

Environmental and Social Impact of the Construction and Operation of a Solar Photovoltaic Power Plant in Mapulanguene, Maputo Province, Mozambique

Impacto ambiental y social de la construcción y operación de una planta de energía solar fotovoltaica en Mapulanguene, provincia de Maputo, Mozambique

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Abstract: This study aims to evaluate the environmental and social impact resulting from the construction and operation of the Mapulanguene Solar Photovoltaic Power Plant, Magude District, Maputo Province. Mozambique, with the objective of assessing its technical, economic and socio-environmental sustainability. With an installed capacity of 100 kWp, the plant aims to contribute significantly to increasing the supply of clean energy in Mozambique's national electricity system. The research followed a mixed methodological approach, combining qualitative and quantitative techniques, supported by Geographic Information System tools, energy modeling, and structured interviews with strategic stakeholders, including Eletricidade de Moçambique, the Energy Fund, the Ministry of Mineral Resources and Energy, engineering companies, and local communities. The key variables of the research were operationalized, including: technical feasibility, technological suitability, operational efficiency, energy productivity, integration into the national electricity grid, economic feasibility, and the costs and revenues associated with the plant's operation. At the same time, the effects on the local energy system were analyzed, especially with regard to the population's access to clean energy, improved grid stability, and increased energy coverage. The results show a high degree of convergence with the objectives of the Mozambican Government's Strategic Plan for the Energy Sector. The Mapulanguene solar power plant is technically feasible, economically sustainable, and socially beneficial.

keywords: clean energy, generation potential, solar photovoltaic power plants, energy sustainability

Resumen: Este estudio tiene como objetivo evaluar el impacto ambiental y social de la construcción y operación de la Planta de Energía Solar Fotovoltaica Mapulanguene, Distrito de Magude, Provincia de Maputo, Mozambique. Con una capacidad instalada de 100 kWp, la planta pretende contribuir significativamente a aumentar el suministro de energía limpia en el sistema eléctrico nacional. La investigación siguió un enfoque metodológico mixto, combinando técnicas cualitativas y cuantitativas, con el apoyo de herramientas del Sistema de Información Geográfica, modelos energéticos y entrevistas estructuradas con actores estratégicos, incluyendo Eletricidade de Moçambique, el Ministerio de Recursos Minerales y Energía, empresas de ingeniería y comunidades locales. Las variables clave de la investigación se operacionalizaron incluyendo: viabilidad técnica y económica, idoneidad tecnológica, eficiencia operativa, productividad energética, integración a la red eléctrica nacional y costos e ingresos asociados a la operación de la planta. Simultáneamente, se analizaron los efectos en el sistema energético local, especialmente en lo que respecta al acceso de la población a energías limpias, la mejora de la estabilidad de la red y el aumento de la cobertura energética. Los resultados muestran un alto grado de convergencia con los objetivos del Plan Estratégico del Gobierno de Mozambique para el Sector Energético. La planta solar de Mapulanguene es técnicamente viable, económicamente sostenible y socialmente beneficiosa.

Palabras clave: Energía limpia, potencial de generación, plantas de energía solar fotovoltaica, sustentabilidad energética

Introduction

The potential of photovoltaic (PV) solar energy systems has been demonstrated in rural electrification projects around the world (Cuenca *et al.*, 2023; Amoroso *et al.*, 2023; Bravo & Gámez, 2024; Camarena & Nahui, 2024; Hilario, Bardales & Bollet, 2025), particularly in the case of domestic solar systems in Mozambique (Gonçalves Fortes, Fernando Beirão & Adelino Mamudo, 2022; Master & Fathia, 2024; Dualia Chamo *et al.*, 2024; Chichango *et al.*, 2024). As a result, the economic importance of photovoltaic systems is growing thanks to the steady decline in their prices, as well as experience in their application in other sectors, such as social and community services, agriculture, and other productive activities capable of significantly impacting rural development (Inca *et al.*, 2024; Aguay-Saquicaray, 2024; Gómez, Gálvez & Mata,

2025; Guamán & Sánchez, 2025). However, more information is needed on the potential and limitations of these applications of photovoltaic systems.

