ENVIRONMENTAL SCIENCES & PRACTICES
http://mlsjournals.com/Environmental-Science-Practices

*(2025) Environmental Sciences & Practices,3(* 1), 75-96

# Project for a photovoltaic Solar Power plant for Public Lighting in the Centrality of Praia Amélia in Moçâmedes, Angola

## Projecto de uma central de energia solar fotovoltaica para iluminação pública, na centralidade da Praia Amélia em Moçâmedes, Angola

**Abel Utalica**
Universidad Europea del Atlántico (utalicaabelbel@gmail.com) (https://orcid.org/0009-0003-1814-5240)

**Información del manuscrito:**

**Recibido/Received:**24/07/25
**Revisado/Reviewed:** 27/07/25
**Aceptado/Accepted:** 10/10/25

**Keywords:**
Renewable energies; Solar photovoltaic energy; Photovoltaic system sizing; Public lighting; Angola

**ABSTRACT**

This research presents, in the introduction, a general objective, which is to develop a photovoltaic power plant for public lighting in the Praia Amélia housing project, and specific objectives, which consist of describing and sizing the components of the plant. The methodology is based on a mixed model (qualitative-quantitative). Through bibliographic research, interviews, and direct measurements, theoretical foundations, as well as electrical and technical data of the housing project, were obtained. Thus, using latitude and longitude, monthly direct and global irradiation values and average temperatures were obtained through PVGIS. The results show that Moçâmedes presents suitable conditions for photovoltaic objectives. From the system sizing, with modules tilted at 15°, the critical month yielded a monthly global irradiation of 179 kWh/m$^2$ and a daily value of 5.78 kWh/m$^2$. With a demand of 116,250 W, the system uses 664 modules of 400 W, 3 controllers of 200 W, 48 batteries, and an inverter of 145,313 W. The system does not account for losses due to shading or dust but does consider 1.56% losses due to temperature and 7,309 W losses in cabling. Therefore, the system demonstrates economic feasibility by presenting a positive Net Present Value (NPV), with payback expected within 11 years. In the discussion, compared to similar photovoltaic projects in Cape Verde and Mozambique, this project proves to be more ambitious and to have greater socioeconomic and environmental impact, due to its higher load and its potential to reduce power demand on the local 63 MW thermal plants by 0.44%. This contributes positively to the reduction of greenhouse gas emissions (GHG). Thus, the plant shows technical value by accounting for total losses of 11,339 W (equivalent to 28 modules) in a system with a surplus margin of 61 modules.

**Palabras clave:**
Energias renováveis; Energia solar fotovoltaica; Dimensionamento de sistemas fotovoltaicos; Iluminação pública; Angola.

**RESUMEN**

Esta investigação apresenta, na introdução, objetivo geral, que consiste em desenvolver uma central fotovoltaica para iluminação pública, na centralidade da Praia Amélia, e específicos, que consistem em descrever e dimensionar componentes da central. A metodologia baseia-se no modelo misto(quali-quantitativo). Por meio da pesquisa bibliográfica, entrevista e medição direta, obtiveram-se fundamentos teóricos, dados elétricos e técnicos da centralidade. Assim, com a latitude e longitude, através do PVGIS, obtiveram-se irradiações mensais direta, globais e temperaturas médias. Dos resultados, Moçâmedes apresenta condições adequadas para objetivos fotovoltaicos. Do dimensionamento e com módulos inclinados à $15^0$, obteve-se no mês crítico, radiação global mensal de 179 $KWh/m^2$ e diária de 5,78$KWh/m^2$. Com demanda de 116250W, o sistema utiliza 664 módulos de 400W, 3 controladores de 200W, 48 baterias e inversor de 145313W. Assim, o sistema não prevê perdas por sombreamento e poeira, porém apresenta perdas de 1,56% devido à temperatura e 7309W no cabeamento. Dessa forma, o sistema demonstra viabilidade econômica ao apresentar um Valor Presente Líquido (VPL) positivo, com amortização prevista para ocorrer em 11 anos. Da discussão, em relação a projetos fotovoltaicos similares de Cabo Verde e Moçambique, este projeto demonstra-se mais ambicioso e com maior impacto socioeconômico e ambiental, por possuir carga maior e, no seu dimensionamento, reduzir a potência nas centrais térmicas de 63MW locais, em 0,44%. Este dado impacta positivamente a redução de emissões de GEE. Portanto, a central apresenta valor técnico, ao acautelar as perdas totais de 11339W (28 módulos), em um sistema com margem superior de 61 módulos.

## Introduction

Renewable energies have been around since ancient times. The search for better living conditions and the discovery of new forms of better accommodation have changed the perspective of man's vision, putting clean sources at the bottom of the list to the detriment of emitters. This has led to important changes in nature and impacts that have led governments to redirect their energy sources towards renewable sources (Pinho & Galdinho, 2014).

In fact, this rethinking is due to changes in the levels of greenhouse gas emissions, which, according to the IPCC (2007, cited by Uczai & Tavares, 2012), increased by 70% between 1970 and 2004. Although this increase is not simply the result of fossil fuels, it is considered the main driver. In this context, any prospect of change must be based on policies to promote research, development and implementation of renewable sources.

Angola's energy approach is making substantial progress in adopting the concept of decarbonization in the energy field. According to Losekann and Botelho (2019), the transition to a low-carbon economy is a notion that is best suited to directing energy policies, with the aim of ensuring environmental stability and mitigating climate change. As proof of this, from 2016 to 2021, Angola increased its energy production from renewable energies by around 14% and supplies 61% of the country's entire energy load (IRENA, 2024).

Public lighting is an essential factor for people's well-being. In this way, providing a central station from a clean source can solve various problems that the centrality has faced, such as public insecurity, crime and/or vandalism, inadequate visibility on the streets and impeded access to leisure venues at night (Leite & Alves, 2023, p. 8228-8236). Thus, with the intention of satisfying the community's socio-economic and environmental needs, this project is necessary.

The photovoltaic plant project has a positive impact on the technical and theoretical development of photovoltaic energy, since it is one of the most widely used energies. In this context, a power station is an innovation, as it has various practical, technical, socio-economic and environmental applications, as well as contributing to the applicability of the energy transition that is needed today (Grijó, 2014, p.28-28)

These applications as a whole aim to generate employment, reduce polluting emissions, diversify Angola's energy matrix and, above all, encourage investment in this source, since the municipality of Moçâmedes has high solar potential (ALER, 2022). However, with this project, not only would the problem relate to seasonal night-time lighting be solved, but it would also provide a theoretical apparatus with a basis for more scientific reflections and with a scientific methodology.

The solution to the problem of street lighting through corrective maintenance has not been effective, since Tsshara (2024) points out that the lack of energy brings with it various problems, such as, on the one hand, the bureaucratic issues involved in resolving the problem and, on the other, the embarrassment of a partial power cut during the maintenance period, which has been in hours of productivity.

This research is justified by the need to contribute to the applicability of energy actions for environmental protection, aimed at in the international agreements that Angola has ratified. In fact, this article makes it possible to use photovoltaic energy for public lighting.

