Solar Irrigation Systems for Family Farming in the Municipality of Boane, Maputo Province, Mozambique

Sistemas de riego solares para la agricultura familiar en el municipio de Boane, provincia de Maputo, Mozambique

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Abstract: Mozambique has high global horizontal radiation compared to good locations in Europe and Asia, and is quite close to some of the best locations in the world, such as South Africa and California. In the Country, global radiation on a horizontal plane varies between 1,785 and 2,206 kWh/m^2/year. Based on global radiation on an inclined plane, analysis of terrain slope, forest density, and flooded areas, Mozambique's solar potential is 23 TWp. This research evaluates the technical and economic feasibility of implementing solar irrigation systems in family farming in the municipality of Boane, Maputo Province. Considering that farmers currently utilize fuel-powered (gasoline/diesel) motor pumps or electric pumps, this research compares these systems with solar photovoltaic alternatives. Data on local solar radiation, characteristics of the Umbeluze River Basin, types of solar irrigation technologies, installation and operating costs, and profitability indicators were analyzed. The results show that, despite the high initial investment, solar systems are economically viable in the medium term and have a positive impact on environmental sustainability and the income of small producers.

keywords: irrigation systems, photovoltaic solar systems, hydrographic basin, profitability indicators

Resumen: Mozambique presenta una alta radiación horizontal global en comparación con buenas ubicaciones en Europa y Asia, y está bastante cerca de algunas de las mejores ubicaciones del mundo, como Sudáfrica y California. En el país, la radiación global en un plano horizontal varía entre 1.785 y 2.206 kWh/m²/año. Con base en la radiación global en un plano inclinado, el análisis de la pendiente del terreno, la densidad forestal y las áreas inundadas, el potencial solar de Mozambique es de 23 TWp. Esta investigación evalúa la viabilidad técnica y económica de implementar sistemas de riego solar en la agricultura familiar en el municipio de Boane, provincia de Maputo.

Considerando que los agricultores actualmente utilizan motobombas o bombas eléctricas alimentadas por combustible (gasolina/diésel), esta investigación compara estos sistemas con alternativas solares fotovoltaicas. Se analizaron datos sobre la radiación solar local, las características de la cuenca del río Umbeluze, los tipos de tecnologías de riego solar, los costos de instalación y operación, y los indicadores de rentabilidad. Los resultados muestran que, a pesar de la elevada inversión inicial, los sistemas solares son económicamente viables en el mediano plazo y tienen un impacto positivo en la sostenibilidad ambiental y en los ingresos de los pequeños productores.

Palabras clave: sistema de riego, sistemas solares fotovoltaicos, cuenca hidrográfica, indicadores de rentabilidad

Introduction

In Mozambique, agriculture stands out for its contribution to the economy, accounting for around a quarter of total GDP, with more than 80% of the workforce concentrated in this sector (Mucavele & Artur, 2021). It is the main economic activity that ensures the subsistence of the rural population (Marassino, de Oliveira & Come, 2020; Marassino, de Oliveira & Pereira, 2021; Chihanhe, Mananze & Machava, 2022, Gobeia *et al.,* 2023).

Since independence, Mozambican agriculture has been characterized, mainly, by small farms cultivating less than 1 hectare, with agricultural activities carried out in traditional ways, with limited mechanization, financing, and improved agricultural inputs, compromising the performance of family farmers, who constitute the majority of those practicing agriculture (Mosca, 2011; Sitoe, 2014; Oliveira, 2016; Mosca, 2017; Rosário, 2019).

Family farming represents an important socioeconomic base for the municipality of Boane, in the province of Maputo (Rosario, Ndava & Faduco, 2022), where production depends heavily on the availability of water and energy sources for irrigation. Currently, farmers use fuel-powered motor pumps and electric pumps, whose operating costs are significantly high. In this context, solar irrigation emerges as a promising alternative (Valverde *et al.,* 2022; Mendez Durán, 2023; Alata-Rey *et al.,*2023; Manrique *et al.,* 2025).

