selected parameters. The time intervals range from 0.1 to 25, resulting in a total execution time varying from 1 hour and 30 minutes to 30 minutes for the entire program run.

3. Validation

In this section, the comparison of the results of this study with those of the literature is established.

In 2025, Abdelmalek et al. [38] experimentally investigated a new hybrid grey wolf equilibrium optimization method for maximum power point tracking (MPPT) to improve the efficiency of a solar photovoltaic system using the Grey Wolf Equilibrium Optimizer (GWEO) algorithm, which integrates a Grey Wolf Optimizer (GWO) and Equilibrium Optimizer (EO) search mechanism. The results show that the electrical power is 289.9 W, whereas in this work it is 3.7 MW for a derating factor of 0.9.

4. Results and Discussion

4.1 Impact of Annual Duration on Solar Irradiance

In Figure 4, the visualize the monthly average solar irradiance for a typical photovoltaic system in the city of Foumbouni. It can be observed that solar irradiation varies with the month. Therefore, the maximum solar irradiation is represented by the month of August with a value of 15.38 Wh/m^2/day which is the hottest month, whereas the irradiation of the coldest month (February) is 8.34 Wh/m^2/day. It can be concluded that the month of August is ideal for optimal electricity production in the city of Foumbouni.

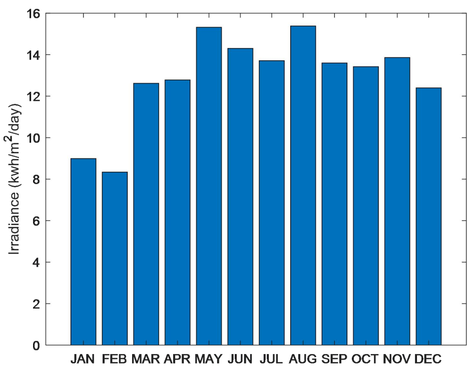

Figure 4. Monthly impact on global solar irradiance.

4.2 Effect of Daily Duration on Energy Efficiency and Electrical Power Produced

In Figure 5, the increase in sunshine time from approximately 8 hours to 12 hours 10 minutes results in a swift increase in the electrical output of the solar system to approximately 50 W, then stabilizes around 5.10 MW before dropping to 0.8 MW. This upward phase of the electric power at its maximum value of 5.10 MW is explained by the gradual rise in solar irradiation due to the more favorable angle of incidence of solar radiation on the panels photovoltaics as the sun rises in the sky. In general, this period corresponds to the rise in global radiation, which mechanically translates into an increase in electricity production. Then, the power stabilizes around 5.10 MW, reflecting a performance level. This can be interpreted as a period when the level of irradiation remains optimal, but the system reaches its maximum operating point or approaches its saturation limits under normal operating conditions (temperature, maximum power point, etc.). The last phase is marked by a drop in power up to 0.8 MW, probably related to the decrease in sunshine (clouds, late afternoon, or temporary shading), which demonstrates the strong dependence of the PV system on the intensity of solar irradiation. In contrast to the solar system's output, which experiences a slight decline from 16.5% to 16.64%, it then reaches a low of 16.1% before rising sharply back to 16.5%.

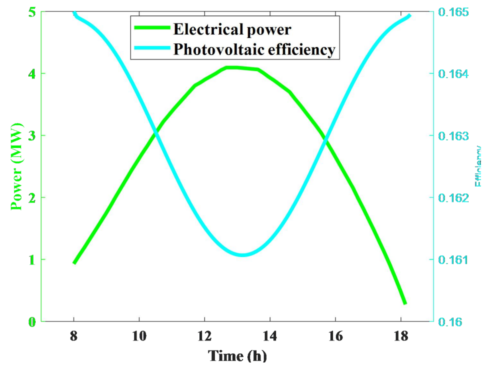

Figure 5. Effect of the sunlight duration on the performance of the photovoltaic system.