The most important experience from this study is that the sustainability of PV programs is greatly enhanced by a holistic and integrated approach. The flexibility of solar PV systems offers a particularly attractive opportunity for the energy sector to provide “bundled” systems for rural areas, for example for health, education, communications, and electricity, as well as for agriculture and water supply. It is hoped that this publication will inspire creativity and communication among the various institutions involved in providing these services to rural areas, thereby contributing to knowledgeable decisions regarding photovoltaic technology options.

The objective of this study is to evaluate the environmental and social impact of the construction and operation of a solar photovoltaic power plant in Mapulanguene, Magude District, considering factors such as job creation, environmental protection, and local community acceptance.

Materials and methods

This research uses descriptive research. Initially, aspects of photovoltaic generation technology and centralized generation are addressed. The next stage addresses the conditions necessary to install a photovoltaic solar plant in the district under study, analysis of the photovoltaic generation potential of the defined location, techniques and conditions for installing the physical structure, and technical field visits to bring theory closer to practical lessons learned. Based on a selective and careful theoretical foundation, drawing on existing works and articles, with attention to the process of sizing and installing the plant and various other aspects, the study concludes the proposed objectives with well-founded information about the installed photovoltaic project that can be shared with the scientific community and engineering professionals.

As the Mozambican government works to increase access to electricity in rural areas, the Energy Fund (FUNAE) plans to power the Mapulanguene Administrative Post headquarters in Magude District, Maputo Province, using containerized photovoltaic power plants. To this end, FUNAE intends to build a 100 kWp photovoltaic power plant to provide basic electricity services to these localities, in order to improve the quality of life and increase access to energy sources in the country.

The photovoltaic power plants must be prepared for connection to the distribution networks, to be built in other contracts, with the contractor for the power plant being responsible for connecting the distribution network to the photovoltaic power plant.

In this context, FUNAE intends to electrify the village of Mapulanguene, Magude District, Maputo Province, by installing mini photovoltaic power plants connected to mini grids, to provide uninterrupted electricity supply. For this purpose, FUNAE has collected all the basic information at this location from which the specific design of the photovoltaic power plant that will power the planned mini-grid will be developed.

Location of the project implementation area

The village of Mapulanguene is located at the headquarters of the Mapulanguene Administrative Post. The village of Mapulanguene is 105 km from the district capital of Magude. The principal infrastructure in this village includes a health center, primary school, administrative office, barracks, meteorological center, market, and small commercial establishments. It currently has a population of approximately 7557, with an average of five people living in each residence.

The methodological description of the work carried out is presented below:

- Design of the containerized photovoltaic power plant project
- Selection of equipment in accordance with the technical requirements
- Supply of converters, equipment boxes, electrical panels, control and regulation devices, monitoring (supervision) system, and all accessories for the proper functioning of the plant
- Connection of solar panels, converters, and battery banks in accordance with the project and interconnection of primary and secondary networks
- Installation of all electrical systems between all equipment and electrical panels at the plant
- Installation of all electronic and communications systems
- Programming/testing of the plant, commissioning of the plant, and connection of the plant to the distribution network
- Supply and installation of monitoring/supervision and operation units for the plant
- Supply of fire extinguishers
- Preparation and delivery of power plant documentation
- Training of power plant operating personnel

- Supply of tool kits for power plant maintenance
- Operational assistance

Regulations and standards applied

The electrical installation to be carried out, in addition to meeting the conditions and requirements of the demands, must be designed as a whole in accordance with the manufacturers' recommendations and the Institute of Electrical and Electronics Engineers (IEEE) regulations.

All work must comply with the applicable regulatory provisions in Mozambique, and in their absence, Portuguese and European provisions, as well as good practice in execution, assembly techniques, and any other rules recommended by national entities.