The main objective of the research is to guide agriculture towards a more sustainable and self-sufficient energy model. This involves a comprehensive approach, which includes the installation of solar panels to generate energy for pumping water for crop irrigation and other agricultural activities in the Boane district, and the strategic implementation of efficient storage and distribution. The research seeks to evaluate the technical and economic feasibility of this pumping system as a reliable and continuous source of energy for the various energy needs of agriculture, taking as a reference an agricultural area of 3.8 hectares in the district, based on actual solar radiation data, available technologies, and cost-benefit scenarios.

Materials and methods

The research adopted a mixed approach (quantitative and qualitative). The following methodologies were used:

First, secondary data on solar radiation in Boane was collected using information from the National Institute of Meteorology (INAM, 2024). Subsequently, a survey was conducted in the scientific literature on existing solar irrigation technologies (direct solar pumping, battery systems, micro-irrigators, and drippers).

Next, interviews were conducted with local farmers on current costs and challenges faced, and finally, an economic model of comparative scenarios was developed: fuel vs. solar energy, in addition to an analysis of water availability in the Umbeluze River Basin.

Analysis and discussion of results

The solar radiation data show an annual average of over 5.0 $kWh/m^2/day$, making Boane a great location for photovoltaic power generation. The systems that were looked at, ranged from 1 kWp kits (for 0.5 ha) to 5 kWp kits (for 2 ha), with an average pumping efficiency of 10 to 15 m^3/day, as shown in the figure 1.

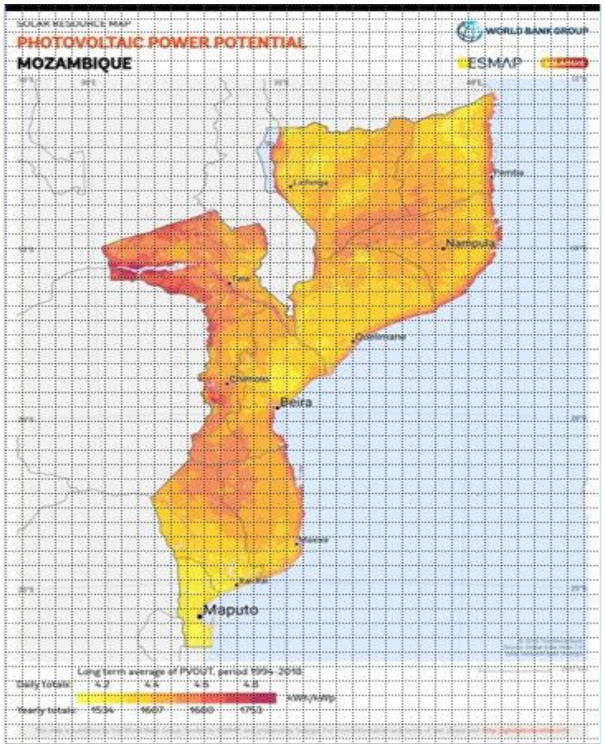

Figure 1. Solar Potential in Boane.

This map reflects the annual average solar irradiation levels across Mozambique, expressed in kilowatt-hours per square meter per year (kWh/m²/year). Boane, situated in Maputo Province, is within a high-irradiance zone, typically ranging between 1,800 and 2,200 kWh/m² per year.

These levels are aligned with excellent suitability for photovoltaic irrigation systems. High GHI implies more efficient solar output, increased water pumping capacity, and reduced payback periods. Specific Data for Maputo Province. The mean daily solar irradiation in Maputo Province averages around 6.14 kWh/m²/day in summer, 5.48 kWh/m²/day in autumn, 4.31 kWh/m²/day in winter, and 5.71 kWh/m²/day in spring.

Figure 2 illustrates a comparison between the costs of using gasoline-powered motor pumps and solar irrigation systems for 1 hectare irrigated over one year.