It is therefore a practical application project, analyzing and describing the current literature on photovoltaic energy, based on achieving the general objective of developing a photovoltaic solar power plant for public lighting and the specific objectives of describing the main components of photovoltaic power plants and sizing them.

Therefore, the following concepts are presented in abbreviated form throughout the approach:

- IESS- Ideal Solar Studies and Solutions
- IRENA- International Renewable Energy Agency
- IRSEA- Regulatory Institute for Electricity and Water Services
- PRODEL- Public Electricity Production Company
- ALER- Lusophone Renewable Energy Association
- PVGIS- Photovoltaic Geographical Information System

***Theoretical Background on Photovoltaic Solar Energy***

**(i) Photovoltaic Solar Energy and Its Caracterization in Angola**

Solar energy is a renewable energy that comes from the light and heat of the sun. Solar modules are used to harness this energy, which, when positioned towards the sun, produces inexhaustible energy (Soares & Santos, 2020). Photovoltaic systems can be isolated (offgrid) or connected to the grid (ongrid).

Angola has an estimated solar potential of 55GW, very close to South Africa and California (ALER, 2022, p. 134). Of this potential, more than 405GWh (2%) will be supplied to the electricity grid from 2022, approximately 10% more than renewable energies. However, the country aims to reach 1GW by 2027 in its 2017 Action Plan (IRENA, 2024).

**(ii) Incidence of Solar Radiation on the Earth and Radiation Incident on the Modules**

The radiation that the sun emits from its corona, coming from its temperature, is enormous. This flux, when measured near the Earth's atmosphere, is 1367W/m$^2$, which is the solar constant. This value, in relation to the radius of the earth, can provide a total power of 174,000 TW. Of this amount, around 46% is absorbed or reflected by the atmosphere, and of the remaining 54%, 7% is reflected and 47% is absorbed, giving a total power on the earth's surface of 94,000 TW. Solar radiation can be Radiation due to albedo, Global Radiation and Total Radiation. (Pinho & Galdinho, 2014). Pereira (2022) sees it as Direct Radiation, Diffuse Radiation and Reflected Radiation.

Due to the various power losses of the flow in the earth's atmosphere, resulting from difficulties, albedo radiation, diffuse radiation, direct radiation and atmospheric conditions, the incident radiation on the earth's surface is 1000W/m$^2$. This radiation becomes the standard value used in the sizing of photovoltaic systems (Ovelha, 2017).

**(iii) Main Components of a Photovoltaic Plant**

The use of photovoltaic solar energy is growing. Therefore, projects are defined according to the size and characteristics of the photovoltaic plant, which, according to Madeira (2022, p. 44), “are large-scale energy production systems made up of components such as modules, inverters, batteries, controllers, voltage transformers, cables and protection and control devices and control devices.

- **Photovoltaic module:** is a component made up of a set of interconnected solar cells responsible for converting solar energy into electricity... (Mariano & Urbanetz, 2022).

Therefore, to achieve high loads, the cells in the modules must be connected in series to increase the voltage and in parallel to increase the current. Photovoltaic modules are guaranteed for 25 years or more, making them resistant to adverse weather conditions (Wood, 2022).

Photovoltaic modules produce direct current (DC) electricity. Thus, depending on the technology used and the arrangement of the cells, the photovoltaic module has specific electrical and thermal parameters and characteristics (Granja, 2017). These parameters and characteristics can be presented as the short-circuit (Isc) and maximum power (Imp) currents, the open-circuit (Voc) and maximum power (Vmp) voltages and the maximum power point (MPP), (IESS, 2019).

Photovoltaic module technologies can be characterized, according to Granja (2017); (Mariano & Urbanetz, 2022) and Azambuja (2022) as: Monocrystalline Silicon cell technology, with efficiencies of 14%, 17%, 20% or more; Polycrystalline Silicon cell technology, with efficiencies of 13 and 15%; Thin film cells, with 6 to 11% and Multijunction a-Si/$\mu$c-Si cells, with 8, 9% or 35% when composed of other elements.

In this context, when choosing a technology, Mariano and Urbanetz (2022) emphasize that project-dependent characteristics and factors must be taken into account. These include efficiency, architectural aspects and the area available.

- **Photovoltaic inverters:** these are devices made up of current control, islanding detection, synchronization and MPPT (Maximum Power Point Tracking) systems. These devices convert the direct current produced by the modules into alternating current, ... (Azambuja, 2022).

Inverters, according to Nogueira (2023, cited by Barreto, 2024), can be central inverters (row) and modular inverters (microinverters). According to Granja (2017), its parameters are efficiency, nominal power and maximum power in direct current (DC), nominal power and maximum power in alternating current (AC), power factor, power on and off, stand-by power and night mode, nominal voltage DC and AC, MPP voltage range (Maximum Power Point), maximum DC voltage, switch-off voltage, nominal and maximum current (DC), harmonic distortion rate, noise level and temperature range.

- **Photovoltaic batteries:** the production of energy in photovoltaic systems is not continuous, so there is a need to store energy in batteries, since the modules only produce energy during the day. This function is of great importance in photovoltaic systems. Its parameters are battery capacity, maximum charge and discharge current, charge and discharge voltage, depth of discharge and useful life (Pinho & Galdinho, 2014, p.163-175).

For certain voltage or current requirements, batteries are connected in series and/or parallel. The batteries to be used must, according to Fadiga (2004), meet shallow cycles every day and deep cycles for several days or weeks, have a high cyclic life for deep discharges; low maintenance; high charging efficiency; the ability to remain discharged; low self-discharge; minimal change in performance when working outside the operating temperature; availability from suppliers and considerable cost and energy density.

- **Load controllers**: are devices that control the flow of power between the generation system and the storage system. These devices protect the battery from overcharging and discharging, prevent it from continuing to charge when it reaches its charging limit and fall below the recommended limit by monitoring the voltage at its terminals (Oliveira, 2023).

Thus, IESS (2019) points out that controllers control voltage values, protect against polarity reversal, short-circuiting.... They are classified as Parallel or Shunt controllers, which prevent reverse currents, and series controllers, which interrupt the supply to extreme loads when the battery reaches the depth of discharge threshold, and MPP controllers, which lower the generator's voltage due to reduced solar incidence, making energy production unfeasible Granja (2017).

In the view of Mariano and Urbanetz (2022) and Oliveira (2023), they classify On/Off controllers as which open and close when the voltage of the battery pack reaches predetermined values; PWM (Pulse Width Modulation) controllers which control the voltage through pulse width modulation control and MPPT controllers which track the point of maximum power of the modules.

- **Protection devices:** photovoltaic systems are subject to damage from the sun. In this context, fuses, circuit breakers, surge protection devices (SPD), earthing systems and lightning protection systems (SPDA) are needed to protect them (Mariano & Urbanetz, 2022).
- **Transformers**: voltage transformers have the role of raising or lowering the voltage supplied by the inverters to values suitable for distribution, working according to load requirements (POOR et al., 2012, cited by Barreto, 2024).
- **Wiring in photovoltaic systems:** the energy produced by the modules is transported by the conductors, which must be considered in conditions that meet the specifications of the photovoltaic installations. The conductors in photovoltaic systems are classified as DC and AC (Pereira, 2021). Therefore, due to extreme solar conditions, high voltages and climatic factors, conductors must have characteristics such as maximum operating voltage, operating temperature, resistance to ultraviolet (UV) radiation and water (Moreno, 2019).