Technical specifications of the solar photovoltaic power plant to be installed

Containerized photovoltaic power plants should be sized to achieve a renewable energy share of close to 100% throughout the year, considering the estimated maximum daily demand and average daily irradiation. The Technical Specifications are guidelines for the design, supply, and installation of mini-grids (Table 1).

Table 1. Technical characteristics of the photovoltaic power plant

Item	Value	Unit
Photovoltaic power generation	100	kWp
Diesel generator (backup)	50	kVA
Minimum net storage capacity available for supply to the netw	600	kWh
Maximum DOD for lithium batteries	80	%
Connections	250	One
Max power supplied to the grid	100	kW

The system must be capable of:

- a) Providing energy 24 hours a day;
- b) Guaranteeing minimum annual reliability of 365 days of annual service (97%);
- c) Guaranteeing the quality of energy supply in accordance with the parameters defined in this document;
- d) Set a target of close to 100% renewable energy throughout the year, considering estimated peak daily demand and average daily sunshine, using a diesel generator as a backup in case of extreme weather conditions and ensuring that at least 95% of the energy comes from renewable sources;

- e) Have a communication system between all components of the installation to enable automatic switching and start-up of the generator set;
- f) Have a monitoring system for the main generation parameters.

Results and discussion

System general configuration

The most important parts of a ground/roof photovoltaic system are: modules, metal structure, inverters, cables, and protection. In floating systems, floats are added as a physical support element, which serve to support the modules, provide access to the modules, store the cables, and provide physical support for the electrical equipment (Sharma, Muni & Sen, 2015).

The right configuration of a solar photovoltaic system is essential to maximize its efficiency, ensure a reliable and stable energy supply, guarantee system safety, and get the best economic and environmental results. An improper configuration can lead to poor performance, the need for premature repairs, and even damage, affecting electricity generation and the system's lifespan. The containerized control center should consist of the equipment described in the table 2.

Table 2. Configuration of the containerized solar photovoltaic power plant

No	Items	General observation
1	Battery Bank	Cells connected in series and parallel; Minimum capacity available for supply to the grid of 600 kWh/day
2	Battery Rack	They must be organized in such a way that each cluster within each rack has a control box
3	Battery Management System (BMS)	The system should have different levels, allowing for the management of each unit, each module, and the bank as a whole
4	Central Control Panel	Provision of AC power to auxiliary systems, including UPS
5	DC Panel	The Battery Bank Control and DC Power Supply to Auxiliary Systems
6	AC system	To air-condition the interior of the plant
7	Fire detection and suppression system	Smoke detector and temperature sensor
8	Container	10 feet HC, including lighting system and emergency system.
9	Cables	Power and communications cables
10	Energy Conversion System (Converters)	Full capacity 100kW, which can be split up as suggested by the bidder They're in charge of converting energy from solar panels to the distribution network and charging batteries
11	Central Management Unit	-
12	Generator	50 kVA

The figure 1 shows a generic view of the system configuration.

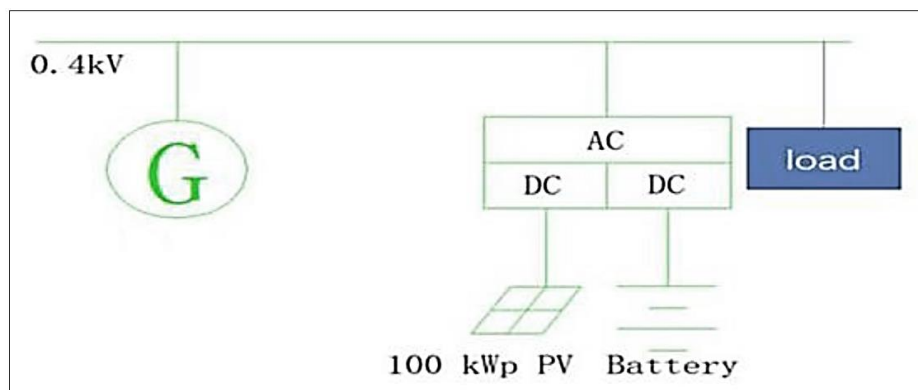


Figure 1. Generic view of the system configuration.

