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Technical-Economic Study of the Photovoltaic Pumping System and Generator of the Madinah Village in Dabola, Republic of Guinea

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Abstract: This work concerns the study and analysis of the technical and economic aspects of the water pumping station in the village of Madina in the prefecture of Dabola, powered by a photovoltaic energy system and a generator. The methodology adopted consists of carrying out the economic analysis of the photovoltaic and generator pumping systems separately, using economic analytical formulas in order to compare the costs between the two systems. The evaluation of the overall updated cost of the cubic meter of water pumped required knowledge of the following data: the lifespan of each component, the initial investment, the annual maintenance costs and the replacement costs of the different subsystems. The results obtained show that the pumping by the photovoltaic generator needs an initial investment of 89000000 GNF, or approximately (9000 US dollars) with a depreciation of 4511428.571GNF or (460 US dollars). The annual maintenance of the pumping system by the photovoltaic generator is therefore 1630000 GNF (165 US dollars). Pumping by the generator set needs an initial investment of 56500000 GNF or (6000 US Dollars) for depreciation of 2902857.143 GNF or (300 US Dollars). The annual maintenance of the pumping system by the generator is therefore 965000 GNF (100 US dollars). For normal operation, the annual operation of the generator will be 36653300 GNF (4000 US dollars). On the basis of this study, it appears that the cubic meter of water pumped by the generator costs 3700.56 GNF or (0.40 US dollars) while with the photovoltaic generator the price of the cubic meter of water is 560.86 GNF or (0.06 US Dollars). Thus, it appears that pumping water by solar photovoltaic energy is more interesting.

Keywords: Technical-Economic, Pumping, Photovoltaic, Generator, Dabola

1. Introduction

Water and energy are among the most important essentials and essentials for life. The increasing demand for energy and the inevitable future depletion of conventional sources require research on alternative sources, such as renewable energies [1, 2]. Solving the problem of drinking water and for irrigation in isolated sites is a major problem [3-5].

In sub-Saharan Africa, more than 300 million people do not have access to safe drinking water sources and most of them live in rural areas. Photovoltaic water pumping systems can improve this drinking water supply in rural villages that are not connected to the electricity grid [6, 7].

Despite Guinea's strong hydrogeological potential and the significant efforts made to exploit it, the rates of access to drinking water in rural and urban areas are still relatively low. Improving the living conditions of populations in rural areas is linked to the search for adequate solutions to this problem [8]. The Republic of Guinea has an appreciable solar potential which is around 1 kW/m^2 and its development requires know-how in order to provide certain solutions to the energy problems of the populations [9].

Today, the demand for water is more and more important, especially in rural areas and isolated sites where access to conventional energy is difficult if not practically impossible. This phenomenon has led to growing interest in the use of photovoltaic generators as a new source of energy. Indeed, photovoltaic systems are interesting because they are easy to install, with acceptable autonomy and excellent service reliability [10].

2. Material and Method

2.1. Material

2.1.1. Site Presentation

The study site is the village of Madinah, one of the sectors of Hamdallaye district in Dabola prefecture. This sector is made up of 150 families including 8 to 10 people per household with 51.5% women and 48.5% men. It is located 382 km from Conakry and 50 km from the capital of Dabola. It lies between 11°26’ W longitude and 10°42’ N latitude, with an average altitude of 639 m. The average annual rainfall is 1642.14 mm, the average relative humidity is 85.5%, with an average temperature 25°C and an average solar irradiation of 5.50 kWh/m^2/d [8].

2.1.2. Technical Characteristics of the Pumping System

The technical characteristics of the Madinah sector pumping system are given in table 1 [8].