## Method

The aim of this research is to develop a photovoltaic power plant in the Praia Amélia Centrality in the municipality of Moçâmedes, Namibe, Angoa. The town has solar insidence that can be used to solve the problem of public lighting.

The electrical characterization shows that it is powered by the Thermal Power Station, which carries a low voltage of around 15,000V to the transformer stations, lowered to voltage levels of around 380V in a three-phase system. The economic characterization shows that it depends on external services, and there is no local economic sustainability in its current operation, but its own spaces tend to enable entrepreneurs to open businesses. The centrality has 465 lampposts distributed along the main roads, verified in the archives and confirmed by the direct count criterion. These poles are 12 meters high, with 250W sodium vapor lamps that provide orange lighting with a radius of 15 meters for 12 hours. The poles are 25 meters apart.

The methodology is based on a mixed model, i.e. qualitative-quantitative, which guides the study towards the questions that aim to achieve the research objective (Morais & Neves, 2007, p. 1-2). In order to gather the theoretical basis, a bibliographical review was carried out of books available on the internet, in the library and in the Renewable Energy laboratory of the Pascoal Luvualu Polytechnic Institute in Moçâmedes.

To obtain the number of lampposts, distances between lampposts, lighting radius, color of lighting, measurement of lamppost heights, participant observation and direct measurement were used.

In order to obtain the technical and electrical data for the centrality, we consulted the physical files available at the local administration and interviewed two (2) local administration technicians for 15 minutes on the first two points in the guide below and two (2) electrical engineers for 10 minutes on the last two points in the guide below.

- Data on the dimension of centrality;
- Data on the total number of homes and their type;
- Data on the source of energy generation for centrality and;
- Data on the local electrification configuration.

The photovoltaic generation system for street lighting was sized using the parameters of latitude -15°11'45" and longitude 012°09'07", with the support of the European Commission's PVGIS (2024) website, which provided specific data on monthly direct irradiation, global irradiation and average temperatures for the site on November 12, 13 and 14, 2024.

Using equations 1 to 11, the components of the photovoltaic system were calculated.

**Equation 1**

*Calculating the number of modules to be installed (Azambuja, 2022, p. 21)*

$$\mathrm{N_p} = \frac{\mathrm{E_t}}{\mathrm{HSP} * \mathrm{P_{max}}}$$

$\mathrm{N_p}$ : Number of modules

HSP : Peak sun time

$\mathrm{E_t}$: Energy demanded

$\mathrm{P_{max}}$ : Module power

**Equation 2**

*Calculation of total system power (Sousa & Franco, 2018, p.54)*

$$P_t = N_p * P_{max}$$

$P_t$ : Total power to be installed

$N_p$ : No. of module

$\mathrm{P_{max}}$ : Module power

**Equation 3**

*Calculating the total energy of the system (Pinho & Galdinho, 2014, p. 328)*

$$E_{GS} = P_t * HSP$$

$E_{GS}$ : Total energy generated

$P_t$ : Total power to be installed

HSP : Peak sun time

**Equation 4**

*Calculating the number of batteries in parallel (Pinho & Galdinho, 2014, p. 313).*

$$N_{bp} = \frac{C_{ts}}{C_{bat}}$$

Nbp: Number of batteries in parallel

Cts: System capacity

$C_{bat}$: Battery capacity

**Equation 5**

*Calculating the number of batteries in series (Pinho & Galdinho, 2014, p. 313)*

$$N_{bs} = \frac{V_s}{V_b}$$

$N_{bs}$: Serial number

$V_s$: System voltage

$V_b$: Battery voltage

**Equation 6**

*Calculation of the installation's total battery quantity (Pinho & Galdinho, 2014, p. 313).*

$$N_{Total} = N_{bs} * N_{bp}$$

**Equation 7**

*Calculating the conductor section specification (Wate, 2023, p. 68)*

$$\mathrm{s} = \frac{0{,}036 * \mathrm{I} * \mathrm{L}}{\mathrm{V_t} * \mathrm{C_t}}$$

S: conductor section.

I: the electric current.

L: the length of the conductor.

Vt: System voltage.

Ct: voltage drop, corresponding to 1%.

Photovoltaic systems are subject to losses associated with the orientation and inclination of the modules, shading, dust accumulation, cabling and module losses due to temperature (Silva, et al., 2018, p. 14; Tonolo, 2019, p. 36). Losses due to temperature and conductors are determined using equations 8 and 9.

**Equation 8**

*Calculation of power loss in the module due to temperature (Teixeira & Silva, 2021, p.10).*

PMPT = (1-(Tm-25$^0$C)*%Pm)

PMPT: Module power due to temperature loss

Tm: average local temperature

Pm: module power coefficient

25$^0$C: Standard module test temperature

**Equation 9**

*Calculation of power loss in conductors (Macita, 2022 p. 30)*

$$\mathrm{P_M} = \frac{2 * \mathrm{N} * \mathrm{L} * \mathrm{I}^2}{\mathrm{S} * \mathrm{K}}$$

$P_M$: Power losses in conductors

N: Number of rows

S: Cable section

K: conductivity of the material

L: Length

I: Electric current

The economic evaluation of the project is carried out using equations 10 and 11.

**Equation 10**

Calculation of Net Present Value (Sousa & Franco, 2018, p.44).

$$VLP = -I_O + \sum_{n=1}^{n=N} \frac{F_{ci}}{(1+i)^n}$$

NPV: net present value.
$I_0$: investment.
n: period analyzed.
$F_{ci}$: Cash flow for the period.

**Equation 11**

*Calculation of the investment's amortization time (Sousa & Franco, 2018, p.44).*

$$\text{Payback}_{\text{simples}} = \frac{I_0}{F_{ci}}$$

Payback: investment amortization time.

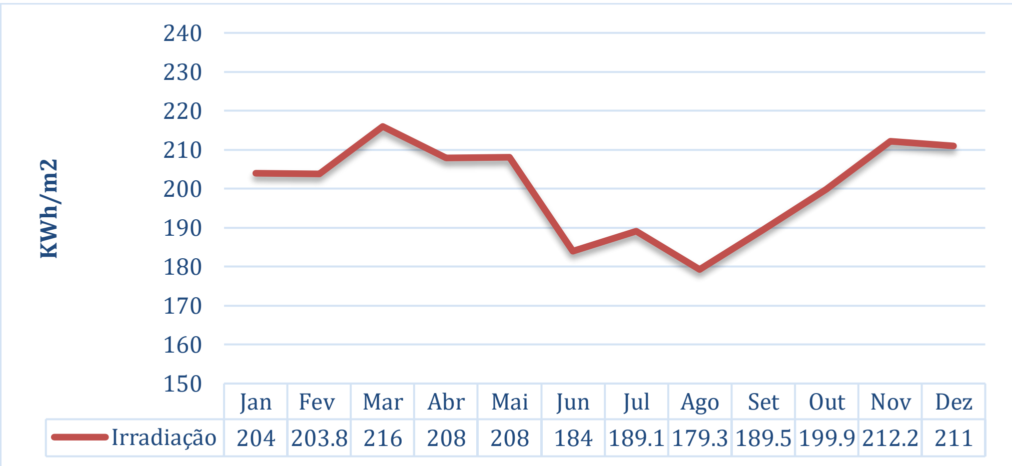
## Results

Based on the interview carried out using the points in the guide, it was found that the centrality is located just under 5 km from the city center, occupying an area of approximately 1,827km². It has 2,000 housing units, spread over 11 blocks, with 3-bedroom houses and apartments, a hospital, sports fields, leisure facilities, a school complex, a kindergarten and the Faculty of Engineering and Technology.