4.3 Effect of Solar Irradiance on Energy Efficiency and the Electrical Power Produced by the Foumbouni Photovoltaic Plant

In Figure 6, the fluctuation of solar irradiation from 100 to 500 W/m^2 leads to an increase in the solar system's electrical production from 0.8 MW to 4.1 MW at high speed. Thus, for an optimization of the electrical power of the photovoltaic system installed in the city of Foumbouni, a strong solar irradiation would be necessary. By taking into account the local environment and adopting appropriate technologies, Foumbouni can optimize its solar installations to efficiently meet its energy needs, thus enhancing the viability and sustainability of its renewable energy supply.

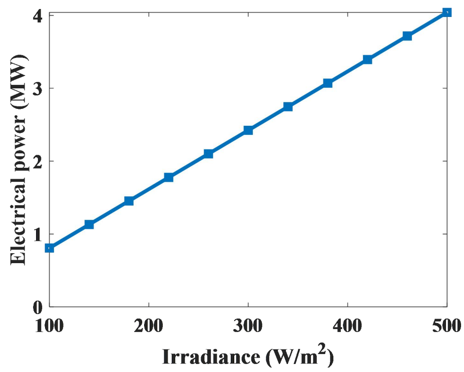

Figure 6. Impact of annual solar irradiance on electrical power.

In Figure 7, the increase in the efficiency of the high-speed photovoltaic power plant from 5% to 6.5%, is observed when the solar irradiance increases from 100 W/m^2 to 350 W/m^2, then at low speed until reaching its maximum value of 13.2%, corresponding to a solar irradiance of 500 W/m^2. In summary, the increase in the yield of the photovoltaic power plant based on solar irradiance clearly illustrates the dynamics between the availability of sunlight and the conversion efficiency of photovoltaic systems. The results pave the way for further research to optimize technologies, manage thermal impacts, and guide system design to maximize yields under various irradiance conditions.

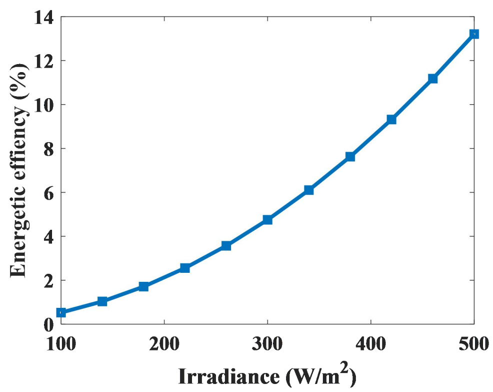

Figure 7. Impact of annual solar irradiance regarding the energy effectiveness of the product deviced.

4.4 Effect of the Derating Factor on the Electrical Power and Energy Efficiency Produced by the Foumbouni Photovoltaic Plant

Figure 8 shows the effects of the derating factor on the electrical power of the photovoltaic system. It is observed that as the derating factor rises from 0.7 to 0.9, the electric power drops at a high speed of 4.307 MW to approximately 3.7

MW, then at a low speed up to 3.35 MW. Therefore, to improve the electrical output of the solar power system, a low value of the derating factor would be necessary. The gradual drop in power with the increase in the derating factor highlights the paramount importance of reducing systemic losses in photovoltaic installations. In Foumbouni, where climatic conditions can exacerbate certain losses (heat, humidity, dust), the optimization of this factor is an essential lever to enhance the system's energy effectiveness. Thus, minimizing the derating factor must be a priority in the design, operation and maintenance of PV power plants.

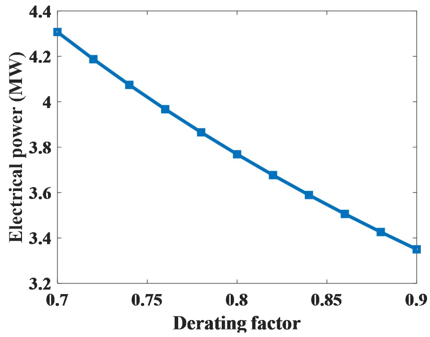

Figure 8. Impact of the derating factor on the electrical power produced photovoltaic system.