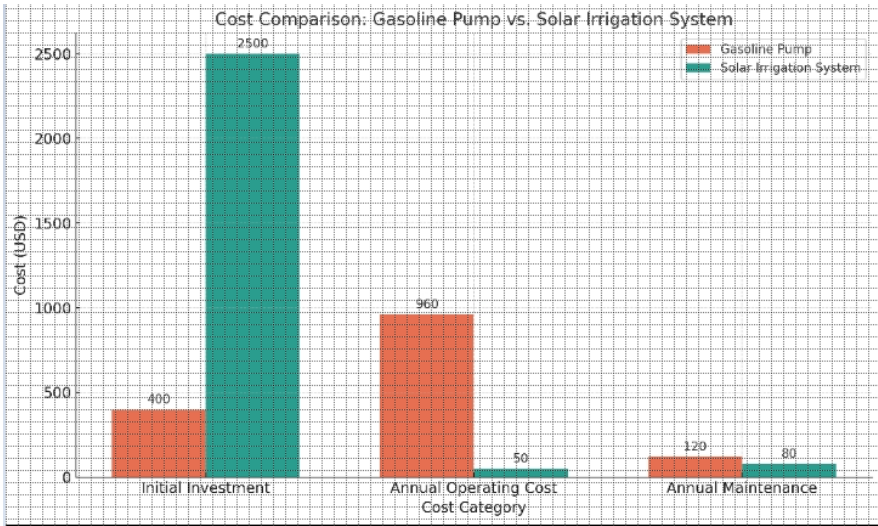

Figure 2. Comparison between the costs of using gasoline-powered motor pumps and solar irrigation systems.

The figure shows that the initial investment is lower for motor pumps, but with high operating costs. In terms of annual operating costs, these are extremely high for motor pumps (fuel), and almost zero for solar systems. Maintenance is also more expensive for motor pumps.

The initial investment for a complete solar system (pump, panel, structure, and controller) range from USD 1,800 to USD 3,000. However, operating costs are almost zero. In contrast, gasoline motor pumps involve monthly fuel costs of over USD 80 at current prices in Mozambique, which compromises profitability.

The return of investment (payback) analysis indicated that, on average, the solar system pays for itself in 2.5 to 3 years, depending on the irrigated area and crop type. Farmers reported greater production predictability and fewer operational failures.

Technical Proposal for a Solar Pumping System for Family Farming covering 3.8 ha

1. Application Context

Location: Municipality of Boane, Maputo Province
Water source: Umbuze River
Agricultural area: 3.8 hectares
Current use: Gasoline-powered motor pumps, high operating costs
Objective: Implement a sustainable and autonomous solar pumping system

2. Assessment of Daily Water Requirements

Average crop requires: 5 mm/day = 5 L/m²/day

Total area: 3.8 ha = 38,000 m²

Calculation of required volume:

→ 38,000 × 5 = 190,000 liters = 190 m³/day

3. Determination of Required Hydraulic Energy

Elevation height (estimated): 15 meters

Useful energy required: ~12.94 kWh/day

Total system efficiency (panels + pump): 60%

4. Solar Radiation in Boane

Average: 5.2 kWh/m²/day

Useful solar pumping time per day: ~6 hours

5. Solar Photovoltaic System Sizing

Required nominal power: ~2.5 kWp

Security margin of 25% → recommended solar system: 3,1 kWp

6. Estimated System Cost

Average price per 1 kWp installed: USD 1,300

Estimated investment: → 3.1 × 1,300 = USD 4,030 (complete system: pump, panels, structure, controller, installation).

7. Components of the proposed system

Table 1 shows a description of the proposed components of the water pumping system for irrigation and their specifications.

Table 1. Components of the proposed system

Component	Specification
Photovoltaic panels	7 modules of 450 W (total 3,150 W)
Submersible or surface solar pump	2.5-3 kW
MPPT controller	Compatible with pump and solar panels
Anti-corrosive support structure	adjustable to local soil conditions
Piping system	PVC or high-pressure HDPE
Water tank (optional)	5,000–10,000 liters

8. Economic Comparison (Annual)

System type Annual cost (USD) Lifespan Comment

Motor pump (gasoline) USD 960+ ~5 years High recurring fuel costs

Solar system USD ~50 (maintenance) 15–20 years Investment recovered in ~3 years

9. Innovative Advantages

Up to 95% reduction in operating costs

Total energy autonomy

Zero CO_2 emissions

Can be integrated with smart irrigation sensors

Greater predictability and efficiency in water use

Future Recommendations Install soil moisture sensors and microcontroller automation. Use techniques such as drip irrigation for maximum efficiency.

