A Comparative Technical-Economic Study of two Water Pumping Systems for an Isolated Community in Algeria

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Abstract

The goal of this work is to size a photovoltaic pumping system built on a brushless DC motor and without accumulators, then to evaluate its cost by comparing the latter with a pumping system powered by a diesel generator for a system of irrigation in an isolated site in the city of Saïda in Algeria, based on a technique known as the cost of the life cycle. The water pumping system is designed to irrigate an area of 8 hectares, planted with onions. Based on the results of this study, the photovoltaic pumping system is more economically viable compared to the system running on diesel.

Keywords: Photovoltaic Pumping System; Diesel generator; Life Cycle Cost; Agriculture.

1. Introduction

Water and energy are among the most important and essential elements of life. Demand for energy and the inevitable future depletion of conventional sources requiring research into alternative sources, such as renewable energies.

The Saharan regions representing 80% of the country are facing major problems to cover drinking water need; Algeria has considerable renewable energy resources, particularly solar and wind energy options that are now relevant solutions to face this problem [1].

In this work, we were particularly interested in the application of photovoltaic solar energy in the water pumping system in a remote site in Saida. The use of photovoltaic water pumping systems for irrigation allows combating desertification and increasing the income of farmers by improving the yield. Consequently, improving the living conditions in rural and poor areas

could further prevent the rural displacement, which is a typical phenomenon in developing countries [2].

What distinguishes Saida from the desert is its low temperature, and this property has a positive effect on the efficiency of the photovoltaic generator (GPV). Despite this particular physical setting, the consumption of solar energy is not generalized due to the lack of sensitivity of the populations and their tendency to use conventional energy sources such as generators, and this exploitation can be a degradation of water and soil quality and has countless consequences for our health, our environment and our economy [3].

To meet the irrigation needs of a farmland of onion farming, a comparative economic analysis of the two pumping systems, one is Brushless Direct Current (BLDC) water pump fed by PV solar energy (in the presence of the sun) and the other powered by diesel takes place in this work. In this analysis we relied on a method called the life cycle cost (LCC) [4][5] where a cost analysis should include the cost of financing the capital as well as the present value of operating costs, maintenance and replacement over the expected life of the pumping system.

2. Case study

Saida is geographically located in the northwest of Algeria with the latitude of the coordinates 34.87 N and longitude 0.15'E. Saida benefits from very significant irradiation per year for which the use of a PV water pumping system can be considered with strong chances of success [6]. Fig.1 shows the energy received per month in the horizontal surface of Saida city. These measurements of solar radiation are mainly carried out in our laboratory [7]. In this figure, the maximum monthly global radiation observed is 173 kWh/m² in summer. In autumn and winter, it is 90 KWh/m².
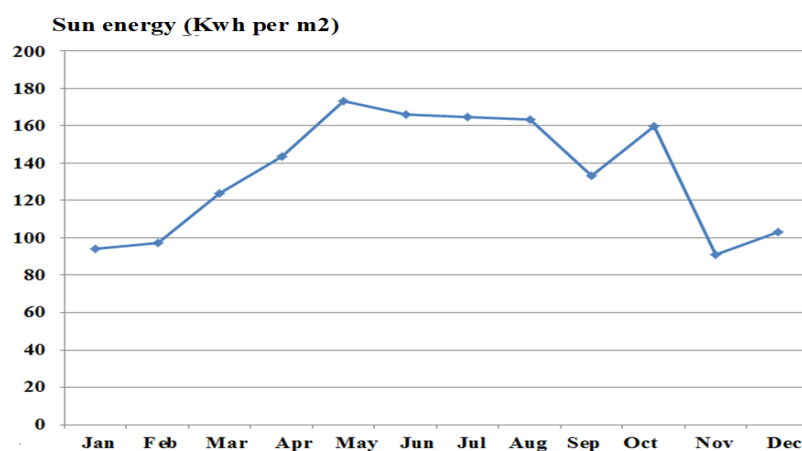

Fig 1. Average sun energy per month in Saida city during the year 2016

The case study considers irrigation of 8 hectares of agriculture land of onion farming, the current architecture is a pumping system powered by a diesel to fill a basin from a well, where the height of this basin from the ground allows watering one-fifth of the agricultural piece without a pump. People in these regions are tending to use conventional energy for irrigation and this exploitation can be a degradation of water and soil quality and has countless consequences for our health, our environment and our economy [2]. A comparative economic analysis of the two pumping systems, one is Brushless Direct Current (BLDC) water pump fed by PV solar energy (in the presence of the sun) and the other powered by diesel generator will be detailed in the next section.

3. Economic Analysis of the photovoltaic pumping system

The architecture of a photovoltaic pumping system is often composed of [8]:

Photovoltaic generator, command and control electronic (Boost converter), electric pump (BLDC Motor),the hydraulic part (drilling, reservoirs, etc.) and accessories.