Information on global monthly irradiation, direct normal irradiation and average temperatures for sizing, obtained from the European Commission PVGIS website (2024), is shown in Figures 1, 2, 3 and 4.

**Figure 1**

*Monthly global irradiation at angle equal to latitude*

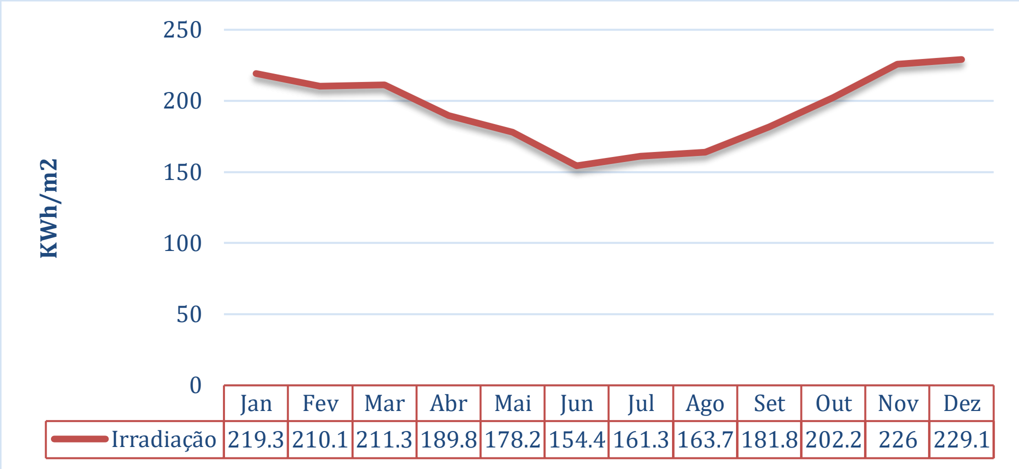



*Note.* Irradiationmonthly irradiation at angle equal to $15^0$, based on data from European Commission PVGIS (2024).

According to figure 1, the monthly global irradiation with modules inclined at $15^0$ provides irradiations with a maximum of 2016 kWh/m$^2$ in March and a minimum of 179 kWh/m$^2$ in August. This shows a rise from January to March, a fall from April to May, a fall in June, a rise in July and then a fall in August, rising until November, with a slight fall in December. August is therefore the critical month. Dividing its monthly radiation by the days of the month gives a daily average of 5.78 kWh/m$^2$/day, used for sizing.

**Figure 2**

*Global horizontal irradiation at the optimum angle.*

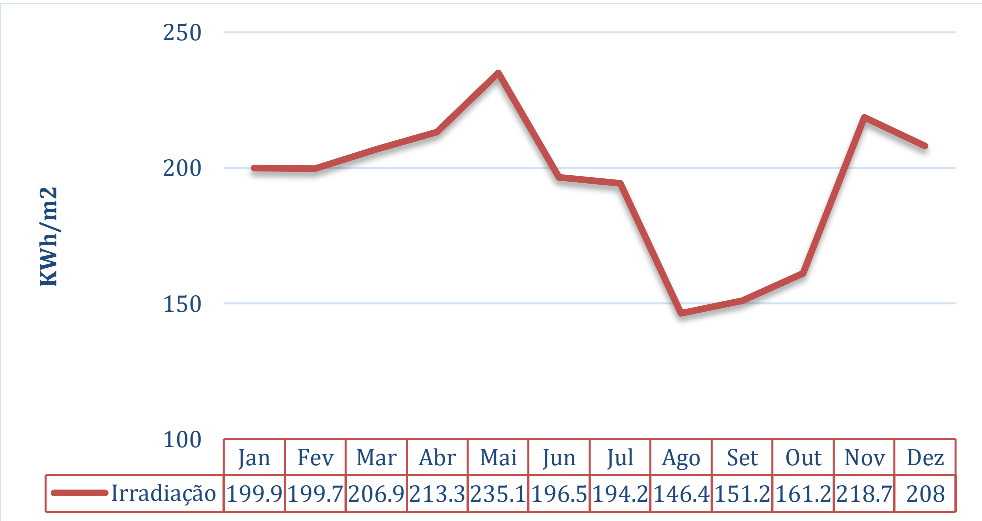



*Note.* This shows monthly irradiation at optimum angle, drawn up using data from European Commission PVGIS (2024).

Figure 2 shows a maximum of 229 kWh/m² in January and a minimum of 154 kWh/m² in June. It also shows a general downward irradiation behavior from January to June and an increase from July to December.

**Figure 3**

*Normal direct irradiation*

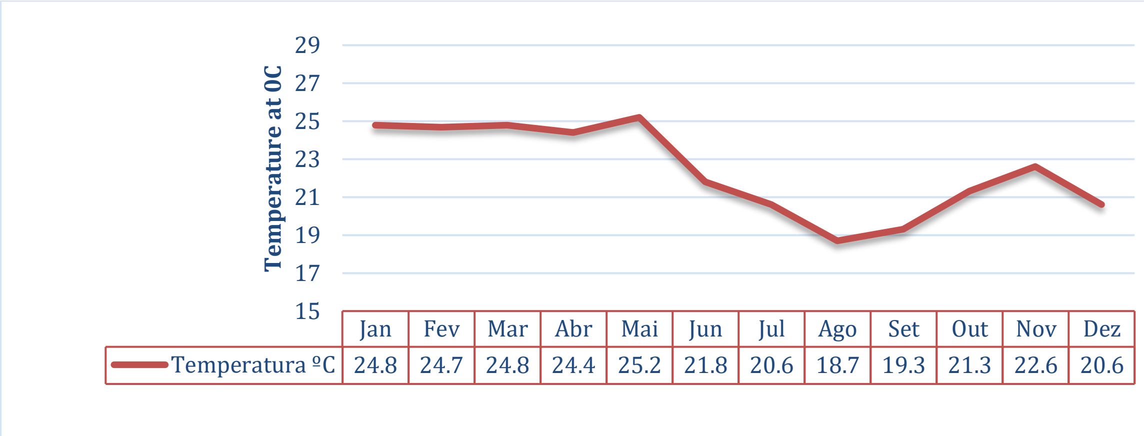



*Note.* This figure shows the monthly direct irradiation, drawn up using European Commission PVGIS data (2024).