The following figure 3 illustrates the energy efficiency of the proposed solar system:

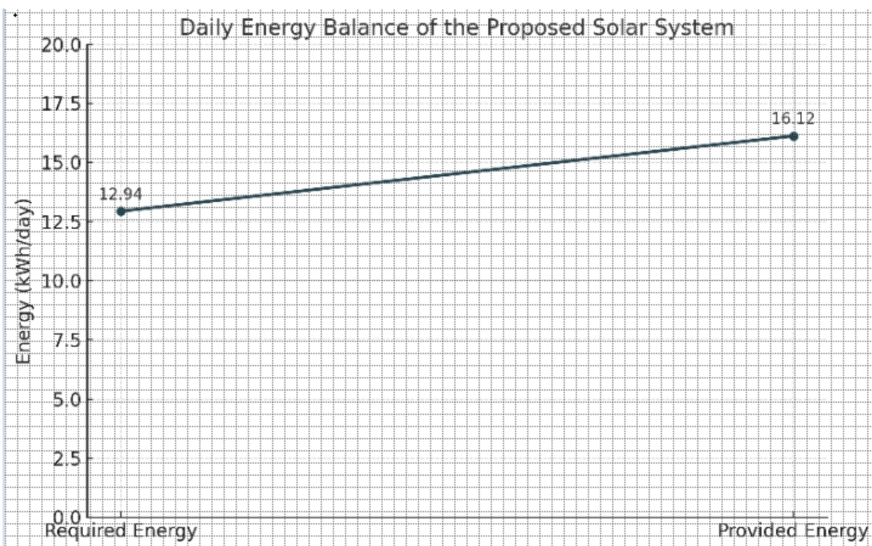

Figure 3. Daily Energy Balance of the solar system.

The bar on the left represents the daily energy required to pump 190 m³ of water from the Umbeluze River (approximately 12.94 kWh). The bar on the right shows the daily energy supplied by the 3.1 kWp solar system in Boane (about 16.12 kWh/day), ensuring energy security and full autonomy. This figure demonstrates that the system has an energy surplus, ensuring operational security even on days with lower radiation.

Figure 4 shows a representation of the proposed system for pumping water to farmers in the Boane district.

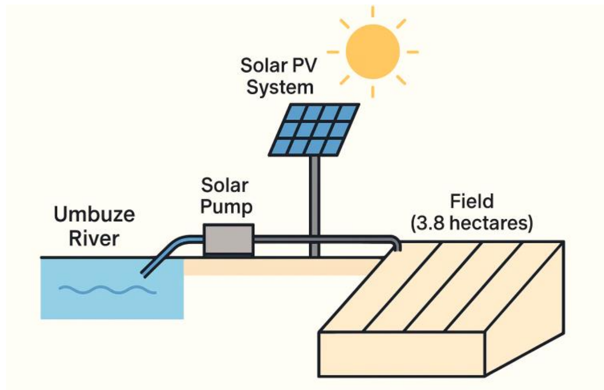

Figure 4. 2D image of the proposed photovoltaic solar system.

Below is a comparative figure illustrating the amount of water to be pumped monthly for a 3.8-hectare plantation. The figure 5 reveals the electrical energy required for this pumping (in kWh) and also the energy that can be generated by a 3.1 kWp photovoltaic system based on the average monthly solar radiation in Boane.

