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A comparative study of the solar pumping system direct and the conventional pumping system

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ABSTRACT: *Water and energy are essential and indispensable elements for life. The growing demand for energy and the inevitable future depletion of conventional (fossil) sources necessitate research into alternative sources, such as renewable energy. It is necessary to harness energy potential for electricity generation and pumping. It is against this backdrop that we have carried out a comparative study between the solar-powered pumping system that operates as the sun moves across the sky and the conventional pumping system using a generator and EDM-SA. To carry out this study, we estimated the installation and operating costs of the various water pumping systems (solar-powered pumping following the sun's path, conventional pumping with a generator, and conventional pumping with EDM-SA).*
Field visits (to two farms) enabled us to ascertain the installation and operating costs of the solar-powered pumping systems on these farms. The results obtained for the solar-powered pumping system allowed us to compare the installation and operating costs with those of conventional pumping systems powered by a generator or by the EDM-SA. These results show that the generator set pumping system is more expensive than both the solar-powered pumping system and the system powered by EDM-SA.
The findings of our comparative study are promising and remain to be validated in practice.
Keywords*: Solar pumping system, conventional pumping system, installation cost, operating cost.*

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I. INTRODUCTION

Since the widespread adoption of electrification, global energy demand has been growing steadily. The challenges associated with energy conversion and storage, combined with the logistical constraints of fuel transport and the rigorous maintenance required for internal combustion engines, make the search for alternative energy sources imperative. At present, the majority of the energy consumed comes from fossil fuels and finite resources, on which conventional hydraulic pumping systems rely heavily. However, the large-scale exploitation of these resources poses a major risk of depleting global reserves whilst causing a critical environmental impact. However, the choice of a pumping system is a strategic decision that directly affects the economic viability of farms.

Consequently, a great deal of research has been carried out into the configuration, optimisation and performance of these installations.

Among these studies, [1] carried out research into the modelling, simulation and optimisation of a solar-powered pumping system designed for the irrigation of a farm in Aïn Sefra (Algeria). Using MATLAB/Simulink, they compared three control techniques: conventional incremental conductance (INC), an improved sliding-mode version (INC-SMC), and a fuzzy logic approach (INC-FLC). Their results demonstrated the superiority of the INC-SMC hybrid strategy in terms of convergence speed, robustness against variations in solar irradiance and overall energy efficiency.

Furthermore, in Niger, [2] carried out a comparative study of the cost-effectiveness of solar and thermal pumping systems in the Soumarana irrigation scheme. Their findings indicate that the solar system performs better economically than the thermal system. This finding is consistent with earlier work by [3] in Algiers, who analysed the investment and operating costs of a photovoltaic system compared with a generator set. Their numerical method demonstrated that the photovoltaic system requires a significant initial investment but entails very low maintenance and operating costs, in contrast to the generator set. More recently, [4] confirmed this dichotomy (high initial investment and low recurring costs for solar, compared with the opposite pattern for thermal systems).

Despite the fact that these studies have explored simulation, optimisation and economic feasibility, there remains a significant lack of research directly comparing the solar-powered, sun-tracking pumping system with conventional solutions (the generator set and Mali's national electricity grid, EDM-SA). This lack of direct comparative data highlights the need for an in-depth study.

This article is set against this backdrop, and its overall aim is to carry out a comparative study between the solar-powered pumping system that operates as the sun moves across the sky and conventional systems (solar-powered pump operating as the sun moves across the sky, a generator, and connection to the EDM-SA grid). More specifically, the aim is, on the one hand, to assess the various initial installation costs and operating costs over a ten (10)-year period. On the other hand, it is to compare these technological configurations in order to identify the most economically viable option.

The remainder of this document is structured as follows: Section 2 sets out the methodology; Section 3 details the results and discusses them; finally, Section 4 presents the conclusions and outlines the implications of this study.

II. MATERIAL AND METHODS

Indeed, based on meteorological data from the sites studied, the electrical characteristics of the materials used, the different sizes of the farms and the quantities of water required, we estimated the installation and operating costs over 10 years for the solar pumping system at these two (2) farms; subsequently, these costs were simulated for a conventional pumping system using a generator and a conventional pumping system supplied by EDM SA, using the RETScreen software.

Finally, the results obtained were compared in order to identify the most economically viable technology for long-term solar pumping system projects in Mali.