These specifications cover the design, manufacture, factory testing, transportation, supply, and installation of all equipment, including all accessories necessary for the proper functioning of the photovoltaic generation system.

The plant will be based on a pre-assembled containerized solution in one or more containers where power electronics, energy storage systems, panels, cabinets, auxiliaries, communications, and other equipment will be installed.

The container must have a protection level higher than IP67 and be equipped with:

- Ventilation or air conditioning to ensure the recommended operating temperature for all equipment
- Insulation
- Fire suppression system
- Lockable doors with three keys per set
- Internal power outlets and lighting system

Recommendations for container setting

Recommend the appropriate solutions for setting the container (raising the foundations above ground level). The bidder must specify the weight of the equipment and all necessary accessories.

Ventilation or air conditioning

The bidder must design and budget for a system with adequate ventilation (forced ventilation or air conditioning) to safely operate the Battery System within the temperature range specified in the manufacturer's warranty. In addition, the air conditioning system shall be an energy-efficient, high-quality product with limited maintenance requirements, which can be performed by trained technicians. Spare parts shall be readily available in Mozambique. All relevant data sheets and estimated energy consumption data shall be provided.

Photovoltaic modules

The photovoltaic modules to be connected are TUV certified and comply with IEC 61730 (2023), IEC 61215-1 (2021), and IEC 61701 (2020) standards.

The minimum number of cell strings connected for each module is 60, which guarantees the nominal power under normal conditions (irradiance 1000 W/m², air mass 1.5 spectrum, and 25 °C).

Each module has an anodized aluminum frame and the cells are properly encapsulated in a suitable material. The top cover of the module is made of tempered glass. The modules are certified as PID (Potential Induced Degradation) free.

Battery bank

Type: Lithium-ion technology or higher performance

DoD: $\geq 80\%$

DC-DC efficiency $> 85\%$

System operating temperature: 0°C to 50°C

Service life: > 5000 cycles at 25 °C, C20

Origin: EU origin would be an advantage in the evaluation criteria

Warranties: 3 years

Spare parts: 1% of capacity

It is recommended that the batteries be installed in a room/container equipped with A/C to ensure normal temperature conditions. The company is invited to submit an

assessment of the air conditioning system's consumption and propose technical solutions to minimize consumption related to the air conditioning system.

The batteries must be designed to operate in a temperature range between 0°C and 50°C, with a discharge capacity below 80 % of their nominal value.

The expected service life is at least 10 years and must comply with IEC 62619 (2022) standards.

The battery must have a minimum life cycle of at least 5000 cycles at 80% discharge (DoD) under C10 conditions at 25 °C.

The storage system must be organized into units with a minimum storage capacity of 50kWh, so that the contractor does not bring cells for assembly on site, but rather brings a module that has been assembled and tested in the factory.

The interconnection cables are made of copper, protected against accidental direct contact, with clamp terminals.

Whenever the lithium charge level drops below 15%, the system requires an appropriate shutdown level, which shuts down the system including monitors, LEDs, and any other small loads that could damage the battery.

The battery system must have a certificate of compliance with the following international standards: IEC 60695-11-10 (2013), IEC 61000-3 (2011), IEC 61427-1 (2013).

The battery manufacturer must be certified in accordance with ISO 9001 (2015) and ISO 14001 (2015) standards;

Thermal dissipation must be considered and calculated due to the variation in the convection coefficient at height in order to meet the minimum required capacity;

The battery management system (BMS) must communicate with other equipment, dynamically limiting the charging current of the battery bank; The expected life cycle is at least 5,000 cycles of 30% discharge when tested in accordance with IEC 60896-21/22 or a similar test, and the monthly self-discharge must be less than 3% of the nominal capacity at 25 °C.