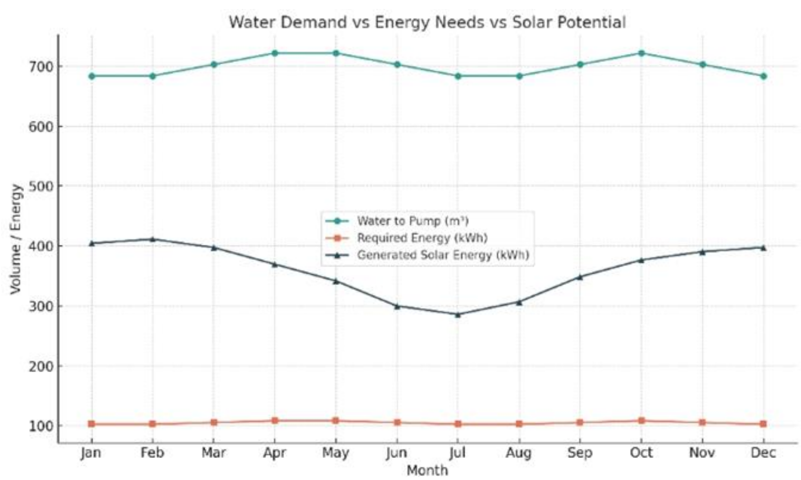

Figure 5. Comparative analysis of the amount of water to be pumped monthly to a plantation.

Complete and innovative design of a 3.1 kWp photovoltaic system to meet the irrigation needs of a 3.8-hectare plantation in the district of Boane, with water collected from the Umbeluze River.

1.Technical and Agronomic Assumptions

Location:

District: Boane, Maputo Province, Mozambique

Water source: Umbeluze River

Average annual solar radiation: ~5.4 kWh/m²/day (based on solar maps of southern Mozambique)

Agricultural Area:

Usable area: 3.8 hectares = 38,000 m²

Typical crops: vegetables and corn (high water demand)

Average irrigation requirement: 5 mm/day = 5 L/m²/day

⇒ Total daily volume required = 38,000 m² × 5 L/m² = 190,000 L/day = 190 m³/day

2. Energy required to pump 190 m³/day

Hydraulic Energy Calculation:

Assuming:

Total manometric height (HMT): 25 m (elevation, losses, minimum pressure)

Total system efficiency (pump + controller + piping): 55% (0.55)

Basic formula:

$$\mathbf{Energy\ (kWh) = \ \rho . g . \frac{QH}{\eta} . 3.6X10^{6}} \ \ (1)$$

Where

ρ = 1000 kg/m³ (densidade da água)

g = 9,81 m/s²

Q = 190 m³/dia = 190.000 L/dia

H= 25 m

ŋ= 0,55

3. Energy Generated by 3.1 kWp Solar System

$$\mathbf{Energy\ day\ = 3,1kWpX5.4\frac{\frac{kWh}{m^{2}}}{dia}\ X0.75\ (factor\ of\ losses)\ (2)}$$

Result: 3.1 kWp system does not cover the entire daily energy demand. Adjusted sizing is necessary.

4. Proper Sizing of Photovoltaic Systems

$$\mathbf{Required\ power = \frac{23,5}{5.4X0.75} \approx 5.8\ kWp}\ \ (3)$$

Recommended system: 6.0 kWp, with safety margin.

5. Recommended System Components

a. Solar Panels

Total power: 6,000 Wp

Number of panels: 15 × 400 Wp

b. Charge controller and inverter

5 kW hybrid or solar AC/DC inverter with MPPT input

Compatible with submersible or surface pump

c. Solar Pump

Type: AC/DC solar submersible pump with a flow rate of ~12 m³/h

Operating time: ~16 hours/month per hectare

d. Support system and cabling

Metal structure fixed to the ground

Cables with UV protection

6. Innovation

Intelligent system with:

Soil moisture sensors for on-demand irrigation

Solar controller with IoT: remote monitoring and shutdown

Elevated compensation tank: storage of water pumped during peak sunlight hours

Table 2. Cost Estimate (approximate values in MZN)

Component	Estimated Cost (MZN)
15 Photovoltaic panels	225.000
5 kW hybrid inverter	150.000
AC/DC solar pump	120.000
Fixing structure	60.000
Installation and cables	55.000
Estimated total 610,000 MZN	

In comparative terms, a system with a gasoline motor pump can cost 250,000 MZN + 400,000 MZN/year in fuel and maintenance.