2.1. Overview of the study area (Kati Circle)

The Kati district is a local authority in Mali, situated in the Koulikoro region. Its geographical coordinates are: 12°30' north and 8°20' west, and its socio-economic activities include agriculture, livestock farming and fishing [5].

The Kati Circle has a Sudano-Sahelian climate. Rainfall is linked to the seasonal oscillation of the Intertropical Convergence Zone, which divides the year into two distinct seasons. The rainy season lasts 6 to 7 months (May to October), followed by a dry season. The average temperature difference between the coolest month (24 °C, December/January) and the hottest month (32 °C, April/May) is 8 °C [6].

Over the year, the average temperature is 27.6 °C and average rainfall is 789.6 millimetres.

Sampling was carried out at two (2) sites:

- The NYETASSOBA farm, specifically in the village of Sikorolé (Kati circle, Koulikoro region, according to Mali's former administrative division). Its geographical coordinates are: (12.37198 North; 8.15742 West) [5].
- Amadou Sidibé's farm in the village of Samaya (Kati circle, Koulikoro region, according to Mali's former administrative division). Its geographical coordinates are: (12.49901 North; 8.09579 West) [5].

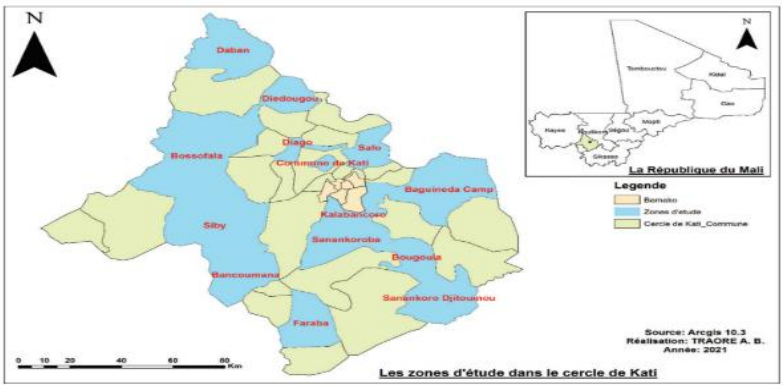

Figure 1 :Study sites *[7]*

2.1.1. NYETASOBA Farm

Located in the rural commune of Mandé, some 30 km from the capital (Bamako), the NYETASSOBA farm covers an area of 65 ha. Indeed, this farm is a leading example in Mali in the fields of livestock farming, fish farming, poultry farming and greenhouse vegetable growing. It is equipped with a modern hatchery for the production of catfish (Clarias) fry; a modern hatchery for the production of single-sex male tilapia fry; a full range of specialised equipment for transporting fry; ponds for stocking broodstock and for rearing Clarias and tilapia; a

vocational training centre for fish farming; a wastewater collection system; a wastewater filtration and treatment unit; a modern fish feed pelletising plant; integrated rearing of chickens, guinea fowl and cattle; a poultry slaughterhouse and a milk processing unit currently under construction; drip-irrigated papaya cultivation on 2.5 ha, 1 ha of modern greenhouse vegetable cultivation currently in operation and a further hectare of greenhouse space under construction/development.
The farm has 23 equipped boreholes with a production capacity of 1,644 m³/day. Data on the farm's solar-powered pumping system are presented in Table 1.

Table 1: Information on solar-powered irrigation at the NYETASOBA farm

Farm NYETASSOBA	
Location	**Type of crop**
The village of Sikorolé	• Vegetables (tomatoes, cabbages, aubergines, melons, etc.) • Papaya trees • Bananas
Farm size: • Papaya trees: 2 ha • Greenhouse: 1 ha in operation + 1 ha under development • Banana plantation: 0.5 ha	Type of irrigation system: Drip irrigation
Technology used: Solar pump with module arrays ranging from 230 to 260 Wp and a 300 Wp combiner	The solar-powered pump generator has a capacity of 90 kVA
Water pumping system: 23 boreholes (flow rates ranging from 16 m³/day to 300 m³/day; average depth of 70 metres)	
Daily water requirement: 1,644 m³	Poultry farming, cattle farming and other livestock farming; a poultry slaughterhouse and a milk processing plant currently under construction; Fish farming via ponds and a fish feed pellet factory.