Table 1. *Technical characteristics of the site pumping system.*

Parameters	Symbols	Values	Units
Daily flow	Q	30	m^3/d
Total Manometric Height	HMT	40	m
Daily energy required	E_{elect}	7431.81	Wh/d
Peak panel power	P_c	2452	Wc
Number of module	N_m	10	-
Inverter power	P_{ond}	2752	W
Power of generator set	P_{ge}	1.5	kVA
Total capacity of six waters tanks	Ré	18	m^3
Currency in Guinean Franc	GNF	1 \$ = 9	920 GNF

2.2. Method

The RETScrem software, charts and archives made it possible to determine the meteorological parameters (temperature, sunshine, rainfall and relative humidity) of the study site. The economic analytical formulas were used for the technical-economic calculations.

The methodology consists of making the economic analysis of the photovoltaic pumping system and the generator set separately, in order to make a comparison between the two systems. The economic analysis of a pumping system provides two types of information, namely the updated costs of the pump (initial investment) and the annual costs it generates (operation and maintenance).

2.2.1. Case of the Photovoltaic Pumping System

We will study separately the investment costs, the operating costs and the maintenance and maintenance costs. The evaluation of the updated global cost of the cubic meter of pumped water requires knowledge of the following data: the lifespan of each component, the initial investment, the annual maintenance costs relating to the photovoltaic system and the replacement costs of the various subsystems [11-13].

Total initial investment

The total initial investment is calculated by formula 1.

$$I_{tot} = C_{GPV} + C_{ond} + C_{Mp} + C_{res} + C_{for} + C_{acc} \quad (1)$$

With: $C_{GPV} = P_m \times N_m$; Where: C_{GPV} is the cost of the photovoltaic generator; Pm is the price of the modules, N_m is the number of modules and C_{ond}, C_{Mp}, C_{res}, C_{for}, C_{acc} are the costs of the inverter, motor pump, tank, borehole and accessories respectively.

Lifetime costs

The lifetime costs or annual aggregate present value cost is calculated by formula 2.

$$C_{GA} = A_{tot} + E_{tot} \quad (2)$$

Where: A_{tot} is the cost of the total depreciation; E_{tot} is the cost of upkeep and total maintenance.

Total amortization

The calculation of the energy cost, taking into account the depreciation over time, takes into account the life of the components as well as the profiles made over the entire active life of the system. This total annual system depreciation is calculated by formula 3 [14].

$$A_{tot} = A_{GPV} + A_{ond} + A_{Mp} + A_{res} + A_{for} + A_{acc} \quad (3)$$

The depreciation of each component is the ratio between its initial investment cost (C) and its active life (N). Thus, the depreciation costs of each component are calculated by the following relationships:

Damping of the photovoltaic generator is:

$$E_{GPV} = C_{GPV} \times K_{GPV};$$

Damping of the inverter is: $E_{ond} = C_{ond} \times K_{ond}$;

Damping of the pump unit is: $E_{Mp} = C_{Mp} \times K_{Mp}$;

Amortization of the reservoirs is:

$$E_{reser} = C_{reser} \times K_{reser};$$

Amortization of the borehole is: $E_{for} = C_{for} \times K_{for}$;

Damping of accessories is: $E_{acc} = C_{acc} \times K_{acc}$.

The average lifespans of the various components of the photovoltaic pumping system are approximately as follows: solar panel modules (25 years), inverter (7 years), motor pump (7 years), tank (25 years), Drilling (40 years) and accessories (25 years) [15].

Annual maintenance and care

The annual maintenance and repair costs of the entire system are given by formula 4.

$$E_{tot} = E_{GPV} + E_{ond} + E_{Mp} + E_{res} + E_{for} + E_{acc} \quad (4)$$

The maintenance costs of each component are a function of the initial investment cost (C) and the coefficients of estimates of the cost of maintenance compared to the initial investment (k). They are given by the following relations:

The photovoltaic generator: $E_{GPV} = C_{GPV} \times K_{GPV}$;

The inverter: $E_{ond} = C_{ond} \times K_{ond}$;

The pump unit: $E_{Mp} = C_{Mp} \times K_{Mp}$;

For tanks: $E_{res} = C_{res} \times K_{res}$;

For drilling: $E_{for} = C_{for} \times K_{for}$;

For accessories: $E_{acc} = C_{acc} \times K_{acc}$.