To assess the discounted overall cost of m^3 pumped water, it is necessary to have certain data, to know [9]:

The lifespan of each component, the cost of the initial investment, the cost of the annual maintenance relating to the photovoltaic system, the cost of the different subsystem replacing.

3.1 Calculation method

From the investor's perspective, the present cost of pumping system allows cost comparison between different options. Its importance is linked to the fact that some options require large initial investment and operating costs and relatively low maintenance, while others present the opposite situation. In these conditions, a cost analysis should include the cost of financing the capital as well as the present value of operating costs, maintenance and replacement over the expected life of the pumping system. This analysis is called the lifetime cost calculation (life cycle cost) [5][10].

3.2 Calculation of the total initial investment

The initial investment lets the user know what price they will have to pay when installing their system.

The total cost I_{Tot} is calculated by the following expression: [11]

$$I_{Tot} = I_{GPV} + I_b + I_{MP} + I_{Acc} \tag{1}$$

Knowing that is the cost of GPV and it is calculated by:

$$I_{GPV} = P_P \cdot N_P \tag{2}$$

with P_P is panel price, N_P is panels number, I_b, I_{MP} and I_{Acc} are respectively cost of the boost converter, motor pump and accessories.

3.3 Calculation of lifespan costs

We use the method known as the calculation of costs over the lifespan (life cycle cost).

The annual global cost of the present value is calculated by the following expression:

$$C_{GA} = C_{Tot} + M_{Tot} \tag{3}$$

With C_{Tot} is total consumption and M_{Tot} is total maintenance.

3.4 Calculation of total consumption

To calculate the cost of energy taking into account the consumption over time, we take into account in our calculation, the component lifespan as well as the benefits realized over the entire active life of the system [11,12].

The total annual consumption of the system C_{Tot} is given by the formula:

$$C_{Tot} = C_{GPV} + C_b + C_{MP} + C_{Acc} \tag{4}$$

$C_{GPV}, C_b, C_{MP}, C_{ACC}$ Are respectively consumption of the photovoltaic generator, the boost converter, motor pump and accessories.

For each component, the consumption is calculated as follows:

$$C = I/L \tag{5}$$

With I is the cost of the initial investment of each component and L is the lifespan of the component.

Lifespan is estimated for each of the elements of the system, are given below

Table 1. Estimates of component lifetimes

Equipment	GPV	Electric pump	Boost converter	Accessories
lifespan (year)	20	7	7	20

3.5 Calculation of the total annual maintenance.

Despite the reliability of solar pumps, it is essential to ensure their proper functioning through periodic maintenance. Since the initial assumptions may be different, the cost of maintenance is very difficult to assess over time. To calculate an average annual cost, the most reasonable approach is based on real experience in the field which, as theoretical as it is, would give a realistic order of magnitude [12].

The calculation of the total annual maintenance cost of the system is given by the expression:

$$M_{Tot} = M_{GPV} + M_b + M_{MP} + M_{Acc} \tag{6}$$

Knowing that the cost of maintaining each component is calculated as follows:

$$M = I \cdot R \tag{7}$$

With I is the cost of the initial investment of each component, R is the ratio of estimation between the cost of maintenance and the initial investment of the components.

The example of calculating the total cost of investment, annual consumption and maintenance considers irrigation of 8 hectares of agriculture land of onion farming, the current architecture is a pumping system powered by 6.4Kwc of PV solar energy (20 panel of 320W) producing 23 Kw per day to fill a basin from a well, where the height of this basin from the ground allows watering one-fifth of the agricultural piece without a pump.
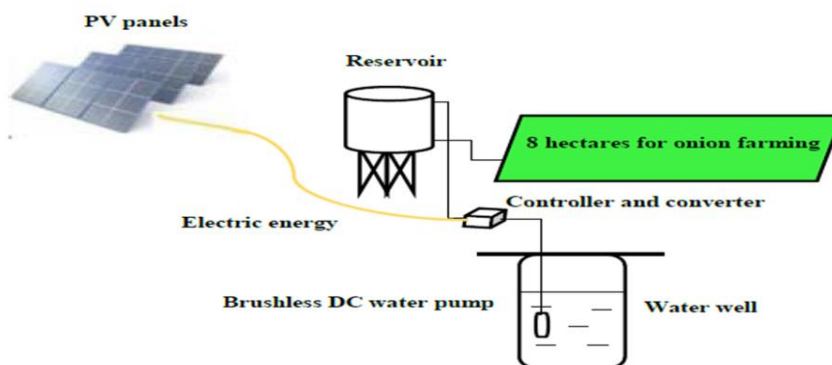

Fig 2. Schematic layout of photovoltaic irrigation system

The results were included in the table 2:

Table 2. The cost of components

	GPV	Boost converter	Electric_pump	Accessories	Total
Investment (DA)	420000	76200	240000	80000	816200
lifespan (ANS)	20	7	7	20	/
consumption (DA)	21000	10885,7	34286	4000	70171
Ratio (%)	2	2	2	2	/
Maintenance	8400	1524	4800	1600	16324

It was found on Table 2 that 'PVPS' photovoltaic pumping systems has an important part of the cost of investing equipment relative to other costs, as maintenance, on the other hand, the operating costs are zero.