2.1.2. Amadou SIDIBE's farm

It covers a total area of 5 ha and is situated in Katibougou in the municipality of Mandé. The farm now has the very first 0.5 ha greenhouse designed for growing tomatoes and melons, as well as a new, ultra-modern 1 ha greenhouse where it cultivates melons, tomatoes, peppers, cucumbers and so on.
The farm has four equipped boreholes with a production capacity of 500 m³ per day.
Details of the solar-powered pumping system on the farm are given in Table 2.

Table 2: Information on solar-powered pumping at Amadou SIDIBE's farm

Farm NYETASSOBA	
Location	**Type of crop**
The village of Samaya	• Vegetables (tomatoes, cabbages, aubergines, melons, cucumbers, strawberries, chillies, peppers, etc.) • Flowers
Farm size: 5 greenhouses: ½ ha; 200 m²; 1 ha; 300 m²; 3,750 m²	Type of irrigation system: Drip irrigation
Technology used: Solar pumping	Solar-powered pumping system: 23.92 kWp
Water pumping system 4 boreholes (50 to 90 metres deep)	
Daily water requirement: 500 m³	

2.2. Calculation of the installation and operating costs over ten (10) years for the solar-powered pumping system at the NYETASSOBA and Amadou Sidibé farms

To calculate installation costs, the data used for the farms includes, amongst other things, the number of boreholes on the farm, the farm's total pumping capacity, the total daily water requirement and the number of hours the pump operates.
Furthermore, the choices regarding the pump and modules were already made during the design phase; we will simply use them for our calculations.

However, other equipment such as the borehole head, the control unit, cables, safety ropes, pipework, panel supports and even installation fittings, plus labour, will be estimated in order to produce a reasonable cost estimate.

Furthermore, we have assumed an operational lifespan of ten (10) years. Accordingly, in addition to installation costs, we will factor in the costs of equipment upkeep and maintenance by technicians.

2.2.1. A financial simulation of alternative scenarios for these same farms, replacing the solar system with a conventional pumping system (generator and connection to the EDM-SA grid)

For this simulation, the equipment is divided into two groups:

- Pumping equipment (the pump, the control unit, cables, safety ropes, pipework, etc.);
- And the power source (the solar panels and their mounting structures).

The pumping equipment will remain intact, but the simulation will affect the solar power source and replace it with conventional sources (a generator set and a connection to the EDM-SA grid).

2.2.2. Replacement of the solar power source with a conventional generator

In fact, the PV modules are replaced by a generator with a capacity equal to or greater than that of the original solar farm. Added to this is the labour cost for installation. For the operational phase, provision must be made in the budget for fuel (diesel). All these elements must be included in a financial estimate. To determine the total cost of fuel, we will take into account the daily operating time (11 hours per day for the Nyetassoba farm and 7 hours per day for the Amadou Sidibé farm), the generator's hourly consumption, the number of operating days in the year and the number of available boreholes. Equations (1) and (2) show, in turn, the expressions for the total cost of fuel and the quantity of diesel used.

$$\boldsymbol{P_{r_C} = Q_L \times P_L} \quad \textbf{(1)}$$

$$\boldsymbol{Q_L = C_{g/h} \times T_f \times 365} \quad \textbf{(2)}$$

Where:

P_{r_C} : Total fuel cost;

$C_{\frac{g}{h}}$: Fuel consumption of the generator per hour;

T_f : Operating time;

N_f : Number of boreholes;

P_L : Price per litre;

Q_L : Quantity in litres.

2.2.3. Replacement of the solar power source with the EDM-SA grid

To this end, the solar panels are replaced this time by EDM-SA meters, the total capacity of which is equal to or greater than that of the solar panels. On top of this comes the labour cost. For day-to-day operation, the electricity bill must be taken into account, and all these factors must be factored into the cost estimates.

Furthermore, to calculate the cost of the electricity consumed, we will take into account the operating time (11 hours per day), the price per kilowatt-hour (kWh), the number of meters and the number of days in the year.

$$\boldsymbol{F = N_{kW/an} \times P_{kWh}} \quad \textbf{(3)}$$

This number can be calculated using the power data. We therefore have:

$$\boldsymbol{N_{kW/an} = \frac{T_f \times 365 \times P}{1000}} \quad \textbf{(4)}$$

F : Electricity bill;

N_c : Number of electricity meters;

P_{kWh} : Price per kilowatt-hour;

365: Number of days in the year;

$N_{kW/an}$: Number of kilowatts per year.