2.2.2. Case of the Pumping System by Generator

The economic analysis of the generator pumping system is based on the following elements: generator set, electric pump, hydraulic part (drilling, reservoirs) and accessories [16].

Generator

The choice of generator set depends on the characteristics of the motor pump. Thus, the power of the generator set (Pge) to be chosen is calculated by relation 5 [17].

$$P_{ge} = \frac{E_h}{\eta_{mp} \times t_p} \tag{5}$$

With: $E_h = C_h \times Q \times HMT$

Where: E_h is the hydraulic energy in (kWh/d);

$\eta_{mp} = 44\%$ and the efficiency of the motor pump;

$t_p = 6$ hours, is the time required for pumping water.

Cost calculation

For this second option, some costs such as the total initial investment and total depreciation are determined in the same way as for the photovoltaic solar pumping system (by relations 1, 2 and 3), while replacing the cost of the photovoltaic generator by the purchase cost of the generator set (C_{GE}). Also, the depreciation cost of the PV generator is replaced by the depreciation of the generator set [18].

Upkeep and maintenance of the pumping station by generator

The evaluation of the annual cost of maintenance and maintenance $C_{e/m}$ of the generator set is determined by formula 6.

$$C_{e/m} = 0.05 \times C_{GE} \times N_H \times D \times C_{Trans} \times C_{prch} \tag{6}$$

Where: C_{GE} is the cost of the Generator; N_H is the number of hours of operation of the generator set; D is the distance from the site to the nearest gas station and C_{prch} is the pick-up cost.

For the other components, the annual cost of servicing and maintaining the system is calculated in the same way as for pumping by photovoltaics.

Annual operating cost of the generator

The total annual operating cost of the generator set is evaluated on the basis of electrical characteristics as well as fuel and lubricant consumption. This total annual operating cost $C_{d/l}$ is calculated by relation 7 [19].

$$C_{d/l} = C_d + C_l \tag{7}$$

With:

$$C_d = P \times C_{ons/year} + D \times C_{Trans};$$

$$C_l = 0{,}2 \times P \times C_{ons/year};\ C_{ons/an} = C_{ons/d} \times 365;$$

$$C_{ons/year} = C_{ons/d} \times 365;\ C_{ons/d} = C_{ons/h} \times N_H.$$

Where: C_d is the cost of fuel; C_l is the cost of lubricants; P is the price per liter of fuel; D is the distance from the installation site to the city (3 km); C_{Trans} is the cost of transport per day and $C_{con/year}$ is the annual fuel consumption.

Cost per cubic meter of water pumped

To estimate the cost per cubic meter (m^3) of pumped water, the annual water requirement (B_{year}) of the study area is calculated by formula 8 [8].

$$B_{an} = B_J \times 365 \tag{8}$$

3. Results and Discussions

3.1. Results

The results obtained during this study are illustrated by the diagrams in the figures below.

3.1.1. Photovoltaic Pumping System

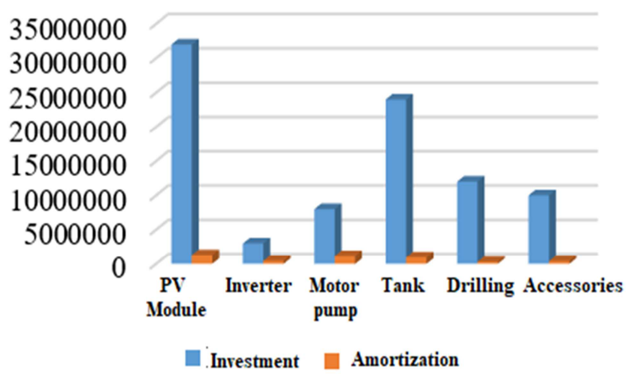

Figure 1. Diagram of investment and depreciation costs of the photovoltaic pumping system.