The interconnection cables are made of copper, protected against accidental direct contact, with clamp terminals. The batteries must be installed in a power room equipped with air conditioning to ensure normal temperature conditions;

The maximum charge and discharge current values, depending on the capacity of the battery banks, must never be exceeded under normal operating conditions;

The nominal capacity of the battery must refer to a 5-hour discharge (C5 or higher) and an ambient temperature of 25 °C.

Accumulator

Batteries: Lithium

Density of 0.53 g/cm³ a 20°C

Reduction power 3.045 V

Supports high charge/discharge rates and deep discharge

Cyclic life of 3,000 cycles in deep discharge

Sophisticated BMS charge controllers must be installed in your facility to prevent them from exploding/catching fire – battery management system.

BESS (Battery Energy Storage System) container Minimum capacity: 100kW / 600 kWh, 10HC container (10 PESHHC), including 600 kWh racks, PCS, BMS, DC panel, central control panel, fire suppression system, lighting, HVAC system, and internal cable.

Converters

Photovoltaic converters will be responsible for converting the current from the solar panels to the distribution network and also for charging the batteries.

These must be pure sine wave, with high start-up capacity/high frequency.

They must be equipped with a self-diagnostic system to report the causes of any stoppages or malfunctions. The display should also show information about the status of the system, instantaneous values of power, voltage, and current, among others.

They should be designed to allow operation in an ISOLATED NETWORK, stand-alone, with an efficiency of not less than 96%, in a service temperature range of -25°C to 60°C.

Inverters must have a manufacturer's warranty of at least 5 years for replacement in case of defects. The manufacturer must have a representative in the region and installed converter capacity worldwide exceeding 500 MW.

Additional requirements:

Converters must be capable of dynamically varying the active and reactive power injected into the grid in order to maintain the AC grid within the established parameters and based on AC loads;

Active or reactive capacitive and inductive power control up to an adjustable compensation factor of 0.8;

The converters must be capable of providing the maximum output power required for all environmental and weather conditions at the specific location;

The converters must have a certificate of conformity with the following international standards: IEC 61727 (2024), IEC 62109 (2020), IEC 62116 (2014), IEC 61000-3 (IEC, 2011), and IEEE 1547 (2018).

Remote access to parameter settings via the internet;

Protection against atmospheric discharges, transients, and overvoltage;

For standardization and spare parts, all grid connection converters must be of a single type (same brand and model).

Warning and protection devices

All devices in this group must be installed in the appropriate compartments individually or as part of a group of warning, protection, and/or control equipment.

All overheating protection devices must be automatically coordinated by means of an appropriate coordination unit. They must be calibrated for adequate current capacity to ensure uninterrupted operation under normal conditions and operation under fault conditions.

The project demonstrates that the expansion of renewable energy necessitates studies that project a 50% increase in the use of clean energy by 2050. Furthermore, research suggests that energy generation from renewable sources will play a more prominent role in future scenarios. The inclusion of renewable energies in energy generation systems brings several benefits for a clean and sustainable electricity matrix. In this sense, countries that adopt policies aimed at the development of clean energy contribute to the macroeconomy and bring improvements such as job creation, social welfare, and quality of life (IRENA, 2019).

Until 2040, forms of electricity generation through sources such as solar photovoltaic and wind power should complement the supply of electricity to the global electricity matrix. Despite ongoing efforts to develop public policies promoting the use of clean energy, the effects caused by the population explosion will continue for decades to come (IEA, 2019).

Conclusions

The expansion of photovoltaic power generation in Mozambique can be seen in the volume and number of photovoltaic system installations, which show significant total installed power values.

The energy produced by the photovoltaic solar plant can supplement the energy supply to auxiliary systems in power plants; provide energy for irrigation, urban networks, and completely replace the national energy matrix with renewable sources. As it is considered an innovative project in the country, it is necessary to further investigate the topic and detail the specific characteristics of this type of installation.

The Mapulanguene photovoltaic plant connected to the electricity grid in the district of Magude is close to the point of consumption and the power utility. This proximity to the grid allows for the injection of surplus energy and also provides the electrical characteristics reference for synchronization necessary for its operation.

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