III. RESULTS AND DISCUSSION

3.1. Cost of installing solar-powered pumping systems, generator sets and systems connected to the EDM-SA grid

3.1.1. Cost of installing the solar-powered pumping system at the NYETASOBA farm

This study is based on the following data:

- Area to be irrigated: 65 hectares;
- Type of farm: year-round market gardening (365 days);
- Daily water requirement: 1,644 m³;
- Operating period: 1 year;
- Pump type: Lorentz PS2 600 pumps with a flow rate of 6.5 m³/h;
- Operating time: 11 hours per day;
- Number of modules: 272;
- Pumping power: 90 kVA;
- Number of boreholes: 23.

The cost of installing the solar photovoltaic pumping system at the NYETASSOBA farm is shown in Table 3.

Table 3 : Installation cost of the solar PV pumping system at the NYETASSOBA farm

N°	Items	Quantity	Unit price (F CFA)	Total (F CFA)
Pumping equipment				
1	Im Lorentz PS2 600 pumps with a flow rate of 6.5 m³/h	23	1 864 554	42 884 742
2	Cu 200 control unit	23	300 000	6 900 000
3	Flexible cable 2×2.5 mm² (50 per borehole)	1150	400	460 000
4	Flexible cable 3×4 mm² (100 per borehole)	2300	1 500	3 450 000
5	Safety rope (115 per borehole)	2645	200	529 000
6	D 36 drill head	23	20 000	460 000
7	Piping/elbow/valve	23	180 000	4 140 000
8	Installation fittings	23	45 000	1 035 000
Power supply				
9	24V-230W modules	272	90 000	24 480 000
10	Module brackets	272	20 000	4 440 000
11	Labour (installation costs)	1	900 000	900 000
TOTAL				**84 338 742**

The cost of installing the solar photovoltaic pumping system at the NYETASSOBA farm is estimated at 84,338,742 CFA francs (eighty-four million, three hundred and thirty-eight thousand, seven hundred and forty-two CFA francs).

3.1.2. Cost of installing the solar-powered pumping system at the Amadou Sidibé farm

This study is based on the following assumptions:

- Area to be irrigated: 5 hectares;
- ype of farm: year-round market gardening (365 days);
- Daily water requirement: 500 m³;
- Operating period: 1 year;
- Pump types: 1 Lorentz PS 1800 with a flow rate of 51 m³/h and 3 Grundfos SQFlex 8A10 with a flow rate of 23 m³/h;
- Operating time: 7 hours per day;
- Number of modules: 72;
- Pumping power: 23 kWp;
- Number of boreholes: 4.

The cost of installing the solar photovoltaic pumping system at Amadou Sidibé's farm is shown in Table 4.

Table 4: Installation cost of the solar PV pumping system at Amadou Sidibé's farm

N°	Items	Quantity	Unit price (F CFA)	Total (F CFA)
Pumping equipment				
1	Lorentz PS 1800 and Grundfos SQFlex 8A10	1 Lorentz 3 Grundfos	Lorentz: 1 900 000 Grundfos: 2 000 000	7 900 000
2	Cu 200 control unit	4	300 000	1 200 000
3	Flexible cable 2×2.5 mm² (50 per borehole)	200	400	80 000
4	Flexible cable 3×4 mm² (100 per borehole)	400	1 500	600 000
5	Safety rope (115 per borehole)	460	200	92 000
6	D 36 drill head	4	20 000	80 000
7	Piping/elbow/valve	4	180 000	720 000
8	Installation fittings	4	45 000	180 000
Power supply				
9	24V-230W modules	72	90 000	6 480 000
10	Module brackets	18	30 000	540 000
11	Labour (installation costs)	1	400 000	400 000
TOTAL				**18 272 000**

The cost of installing the solar photovoltaic pumping system at Amadou Sidibé's farm is estimated at 18,272,000 CFA francs (eighteen million two hundred and seventy-two thousand CFA francs).