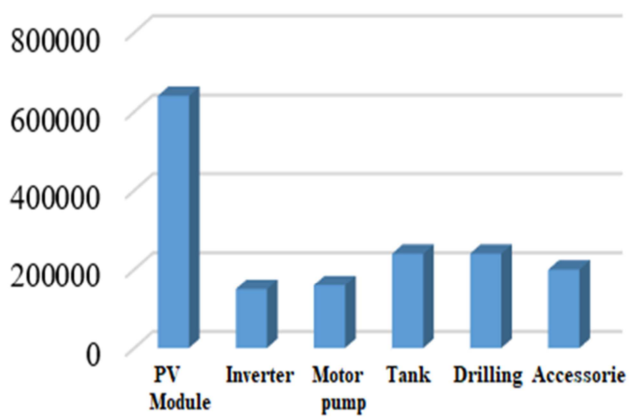

Figure 2. Diagram of total maintenance per year of the photovoltaic pumping system.

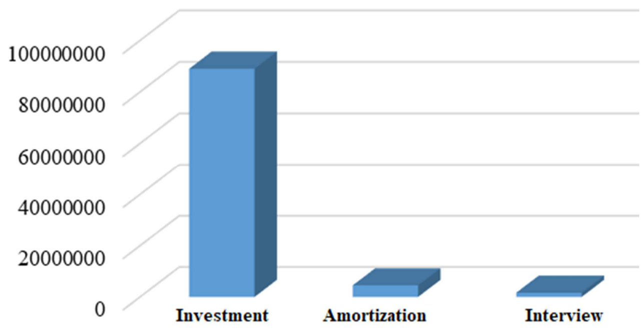

Figure 3. *Diagram of the economic parameters of photovoltaic pumping.*

3.1.2. Pumping System by Generator

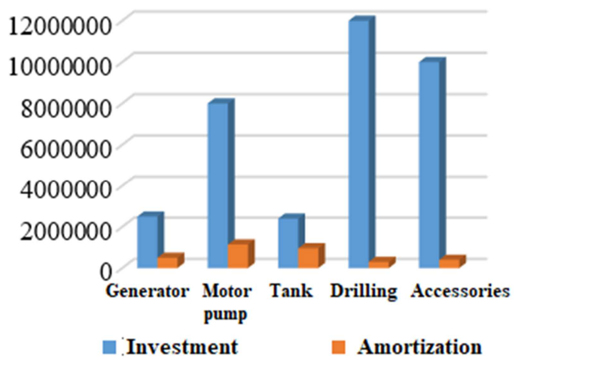

Figure 4. *Diagram of investment and depreciation costs of the generator pumping system.*

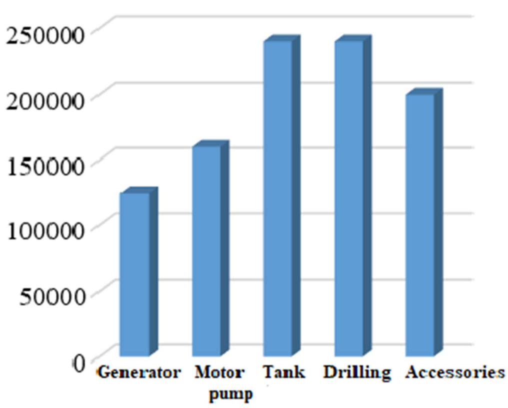

Figure 5. *Diagram of total maintenance per year of the pumping system by generator.*