Figure 3 shows a maximum of 235 kWh/m² in May and a minimum of 146 kWh/m² in August. The general trend is flat from January to February, up from February to May, down from June to August, up from September to November and down in December.

**Figure 4**

*Temperature variation in Moçâmendes*




*Note.* This figure shows the daily temperature drawn up from the European Commission PVGIS (2024).

Figure 4 shows the temperature with a maximum of 25.2$^0$C in May and a minimum of 18.7$^0$C in August. There was growth from January to April, a rise in May, followed by a fall from June to August, a rise in September to November, followed by a fall in December.

From these parameters of incident irradiation and average temperatures at the site, the European Commission PVGIS (2024) website, which provides direct and global irradiation and the average temperature of Moçâmedes for sizing the photovoltaic plant, the following analogies were made of the irradiation and temperatures provided.

As shown in figure 1, global irradiation at an angle of 15$^0$corresponds to a monthly average of 209 kWh/m$^2$ and an annual average of 2504.75 kWh/m$^2$.

In figure 2, which shows horizontal global irradiation, the monthly average is estimated at 193.92 kWh/m$^2$ and the annual average at 2327.04 kWh/m$^2$.

Figure 3 shows normal direct irradiation, where the monthly average is 193.42 kWh/m$^2$ and the annual average is 2321.12 kWh/m$^2$.

Figure 4 shows the average monthly temperatures, which correspond to approximately 22.4$^0$ C.

**Sizing the Photovoltaic Generation System**

In order to size the generation system, some data is needed, namely the consumption parameters and the characteristics of the photovoltaic module. These are shown in table 1.

**Table 1**

*Consumption parameters and the module.*

| Load | No. of poles | Time | Energy per pole | Total energy |
|---|---|---|---|---|
| 250W | 465 | 12 hours | 3000 Wh | 1.4MWh |
| Daily incident irradiation of the worst month (August) | | | | 5.78KWh |
| Module power | | | | 400W |
| Power coefficient | | | | -0,6% |
| Module voltage/ Module current | | | | 31.01V/12.90A |

*Note.* Consumption parameters in the centrality of Praia Amélia.

Depending on the specifications in table 1, the number of modules to be installed is determined using equation 1.

$$N_p = \frac{1395000\text{Wh}}{5{,}78\text{h} * 400\text{W}}$$

$N_p$ =603,373

In this context, the number of modules will be 603.3. To this value must be added 10%, which is the configuration correction and safety factor due to wiring and temperature losses. Therefore, the number of modules to be installed will be 664. In fact, the system has no shading losses, no orientation losses and no significant dust losses, as the installation site is preferably rocky. It is therefore possible to determine the total photovoltaic generation power and the energy generated using equations 2 and 3.

$P_t = 664 * 400W$

$P_t = 243200\text{W}$

$E_{GS} = 265600W * 5{,}78h$

$E_{GS} = 1535168Wh$

From these values, the installation conditions are given in the following descriptions.

- ❖ System voltage: 600V;
- ❖ System current: 452A;
- ❖ Number of modules in series: 19;
- ❖ Number of rows: 35;
- ❖ Number of modules in parallel (rows): 35.

**Sizing the Controller**

When sizing the controller, the maximum current that the system will supply must be taken into account, corrected by 25% and in line with the battery specifications. These parameters are checked in the description below.

- System current: 452 A
- Corrected current (15%): 520 A
- Current of each controller: 200A
- Total power of the controllers: 312000W

***Sizing the Battery Bank***

In order to supply the lighting load demand in the time considered, the battery bank must be sized and chosen with the following characteristics:

1. Demand corrected by 15%: 1604250Wh
2. Battery voltage chosen: 51,2V
3. System voltage: 600V
4. Days of autonomy: 0.5
5. Determined system capacity: 1485.4Ah

Determine the number of batteries in parallel using equation 4.

$N_{bp} = \frac{1485{,}4Ah}{410Ah}$

$N_{bp} = 3{,}6$

For the stability of the system, 4 batteries are used, thus storing a higher margin of charge, increasing the useful life. The number of batteries in series is then calculated using equation 5.

$N_{bs} = \frac{600V}{51{,}2V}$

$N_{bs} = 11{,}718$

This value is rounded up to 12 batteries connected in series. However, the total number is determined by equation 6.

$N_{Total} = 12 * 4$
$N_{Total} = 48$

This result implies that the storage system will have 4 columns in parallel, each containing 12 batteries in series.

**Inverter Sizing**

The sizing of the load inverter is based on the power demanded by street lighting consumption. From this value, a safety correction factor of 25% of the power demanded is taken into account. So these parameters are:

- Power demanded: 116250W, which is the result of the product of the number of poles, 465, and the lamp wattage, 250 W.
- Power corrected by 25%: 145313W

**Cable sizing**

The conductors are dimensioned based on the parameters in equation 7. The characteristics of the categories are shown in Table 2:

**Table 2**

*Cabling sizing.*

| *Categories* | *Distances (m)* | *Current (A)* | *Voltage (V)* | *Section (mm²)* |
|---|---|---|---|---|
| *Modules* | 1 | 12.90 | 31.01 | 2.5 |
| *Strings* | 2 | 155 | 600 | 2.5 |
| *Strings to regulators* | 5 | 155 | 600 | 5 |
| *Battery regulators* | 3 | 465 | 600 | 10 |
| *Batteries on sale* | 3 | 465 | 600 | 10 |
| *Inverter to main switchboard* | 3 | 632 | 230 | 30 |

*Note.* This table shows the sizing of cabling by category.

**System Losses**

The losses associated with the plant were taken into account when sizing. For example, the modules are inclined at $15^0$, favoring self-cleaning, and oriented to the geographical north, due to the site's southern location. As for dust losses, the region has conditions that favor the absence of significant dust and dirt, corrected by tilting and maintenance whenever possible.

The module's losses due to temperature are calculated using equation 8, considering that the power coefficient of the chosen module is equal to -0.6%/$^0$C (0.006) and the average local temperature is 22.4$^0$C.

$P_{MPT}$=1- ( 22,4-25)*(-0,006)
$P_{MPT}$ = 0,9844
$P_{MPT}$ = 98,44%

This result shows that the module will supply 98.44% of its maximum load under the local temperature conditions.

In order to determine the losses in the cables using equation 9, the current, section and length of the cables will be taken into account, considering copper as the material from which they are made.

Losses in the connection between modules:

$P_M = \frac{2*1*19*12,90^2}{2,5*56}$

$P_M$ =45W

1- Losses in the connection between rows:

$P_M = \frac{2*2*12*12,90^2}{2,5*56}$

$P_M$=457W

2- Connection losses for controllers:

$P_M = \frac{2*5*1*155^2}{5*56}$

$P_M$=2574W

3- Connection losses to the batteries

$P_M = \frac{2*3*1*465^2}{10*56}$

$P_M$=2317W

$P_M = \frac{2*5*1*155^2}{5*56}$

$P_M$=2317W

**Economic Viability**

The economic feasibility analysis was based on the material prices in Table 3 and the production parameters in Table 4.