3.1.3. Cost of installing the generator-powered pumping system at the NYETASOBA farm

This study is based on the following assumptions:

- Area to be irrigated: 65 hectares;
- Type of operation: year-round market gardening (365 days);
- Daily water requirement: 1,644 m³;
- Duration of operation: 1 year;
- Operating time: 11 hours per day;
- Pumping capacity: 90 kVA;
- AKSA AP 110 generator with a capacity of 110 kVA, consuming 23 L/h;
- Number of boreholes: 23.

The cost of installing the farm's generator-powered pumping system is shown in Table 5.

Table 5: Installation cost of the generator-powered pumping system at the NYETASSOBA farm

N°	Items	Quantity	Unit price (F CFA)	Total (F CFA)
Pumping equipment				
1	Im Lorentz PS2 600 pump with a flow rate of 6.5 m³/h	23	1 864 554	42 884 742
2	Cu 200 control unit	23	300 000	6 900 000
3	Flexible cable 2 × 2.5 mm² (50 per borehole)	1150	400	460 000
4	Flexible cable 3 × 4 mm² (100 per borehole)	2300	1 500	3 450 000
5	Safety rope (115 per borehole)	2645	200	529 000
6	Drill head D 36	23	20 000	460 000
7	Piping/elbow/valve	23	180 000	4 140 000
8	Installation accessories	23	45 000	1 035 000
Power supply				
9	AKSA AP 110 generator with a capacity of 110 KVA	1	12 281 250	12 281 250
11	Labour (installation costs)	1	900 000	900 000
TOTAL				**73 039 992**

The cost of installing the NYETASSOBA generator-powered pumping system is estimated at 73,039,992 CFA francs (seventy-three million thirty-nine thousand nine hundred and ninety-two CFA francs).

3.1.4. Cost of installing the generator-powered pumping system at the Amadou Sidibé farm

This study is based on the following assumptions:

- Area to be irrigated: 5 hectares;
- Type of farm: year-round market gardening (365 days);
- Daily water requirement: 500 m³;
- Operating time: 7 hours per day,
- Pumping power: 23 kWp,
- Perkins Pramac GSW generator with a power rating of 30 kVA and a fuel consumption of 6.9 L/h.
- Number of boreholes: 4.

The cost of installing the farm's generator-powered pumping system is shown in Table 6.

Table 6 : Cost of installing the generator-powered pumping system at Amadou Sidibé's farm

N°	Items	Quantity	Unit price (F CFA)	Total (F CFA)
Pumping equipment				
1	Lorentz PS 1800 and Grundfos SQFlex 8A10	1 Lorentz 3 Grundfos	Lorentz : 1 900 000 Grundfos : 2 000 000	7 900 000
2	Cu 200 control unit	4	300 000	1 200 000
3	Flexible cable 2×2.5 mm² (50 per borehole)	200	400	80 000
4	Flexible cable 3×4 mm² (100 per borehole)	400	1 500	600 000
5	Safety rope (115 per borehole)	460	200	92 000
6	D 36 drill head	4	20 000	80 000
7	Piping/elbow/valve	4	180 000	720 000
8	Installation fittings	4	45 000	180 000
Power supply				
9	Pramac GSW Perkins generator, 30 kVA	1	6 130 800	6 130 800
10	Labour (installation costs)	1	350 000	350 000
TOTAL				**17 332 800**

The cost of installing the generator-powered pumping system at Amadou Sidibé's farm is estimated at 17,332,800 CFA francs (seventeen million three hundred and thirty-two thousand eight hundred CFA francs).

3.1.5. Cost of installing the pumping system by EDM-SA at the NYETASOBA farm

This study is based on the following assumptions:

- Area to be irrigated: 65 hectares;
- Type of operation: year-round market gardening (365 days);
- Daily water requirement: 1,644 m³;
- Duration of operation: 1 year;
- Current rating: 30 A
- Operating time: 11 hours per day;
- Pumping power: 90 kVA,
- Number of three-phase 30 A meters with a power rating of 18 kVA: 5;
- Number of boreholes: 23.

The installation cost of the EDM-SA pumping system for the farm is shown in Table 7.