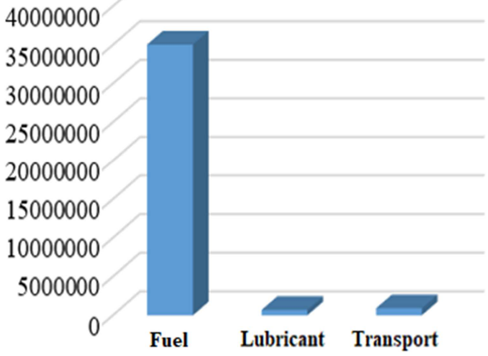

Figure 6. *Total annual operating cost of pumping by generator.*

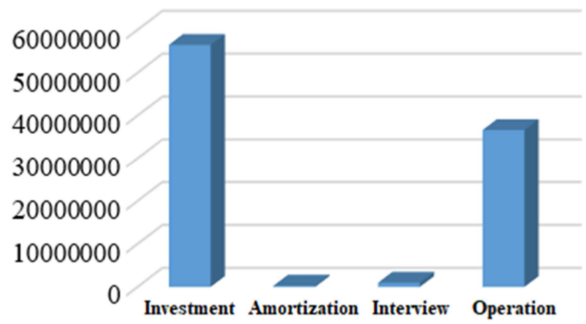

Figure 7. *Diagram of the economic parameters of pumping by generator.*

3.1.3. Cost Comparison of the Two Pumping Systems

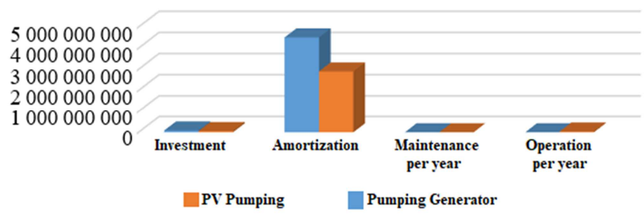

Figure 8. *Cost comparison of the two pumping systems.*

3.1.4. Cost Comparison of the Two Pumping Systems

The installation and maintenance costs of the two pumping systems are illustrated in the diagrams in Figure 9.

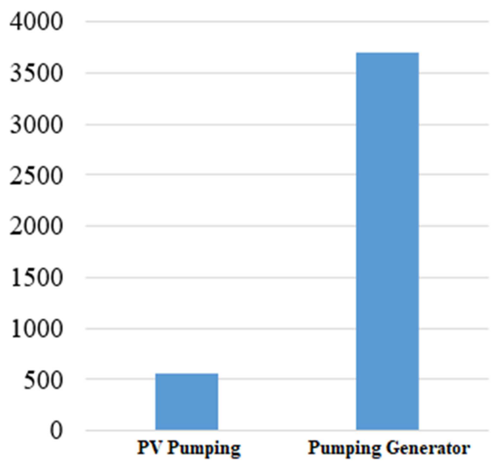

Figure 9. *Diagram comparing the cost of cubic meter of water pumped by the two photovoltaic systems and generator.*

3.2. Discussion of the Results

The meteorological parameters of the study area show that the site is favorable to the solar photovoltaic system. The annual average temperature is around 25°C, with an average annual irradiation of 5.54 $kWh/m^2.d$. The annual average precipitation is 1642.14 mm, with an annual average humidity of 85.5%.

Pumping by the photovoltaic generator needs an initial investment of 89000000 GNF or approximately (9000 US dollars) with depreciation of 4511428.571GNF or (460 US dollars). The annual maintenance of the pumping system by the photovoltaic generator is therefore 1630000 GNF (165 US dollars). Pumping by the generator set needs an initial investment of 56500000 GNF or (6000 US Dollars) for depreciation of 2902857.143 GNF or (300 US dollars). The annual maintenance of the pumping system by the generator is therefore 965000GNF (100 US dollars). For normal operation, the annual operation of the generator will be 36653300 GNF (4000 US dollars). On the basis of this study, it appears that the cubic meter of water pumped by the generator costs 3700.56 GNF or (0.40 US dollars) while with the photovoltaic generator the price of the cubic meter of water is 560.86 GNF or (0.06 US dollars). Thus it appears that pumping water by photovoltaic solar energy is more interesting.

4. Conclusion

This study showed that the Madinah site has a favorable climate for the exploitation of photovoltaic energy, with an average sunshine of 5.54 $kWh/m^2.d$. We carried out the technical and economic study of the entire system. All related parameters (investment cost, depreciation, annual maintenance and annual operation) were calculated. A detailed comparative study between the studied solar pumping system and that using a generator set, highlighted the advantage of using solar photovoltaic pumping. We recommend, in relation to our results, the development of this type of decentralized energy (photovoltaic) to promote access to drinking water for populations at a lower cost in villages or isolated areas.

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