Figure 9 clearly shows that the energy performance of the solar power system decreases sharply as the derating factor increases. More precisely, when this factor changes from 0.7 to 0.9, the efficiency drops rapidly from 10.17% to 8.68%, then decreases more slowly until reaching a minimum value of 7.9%. This behavior confirms the negative effect of the derating factor on the overall effectiveness of the solar power system set up in Foumbouni. The energy efficiency of a PV system denotes the capacity to transform incoming solar energy into usable electrical power. It depends not only on the technology of solar panels, but also on all the accumulated losses in the system. The derating factor, precisely, groups together these losses: thermal losses, reflection losses, fouling, module aging, inverter inefficiencies, shading effects, etc. Thus, the strongly negative relationship between the derating factor and energy efficiency highlights a critical point in the design and operation of photovoltaic systems. In Foumbouni, where the solar potential is high, minimizing the derating factor becomes a technical and economic imperative to ensure a good level of performance and profitability. Thus, rigorous loss management at all levels of the system is an essential strategy to optimize energy efficiency.

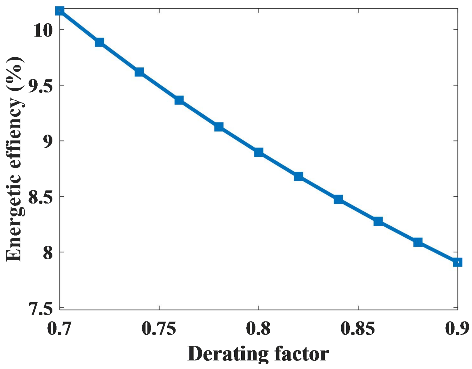

Figure 9. Impact of the derating factor regarding the energy performance of the solar power system.

To maintain a low derating factor (around 0.1) of photovoltaic systems in a tropical environment subject to dust and humidity, several strategies can be implemented. It's essential to organize regular panel cleaning, use non-stick coatings, and design the system with adequate elevation and optimum angle. Choosing moisture-resistant materials and installing sensors for real-time monitoring are also crucial. Finally, integrating active ventilation systems can help reduce overheating and maintain optimum performance.

4.5 Impact of the Temperature of the Photovoltaic Cell on Energy Efficiency and the Electrical Power Produced by the Foumbouni Photovoltaic Plant

Figure 10 highlights the direct influence of the temperature of the photovoltaic cell on the energy performance of the deviced power plant that will be installed in Foumbouni. The data show that an increase in the temperature of the module from 200 K to 600 K leads to a gradual decrease in energy efficiency, from 15.19% to 14.8%. This trend confirms a well-known phenomenon in photovoltaics: temperature has a negative effect on the efficiency of solar cells. In this context, the yield drop from 15.19% to 14.8% remains moderate but significant, especially in a tropical or equatorial climate like that of Foumbouni (Comoros), where ambient temperatures can often exceed 30-35 °C (about 303-308 K). Thus, the gradual decrease in efficiency observed with the increase in the temperature of the photovoltaic cell highlights the importance of effective thermal management for solar installations, particularly in tropical areas like

Foumbouni. To guarantee optimal energy performance, it is therefore crucial to keep the temperature of the cells as low as possible thanks to a technological choice and an adapted thermal design.

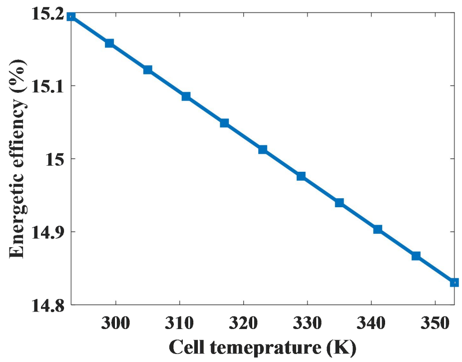

Figure 10. Impact of the photovoltaic cell temperature on energy efficiency.