4. Economic Analysis of diesel pumping system

For the same pumping station, we supply the motor pump by diesel.

The new system is composed by Diesel, electric pump, the hydraulic part (drilling, reservoirs, etc.) and accessories.

Diesel is selected on the basis of the characteristics of the electric pump.

The power P of Diesel is calculated by the following formula:

$$P = \frac{E_h}{\eta_{MP} \cdot t_p} \tag{8}$$

With E_h is Hydraulic energy (given by the builder), η_{MP} is The efficiency of the motor pump (given by the builder) and t_p is The time required of pumping per day.

4.1 Calculation of the total initial investment

In the same way as for the solar pumping system, from the moment when the components of the system are chosen, the total cost of the investment is calculated as follows:

$$I_{Tot} = I_D + I_{MP} + I_{Acc} \tag{9}$$

Knowing that I_D is the cost of diesel, I_{MP}, I_{Acc} Are respectively cost of motor pump, accessories.

4.2 Calculation the total consumption

We use the same method (known as the lifespan cost calculation) to calculate the total consumption annual of the system by the formula:

$$C_{Tot} = C_D + C_{MP} + C_{Acc} \tag{10}$$

Knowing that for each component, the consumption is calculated as follows:

$$C = \frac{I}{L} \tag{11}$$

With I is the cost of the initial investment of each component and L is the lifespan of the component.

4.3 Calculation of the total annual maintenance

The evaluation of the annual cost of maintenance C_m of diesel is determined by the following expression:

$$C_m = 5\% I_D . NH \tag{12}$$

Where I_D is diesel cost and NH is the number of hours of operation of diesel.

For the other components, the calculation of the annual cost of maintenance is carried out in the same way used in the previous case of the solar PV pumping system.

4.4 Calculation of the total annual operation

The operating cost of diesel is assessed on the basis of the data relating of the electrical characteristics plate as well as the fuel and lubricant consumption of diesel.

We calculate the total annual operating cost $C_{F/l}$ by the formula [12] :

$$C_{F/l} = C_F + C_l \qquad (13)$$

Knowing that:

$$C_F = P \cdot Cons / year \qquad (14)$$

$$C_l = P \cdot \frac{Cons}{year} \cdot 20\% \qquad (15)$$

Where C_F is fuel cost and C_l is lubricant cost, P is liter fuel price and $Cons / year$ is annual consumption and it is calculated by:

$$\frac{Cons}{year} = \frac{Cons}{d} \cdot 365 \qquad (16)$$

$$\frac{Cons}{d} = \frac{Cons}{h} \cdot NH \qquad (17)$$

With Cons/d is daily consumption, NH is the number of hours of diesel operation

Cons/h: hourly consumption (manufacturer data)

The example of calculation of total cost of the investment, the annual consumption and the maintenance of diesel pumping system.
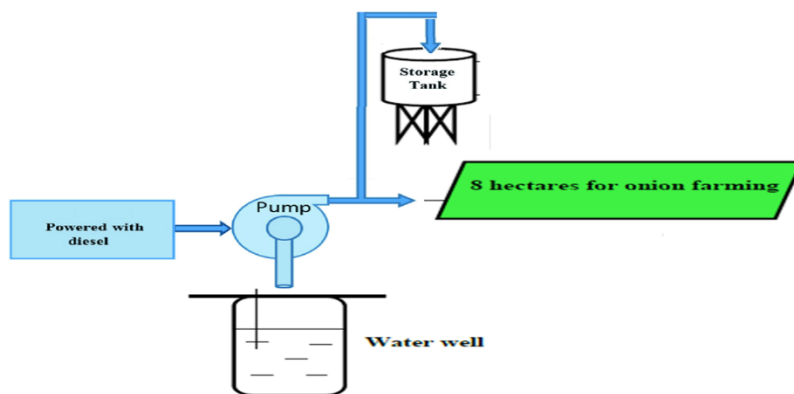

Fig 3. Schematic layout of diesel generator irrigation system

The results were included in the table 3:

Table 3. The cost of components

	Diesel	Electric pump	Accessories	Total
Investment (DA)	620000	45400	80000	745400
lifespan (ANS)	5	7	20	/
consumption (DA)	124000	6486	4000	134486
Maintenance	186000	908	1600	188508
Total cost operating(DA)	800000	0	0	800000

For 'DPS' diesel pumping systems, maintenance costs are not negligible compared to the cost of the total system investment and the total operating cost

5. Results and discussion

The LCC analysis allows cost comparison between different options. Its importance is linked to the fact that some options require large initial investment and operating costs and relatively low maintenance, while others present the opposite situation.