**Table 3**

*Data on the plant's economic viability.*

| Parameters | | Brand | Value (KZ) | Quantity | Total (kz) |
|---|---|---|---|---|---|
| **Module** | | Shinefar | 40.145,00 | 608 | 24.408.160 |
| **Controller** | | DM | 5.291.804,00 | 3 | 15.875.412 |
| **Inverter** | | ATESS | 2.965.244,75 | 1 | 2.965.244,75 |
| **Battery** | | Dawnice | 692.498,70 | 48 | 33.239.937,6 |
| **Protective devices** | Circuit breaker | TOMZN | 1.368,57 | 32 | 43.794,24 |
| | | TOMZN (2p/4p) | 5.494,4/22.959,2 | 5/1 | 50.431,06 |
| | SPD | EARU | 903,26 | 3 | 2.709,78 |
| | | EARU | 5.277,40 | 2 | 10.554,8 |
| **Cabling and connectors** | | | | | 100.700 |
| **Total** | | | | | 76.696.944,2 |
| **Project (5%)** | | | | | 3.834.847,21 |

| | |
|---|---|
| **Installation and maintenance (15%)** | 11.504.541,6 |
| **Investment value** | 92.036.332,8 |

*Note.* This table shows the values for assessing the economic viability of the plant.

**Table 4**

*Production data from the photovoltaic plant.*

| Parameters | Value | Unit |
|---|---|---|
| **Daily production** | 1.405,696 | KWh |
| **Annual Production** | 513.079,04 | KWh |
| **Kwh price** | 15,61 | Kz |
| **Annual cash flow ($F_{ci}$)** | 8.009.163,81 | Kz/KWh |
| **Investment value $I_0$** | 92.036.332,8 | Kz |
| **Discount rate (t)** | 10 | (%) |
| **Design lifetime** | 30 | Years |

*Note.* This table shows the plant's electrical and economic production data.

Based on table 4, the NPV (Net Present Value) is calculated using equation 10, which, when positive, means that the project is economically viable.

$\mathrm{VLP}_{30} = -92036332{,}8\mathrm{kz} + \sum_{t=30}^{t=30} 7281058{,}01Kz$

$\mathrm{VLP}_{30} = -92036332{,}8\mathrm{kz} + 30 * 7281058{,}01Kz$

$\mathrm{VLP}_{30} = 126395407\mathrm{Kz}$

Over the course of 30 years, the project will appreciate in value, as the VLP is positive. The time over which the project will be amortized by equation 11 is:

$Payback_{\mathrm{simples}} = \frac{92036332{,}8\mathrm{kz}}{8009163{,}81\mathrm{kz}} ano$

$Payback_{\mathrm{simples}} = 11{,}49 \text{ anos}$

Therefore, the investment value will be amortized over a period of approximately 11 years.

## Discussion and Conclusions

In this discussion, reference is made to comparing the results of this study in Angola with the projects in Cape Verde and Mozambique, as well as with the similar project in Huambo, also in Angola.

Angola, Cape Verde and Mozambique are heavily dependent on fossil fuels for energy production. Thus, in the fight for environmental stability, significant steps have been taken in the use of renewable solar and wind sources (Varela, 2021; Macita, 2022).

Angola has 2.7% public lighting (IRSEA, 2022), which is considered low when compared to Cape Verde, which has 10% public lighting (Varela, 2021). This low percentage of electrical development in lighting leaves room for investment in research and lighting projects, compared to Cape Verde.

In fact, this public lighting plant project is a first approximation to this investment, and can be compared with the public lighting project in the city of Ribeira Grande de Santiago in Cape Verde based on photovoltaics (Varela, 2021, p.53) and the lighting project for the 3 de Fevereiro neighborhood in Maputo, Mozambique (Macita, 2022).

This comparison shows a similarity in the use of isolated photovoltaic systems and technical differences in the sizing and loads for lighting, where the present project has 11,6250W, operating over 12 hours, the Cape Verde project has 11,268W (9.6% of Centrality), operating over 11 hours and the Mozambique project has 8051W (6.9% of Centrality) and operates over 12 hours.

Thus, the percentage of Cape Verde's lighting project at 9.6% and Mozambique's at 6.9% makes this project more ambitious and with a greater positive impact on reducing the levels of polluting gas emissions and greater social and economic relevance.

The projects in Cape Verde and Mozambique, although focused on public lighting, clearly show a partial approach to taking advantage of the enormous potential in photovoltaic energy. Thus, one way of supporting the reduction of polluting gas levels would be the need for more comprehensive projects. That's why, in comparison, the Centralidade project is a production plant, while the others focus on integrated use of the lampposts.

Another comparison at country level can be made with the photovoltaic plant project for the Ngongoinga neighborhood in the province of Huambo in Angola, which is more comprehensive and has a total load of 2MW (Pinto, 2024), which produces 6% more than the present project, due to its total coverage of the neighborhood's load.

However, since Moçâmedes produces 71.8MW from fossil fuels, supplied by the Xitoto 2, 3 and Aeroporto thermal power plants (PRODEL, 2025). Thus, this project, with a production margin of 265600W in the critical month, shows a considerable decrease of 0.37%.

Thus, this 0.37% reduction in fuel used by thermal power stations is of considerable socio-economic value in the municipality and in Angola, since it redirects this percentage of fuel to other purposes, as well as reducing the levels of polluting gases in the atmosphere and bringing the country onto the scale of countries firmly committed to environmental decarbonization.

From the annual and monthly irradiation values provided, it can be seen that the global irradiation at the angle equal to the latitude ($15^0$) is the most significant as it has the highest value among the other irradiation values. This result reinforces the idea that the inclination of the modules, when equal to the latitude of the location, makes it possible to use energy that makes photovoltaic systems economically viable.

This inclination not only allows the system to make high use of energy, but also allows the system to be self-maintaining, based on the self-cleaning of the modules by action, waste and rainwater.

In fact, the average local temperature can satisfy photovoltaic objectives, since when the high and low temperature curves are analyzed, it is possible to see limits of no more than 26 °C and no less than 18 °C.

The system is suitable for orientation to the northern hemisphere, and as it is located in a desert and rocky area, there is no room for shading. As for significant losses due to dust, this is not expected, but in a variety of situations, regular maintenance could prevent them. On the other hand, with a 15.$^{0}$ slope, the effect of dust accumulation will be less, as the module can be cleaned in the rain (Silva, et al., 2018, p. 15).

Therefore, temperature has a great influence on energy generation, and increasing it to levels above the laboratory conditions of 25$^{0}$C decreases the considerable levels. Thus, according to Almeida (2012, cited by Silva, et al., 2018, p. 16), the power of the photovoltaic generator drops by between 0.3 and 4% with each increase of 1 °C.

In this context, depending on local temperature conditions, the modules have losses of around 1.6% (6W). The module thus provides a significant load of over 98% (394W) of the 400W of nominal power.