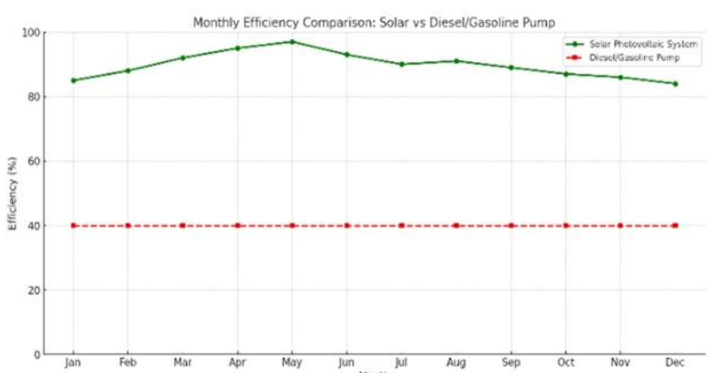

Figure 6. Comparison between a motor pump system and a solar system.

This is a comparative chart illustrating the monthly efficiency of the proposed solar photovoltaic system compared to diesel or gasoline-powered motor pumps. As can be seen, the solar system maintains high efficiency throughout the year, while motor pumps perform much worse and consistently (Figure 7).

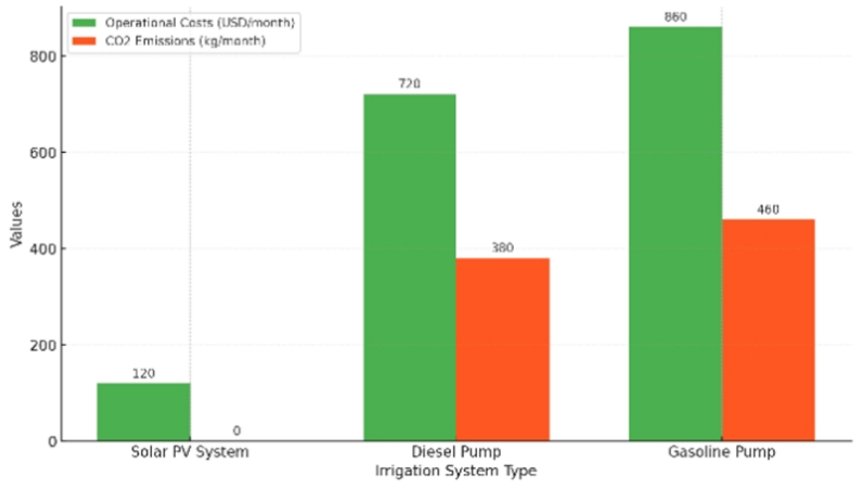

Figure 7. Comparative illustration of the operating costs and carbon emissions of the three irrigation systems.

This comparative chart illustrates the operating costs and carbon emissions of the three irrigation systems for 3.8 hectares from the Umbeluze Basin: Solar PV System: minimal operating costs and zero carbon emissions. Diesel Pump and Gasoline Pump: high costs and high CO_2 emissions.

The 6 kWp system is technically feasible and energy self-sufficient to irrigate the 3.8 hectares. It has a payback period of ~3.5 years, with significant energy and fuel savings, as well as being sustainable, quiet, and non-polluting.

The research results confirm the findings of Et-taibi *et al.* (2024), that renewable energy is becoming increasingly important in agriculture, improving its sustainability and reducing its impact on the environment. As the agricultural industry aims for energy self-sufficiency and sustainability, the use of energy sources such as solar energy is gaining popularity.

They also explain that eco-friendly energy solutions not only help reduce the carbon footprint of agricultural operations, but also lead to long-term cost savings.

Solar energy, specifically, is widely used in agriculture. Solar panels can provide energy for agricultural needs such as sensors, irrigation systems, and even entire data centers. This shift to energy makes farms more independent and reduces their dependence on non-renewable energy sources.

It is especially advantageous in areas without electricity grids, allowing for smoother agricultural activities. Wind energy is another asset for farms located in windy regions

Conclusion

Solar irrigation systems are technically and economically viable for family farming in Boane, especially considering the high levels of solar radiation and the challenges with fossil fuels. The gradual replacement of motor pumps with solar systems will contribute to the economic and environmental sustainability of the region.

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