A comparison of the two water pumping systems, PVPS and DPS in terms of a lifetime cost analysis, is shown in Table 4. Fig 4 shows a cost comparison between the two systems

Table 4. The cost of components

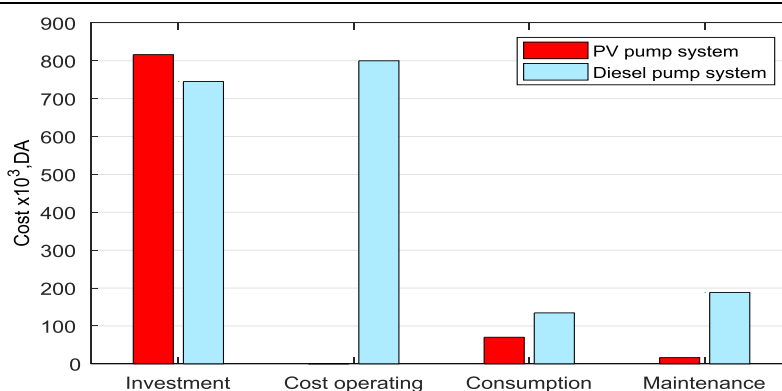|	Photovoltaic System	Diesel System
Investment	816200	745400
Cost operating	0	800000
Consumption	70171	134486
Maintenance	16324	188508
Global cost	902695	1868394

Fig 4. Comparative cash flow summary for the two systems

We can notice in Fig. 4 that the PV system has a much higher initial cost than that of the system with Diesel; the "weak point" of the photovoltaic pumping solution remains the initial investment. By comparing the costs of the two pumping systems fed differently, it was noted in Fig. 4 that the solar photovoltaic pumping systems constitute an important part in the cost relating to the investment of the equipment by compared to other costs, such as consumption and maintenance, on the other hand the operating cost being zero.

From the analyse results, it is noticed that the PV system has a much higher initial cost than that of the system with Diesel; the "weak point" of the photovoltaic pumping solution remains the initial investment..

Table 5. Global cost of two pumping systems

Global cost	Costs(DA))
Photovoltaic pumpimg system	929719.16
Diesel pumpimg system	1924329.60

It was found that the Diesel pumping system global cost is higher than that of the PVP global cost for irrigation in Saida; this can be explained by the fact that this system doesn't have operating cost. Regarding pumping systems using a Diesel generator the costs of maintenance and operation are not negligible compared to the cost of the investment
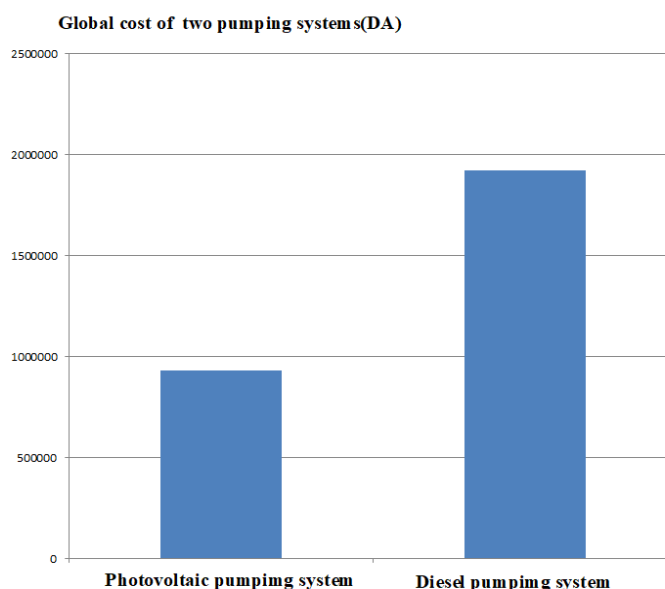
Fig 5. Comparison between the total investment for the two systems

On the other hand, the solar energy is a clean and renewable energy contrary to diesel generators which cause noise and produce gases.

6. Conclusion

The objective of this paper is to present a comparative technical-economic study of two water pumping systems (photovoltaic and diesel) in an isolated site in Saida city in Algeria. The case study considers irrigation of 8 hectares of agricultural land of onion farming, the current architecture is a pumping system powered by diesel to fill a basin from a well, where the height of this basin from the ground allows watering one-fifth of the agricultural piece without a pump.

According to this analytic study, it can be concluded that the pumping system powered by a PV generator is the best solution from an economic point of view and that the configuration of a pumping system without energy storage (pumping over the sun) with water storage is the favorable way to lower the price of the system and use the quantities pumped rationally.

7. References

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