Wiring losses throughout the system were estimated at 7309 W. This figure does not constitute losses that compromise the system or the possibility of meeting demand. This constitutes a power of 19 modules working with power related to temperature loss (394W), in a system with a demand of 603 modules in the critical month and with an availability of 664 modules in generation.

The project is economically viable, as the investment of 92,036,332.8Kz (92,036.33 Euro) is amortized in 11 years, compared to the Huambo project with an investment of 1,604,241,750 Kz (1,604,241.75 Euro), which is viable in 18 years (Pinto, 2024), while the Maputo project is amortized in 9 years (Macita, 2022, p.51)finally, the Cape Verde project is unviable, as it has not been amortized after 25 years (Varela, 2021, p. 78).

The current environmental situation is worrying. This concern, the result of anthropogenic activities, makes the energy sector, based on fossil fuels, one of the main villains. In this context, there is a common desire among states to reverse the situation by creating public or private energy policies based on renewable energies. In this way, the choice of clean source must be based on an in-depth study of structural issues, with a focus on the availability of the resource, a real dimensioning and the social and economic impacts of the region.

The Angolan state has already made use of renewable energies, the result of which are the various projects that have been implemented and the various ongoing studies to make available resources called new renewables. In order to meet local and global objectives, this article locates the solar source as the most viable and tries to size the plant to take advantage of the enormous photovoltaic potential available in Moçâmedes (ALER, 2022).

From these allegations it can be concluded that photovoltaic energy, characterized by its daily renewability, has the potential that, when harnessed with the most up-to-date photovoltaic components, provides energy to meet the energy needs demanded.

In another conclusion, the centrality of Praia Amélia, due to the difficulties caused by irregular public lighting, is in need of an auxiliary supply that could come from making use of the available solar resource.

On the other hand, it can be concluded that the sizing of the plant was based on the criteria of assessing the solar resource, assessing the energy needs for lighting and studying the losses inherent in the system. Therefore, the sizing has met the demand, as the solar resource is usable, the needs have been met and possible losses have been taken into account, without compromising energy generation at adequate levels.

With regard to the plant's economic viability, it can be concluded that the NPV, being positive over the plant's lifetime, shows that the plant is viable. In another case, however, the payback shows that the project will be amortized in approximately 11 years, a considerable amount of time for photovoltaic generation systems.

Important limitations include seasonality and constant changes in meteorological information, which can have a significant impact on irradiation parameters.

Another limitation is the possibility of implementing this project, since any photovoltaic plant project initially involves a high economic outlay. This means that it is often not financed, especially in a country that is mostly dependent on oil for immediate energy generation.

Another limitation to implementation is the significant differences in their state of government. This slows down the embryonic energy prospects of using renewable energies with a photovoltaic focus. Another limitation is the cost of electricity in Angola, which is considered very low, making projects take longer to become viable.

Some of these limitations have been taken into account, especially possible variations in irradiation levels and possible dust levels. These limitations are of little relevance, as the region has favorable weather conditions and with the safety margin considered in the design, these limitations can be overcome. As for the economic analysis, the plant is viable and can therefore be financed because, according to Pinho and Galdinho (2014, p. 477), photovoltaic projects have a useful life of 25 years of normal operation and can reach 30 years.

However, this project opens up a broad vision for other future projects. In the future, a hybrid renewable power plant (solar, wind) that could supply all the centrality's loads could support and continue this research project.

## Acknowledgement

First of all, I thank God Almighty for giving me the breath of life on which all my strength and wisdom are based.

I would like to thank my wife, Luciana Micayela Tomás Abel, for helping and accompanying me on my scientific journey and my children, Judith Abel and Eliezer Abel, for being my inspiration.

## Conflict of Interest

The article is wholly owned by the author who outlined all the activities individually and there is no link to other authors.

## References

Azambuja, A. V. R. (2022). *Estudo e projeto de um sistema fotovoltaico para a casa do estudante* [Monografia de licenciatura, Federal University of Grande Dourados]. Repositório Institucional UFGD. http://repositorio.ufgd.edu.br/jspui/handle/prefix/5027

Associação Lusófona de Energias Renováveis (ALER). (2022). *Energias renováveis em Angola: Relatório nacional do ponto de situação*. https://www.aler-renovaveis.org/contents/activitiesdocuments/aler-relatorio-angola_9528.pdf

Barreto, F. J. (2024). *Planeamento centrado na manutenção de usinas fotovoltaicas: Uma abordagem visando a eficiência* [Monografia de licenciatura, Universidade Federal do Rio Grande do Sul]. LUME Repositório Digital. https://lume.ufrgs.br/handle/10183/274163

European Commission, Joint Research Centre. (2024). *Photovoltaic Geographical Information System (PVGIS)* [database]. https://re.jrc.ec.europa.eu/pvg_tools/en/

Fadigas, E. A. F. A. (2004). *Energia solar fotovoltaica: Fundamentos, conversão e viabilidade técnico-econômica*. GEPEA – Grupo de Energia, Escola Politécnica, Universidade de São Paulo. https://pt.slideshare.net/alvferreira/apostila-energia-solar-fotovoltaica-fundamentos-converso-e-viabilidade-tcnicoeconmica

Granja, A. V. C. (2017). *Estudo e otimização de uma central fotovoltaica de 1 MW* [Dissertação de mestrado, Universidade do Porto]. Repositório Aberto. https://repositorio-aberto.up.pt/handle/10216/102539

Grijó, M. T. S. P. M. (2014). *O impacto da produção de energia solar fotovoltaica no crescimento económico: Casos da Alemanha, Espanha, França, Itália, Portugal e Reino Unido* [Dissertação de Mestrado, Universidade do Porto]. https://sigarra.up.pt/fep/pt/pub_geral.show_file?pi_doc_id=26943

Ideal Estudos e Soluções Solares (IESS). (2019). *Guia de boas práticas em sistemas fotovoltaicos*. IESS. https://cooperacaobrasil-alemanha.com/SEF/Guia_de_Boas_Praticas_Sitemas_Fotovoltaicos.pdf

Instituto Regulador dos Serviços de Electricidade e de Água (IRSEA). (2022, December 14-15). *Transition to clean and renewable energies*. Conferência Anual da RERA, Palmeiras Suites Hotel, Luanda, Angola. http://www.irsea.gov.ao/wp-content/uploads/2023/02/Eng-Joao-Pacata-Fernandes-Iniciativas-Estrategicas-de-Energias-Renovaveis-em-Angola-Politicas-Plano-Nacional-PND-Angola-2025.pdf

International Renewable Energy Agency (IRENA). (2024). *Country indicators and SDGs: Energy profile Angola*. https://www.irena.org/-/media/Files/IRENA/Agency/Statistics/Statistical_Profiles/Africa/Angola_Africa_RE_SP.pdf

Leite, E. D., & Alves, W. F. (2023). Iluminação pública: sua relevância para a segurança e qualidade de vida do cidadão. *Revista Contemporânea*, *3*(7), p.8223-824. https://doi.org/10.56083/RCV3N7-046