Figure 11 clearly illustrates the impact of the temperature of the photovoltaic cell on the electrical power produced by the photovoltaic plant intended to be installed in the city of Foumbouni. The results show that as the temperature of the module varies from 350 K to 393 K, the electrical power decreases from 3.49 MW to 3.41 MW, a loss of 0.08 MW. This decrease, although moderate in absolute value, is significant in proportion and highlights the sensitivity of the PV system to temperature. In a hot climate context like that of Foumbouni, where ambient temperatures are naturally high, it becomes essential to minimize the operating temperature of photovoltaic cells in order to preserve a high level of electrical power. The drop in the electrical power produced, from 3.49 MW to 3.41 MW between 353 K and 393 K, highlights that the temperature of the cell is a major limiting factor for the performance of photovoltaic power plants. To ensure optimal electrical production in Foumbouni, it is imperative to keep the temperature of the cells as low as possible, through a relevant technological choice and appropriate thermal engineering.

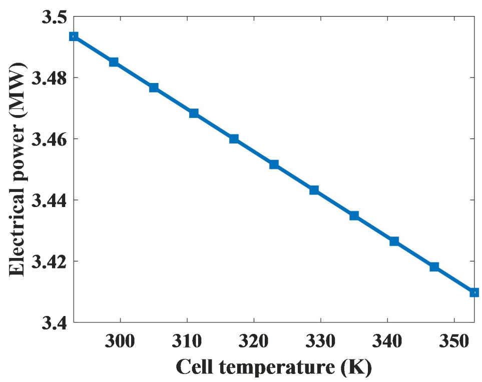

Figure 11. Impact of the photovoltaic cell temperature on energy efficiency.

The reduced performance of high-irradiance photovoltaic systems can be attributed to overheating, which reduces conversion efficiency, and to simplified modeling assumptions. These factors, combined with cell-cell interaction effects, may explain the counter-intuitive behavior observed under these conditions.

5. Conclusion

This study made it possible to present in detail the technical design of the photovoltaic system envisaged for the city of Foumbouni. The analysis focused on the optimization of design and operational parameters of a photovoltaic power plant. The sizing of the photovoltaic field, storage equipment, regulators and cables was carried out taking into account technical standards, local energy needs and climate data from PVgis. The simulations showed that the system's effectiveness is significantly affected by factors such as irradiance, cell temperature and the derating factor. These variables have a direct effect the electrical power produced and energy efficiency. It is clear that to ensure optimal performance in a tropical climate such as Foumbouni, it is essential to optimize the system thermally, minimize losses and adapt technological choices to local environmental conditions. Thus, this technical design constitutes the necessary basis for the success of the photovoltaic project, ensuring both reliable, sustainable and economically viable energy production for the community of Foumbouni.

6. Recommendations for Implementation

For a successful implementation, the recommend: (1) Start with a pilot project in a strategic area (e.g. administrative or school site). (2) Ensure continuous technical support during the first two years of operation. (3) Strengthen local capacities through a partnership with training institutions and non-governmental organization (ONG). (4) Set up a monitoring/evaluation system in real time, via a digital platform open to donors and partner institutions. (5) Mobilization of financial resources (calls for tenders, search for donors). (6) Drafting of the technical specifications. (7) Consultation with local and regional authorities. (8) Start of construction work and pilot installation.

Abbreviations

Ah: Ampere-Hours

C_o_m: Annual Operation & Maintenance Cost

CT: Cell Type

DoD: Depth of Discharge

Ej: Sunshine (irradiation) on the Module Plane, kWh/m² /d.

Hsolar: Number of Equivalent Hours of Sunshine Per Year (e.g. 1800 to 2200 h/year in the Comoros)

Imx: Maximum Power Current

J: Number of Days of Autonomy, h

Pcc: Installed Power, kWp

Pc: PV Field Power, kW

Pmod: Module Power

T_pv: PV Nominal Temperature

tPV: PV System Lifetime

Uc: load Terminal Voltage, V

Umod: Module Terminal Voltage, V

Umx: Maximum Power Voltage

V: Nominal Voltage

η: Overall Efficiency, %

Conflict of Interest

The authors declare they have no conflicts of interest.

Data Availability Statement

The data supporting the findings of this study are available upon reasonable request from the corresponding author. The authors confirm that there is no copyright issue of this manuscript.

Generative AI Statement

The authors declare that no Generative AI was used in the creation of this manuscript.

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