Lemba, I., Ferreira, D. M., & Robaina, M. (2021). Electric energy planning in Namibe, Angola: Inserting renewable energies in search of a sustainable energy mix. *Journal of Energy in Southern Africa*, *32*(4), 69–86. https://www.researchgate.net/publication/357007321

Losekann, L., & Botelho, F. T. (2019). *Política energética no BRICS: Desafios da transição energética*. Instituto de Pesquisa Econômica Aplicada. https://www.econstor.eu/bitstream/10419/211446/1/167178071X.pdf

Madeira, O. U. (Coord.). (2022). *Relatório de estudo de pré-viabilidade ambiental e definição de âmbito EPDA: Projeto de construção e operação de uma central solar fotovoltaica de 40 MWp*. Manje. https://proler.gov.mz/wp-content/uploads/2022/04/Manje_EPDA_27032022.pdf

Macita, D. E. (2022). *Optimização da iluminação pública utilizando sistema fotovoltaico em um lote do bairro 3 de fevereiro* [Monografia de licenciatura, Faculdade de Engenharia da Universidade Eduardo Mondlane]. http://monografias.uem.mz/jspui/bitstream/123456789/2669/1/2022%20-Macita%2c%20Dan%c3%adlson%20Eug%c3%a9nio.pdf

Mariano, J. D., & Urbanetz, Junior, J. (2022). *Energia solar fotovoltaica: Princípios fundamentais*. Atenas Editora. https://doi.org/10.22533/at.ed.752221803

Morais, A. M., & Neves, I. P. (2007). Fazer investigação usando uma abordagem metodológica mista. *Revista Portuguesa de Educação, 20* (2), 75-104 (2007). .https://repositorio.ulisboa.pt/bitstream/10451/4392/1/Morais%20A%20M%20&%20Neves%20I%20P_Fazer%20Investigacao.pdf

Moreno, H. (2019). *Cabos elétricos para instalações fotovoltaicas*. Scribd. https://pt.scribd.com/document/440706225/Cabos-Eletricos-Para-Instalacoes-Fotovoltaicas-Hilton-Moreno-COBRECOM

Oliveira, M. S. (2023). *Desenvolvimento de sistema de monitoramento e gerenciamento para microgeradores residenciais dotados de geração solar fotovoltaica e sistema de armazenamento de energia por bateria* [Monografia de licenciatura, Universidade Federal de Pernambuco]. Repositório Institucional UFPE. https://repositorio.ufpe.br/handle/123456789/50259

Ovelha, R. M. R. V. (2017). *Projeto, dimensionamento e instalação de solução fotovoltaica numa moradia off-grid* [Dissertação de mestrado, Universidade de Lisboa]. Repositório ULisboa. https://repositorio.ulisboa.pt/handle/10451/31733

Pereira, A. J. S. (2022). *Concepção de uma central fotovoltaica* [Dissertação de mestrado, Universidade do Minho]. Repositório Institucional UMinho. https://repositorium.sdum.uminho.pt/handle/1822/83389

Pinho, J. T., & Galdino, M. A. (2014). *Manual de engenharia para sistemas fotovoltaicos*. CEPEL. https://cresesb.cepel.br/publicacoes/download/Manual_de_Engenharia_FV_2014.pdf

Pinto, V. P. (2024). *Implementação de uma central fotovoltaica para o bairro de Ngongoinga, município do Huambo* [Monografia de licenciatura, Instituto Superior Politécnico de Caála]. https://sigiisp.ispcaala.com/_repositorio/Arqui_VITORINA%20PAULINA%20PINTO_273fe7cdf5e51456d96255d937e1dce0.pdf

Empresa Pública de Produção de Eletricidade (PRODEL). (2025). *Produção Térmica em Angola*. https://www.prodel.co.ao/o-que-fazemos/producao-termica

Silva, P. H. T., Florian, F., & Pestana, F. A. B. (2018). *Estudo de perdas em sistemas fotovoltaicos*. Universidade de Araraquara. https://semanaacademica.org.br/system/files/artigos/artigo_pedrohenriquetronco_04dez2018.doc__3.pdf

Soares, D. O., & Santos, M. G. C. dos. (2020). *Possíveis benefícios da utilização do sistema de energia solar fotovoltaica para a sustentabilidade ambiental*. *Anais do Fórum Regional de Administração*, 87–107. https://www.unirios.edu.br/eventos/forumadm/anais/arquivos/2020/possiveis_beneficios_da_utilizacao_do_sistema_de_energia_solar.pdf

Sousa, C. P., & Franco, T. A. S. (2018). *Projeto e instalação de um sistema fotovoltaico residencial conectado à rede de distribuição* [Monografia de licenciatura, Universidade Federal do Paraná – Campus Curitiba]. Repositório Institucional UFPR. https://www.eletrica.ufpr.br/p/arquivostccs/493.pdf

Teixeira, V. A., & Silva, O. (2021). *Sobre as perdas de potência em painéis fotovoltaicos: Uma abordagem à luz das teorias físicas dos semicondutores*. Instituto Federal de Pernambuco. https://repositorio.ifpe.edu.br/xmlui/bitstream/handle/123456789/985/Sobre%20as%20perdas%20de%20pot%C3%AAncia%20em%20pain%C3%A9is%20fotovoltaicos%20-%20Uma%20abordagem%20%C3%A0%20luz%20das%20teorias%20f%C3%ADsicas%20dos%20semicondutores.pdf

Tonolo, E. A. (2019). *Análise dos fatores de perdas nos sistemas fotovoltaicos da UTFPR campus Curitiba* [Dissertação de mestrado, Universidade Tecnológica Federal do Paraná]. https://repositorio.utfpr.edu.br/jspui/handle/1/4664

Tsshara, (June 19, 2024). *9 problemas causados pela falta de energia elétrica.* https://tsshara.com.br/blog/falta-de-energia/9-problemas-causados-pela-falta-de-energia-eletrica-e-como-resolver/#:~:text=4.-,Interrup%C3%A7%C3%A3o%20de%20Servi%C3%A7os%20Essenciais,sistemas%20de%20seguran%C3%A7a%20e%20comunica%C3%A7%C3%A3o.

Uczai, P., & Tavares, W. M. (Coord.). (2012). *Energias renováveis: Riqueza sustentável ao alcance da sociedade* (Série Cadernos de Altos Estudos, nº 10). Edições Câmara. https://www2.camara.leg.br/a-camara/estruturaadm/altosestudos/pdf/energias-renovaveis-riqueza-sustentavel-ao-alcance-da-sociedade

Varela, E. L. (2021). *Sistemas autónomos de iluminação pública com energias renováveis em Cabo Verde* [Dissertação de mestrado, Universidade do Algarve]. https://sapientia.ualg.pt/server/api/core/bitstreams/2bc6a6ea-d3b3-49f1-af7e-84c5652bd7c4/content

Wate, E. V. (2023). *Dimensionamento de sistema fotovoltaico para fornecimento de energia elétrica à empresa Sumol+Compal Moçambique SA* [Monografia de licenciatura, Universidade Eduardo Mondlane]. http://monografias.uem.mz/bitstream/123456789/3992/1/2023%20-%20Wate%2C%20Eduardo%20Vasco.pdf