Table 7 : Installation cost of the EDM-SA pumping system for the NYETASSOBA farm

N°	Items	Quantity	Unit price (F CFA)	Total (F CFA)
Pumping equipment				
1	Im Lorentz PS2 600 pump with a flow rate of 6.5 m³/h	23	1 864 554	42 884 742
2	Cu 200 control unit	23	300 000	6 900 000
3	Flexible cable 2 × 2.5 mm² (50 per borehole)	1150	400	460 000
4	Flexible cable 3 × 4 mm² (100 per borehole)	2300	1 500	3 450 000
5	Safety rope (115 per borehole)	2645	200	529 000
6	Drill head D 36	23	20 000	460 000
7	Piping/elbow/valve	23	180 000	4 140 000
8	Installation accessories	23	45 000	1 035 000
Power supply				
9	Three-phase meters: 18 kVA and 30 A	5	112 000F	560 000F
11	Labour (installation costs)	1	900 000	900 000
TOTAL				**61 318 742**

The cost of installing the EDM-SA pumping system at the NYETASSOBA farm is estimated at 61,318,742 CFA francs (sixty-one million, three hundred and eighteen thousand, seven hundred and forty-two CFA francs).

3.1.6. Cost of installing the pumping system by EDM-SA at the Amadou Sidibé farm

This study is based on the following assumptions:

- Area to be irrigated: 5 hectares;
- Type of farm: year-round market gardening (365 days);
- Daily water requirement: 500 m³;
- Current rating: 30 A;
- Operating time: 7 hours per day;
- Pumping power: 23.92 kWp;
- Number of three-phase 30 A meters with a power rating of 18 kVA: 2;
- Number of boreholes: 4.

The cost of installing the EDM-SA pumping system at Amadou Sidibé's farm is shown in Table 8.

Table 8: Installation cost of the EDM-SA pumping system at Amadou Sidibé's farm

N°	Items	Quantity	Unit price (F CFA)	Total (F CFA)
Pumping equipment				
1	Lorentz PS 1800 and Grundfos SQFlex 8A10	1 Lorentz 3 Grundfos	Lorentz: 1 900 000 Grundfos: 2 000 000	7 900 000
2	Cu 200 control unit	4	300 000	1 200 000
3	Flexible cable 2×2.5 mm² (50 per borehole)	200	400	80 000
4	Flexible cable 3×4 mm² (100 per borehole)	400	1 500	600 000
5	Safety rope (115 per borehole)	460	200	92 000
6	D 36 drill head	4	20 000	80 000
7	Piping/elbow/valve	4	180 000	720 000
8	Installation fittings	4	45 000	180 000
Power supply				
9	Three-phase power meters, 18 kVA and 30 A	2	112 000F	224 000
10	Labour (installation costs)	1	350 000	350 000
TOTAL				**11 426 000**

The cost of installing the pumping system by EDM-SA at Amadou Sidibé's farm is estimated at 11,426,000 CFA francs (eleven million four hundred and twenty-six thousand CFA francs).

3.2. Operating costs of solar-powered pumping systems using a generator set and EDM-SA

3.2.1. Operating costs of the solar-powered pumping system at the NYETASOBA farm

The operating costs of the solar-powered pumping system at the NYETASSOBA farm are set out in Table 9.

Table 9: Operating costs of the solar-powered pumping system at the NYETASSOBA farm

N°	Items	Quantity	Unit Price (F CFA)	Total amount over 10 years (F CFA)
1	System Servicing and Maintenance	10	1 400 000	14 000 000
2	Exchange of materials	10	3 000 000	30 000 000
TOTAL				**44 000 000**

The total expenditure over ten (10) years on operating a solar photovoltaic-powered pumping system at the NYETASSOBA farm amounts to 44,000,000 CFA francs

3.2.2. Operating costs of the solar-powered pumping system at the Amadou Sidibé farm

The operating costs of the solar-powered pumping system at Amadou Sidibé's farm are set out in Table 10.

Table 10: Operating costs of the solar-powered pumping system at Amadou Sidibé's farm

N°	Items	Quantity	Unit Price (F CFA)	Total amount over 10 years (F CFA)
1	System Servicing and Maintenance	10	800 000	8 000 000
2	Exchange of materials	10	1 500 000	15 000 000
TOTAL				**23 000 000**

The total expenditure over ten (10) years on operating a solar photovoltaic-powered pumping system at Amadou Sidibé's farm amounts to 23,000,000 CFA francs.

3.2.3. Operating costs of the generator-powered pumping system at the NYETASOBA farm

The operating costs of the generator-powered pumping system at the NYETASSOBA farm are set out in Table 11.

Table 11: Operating costs of the generator-powered pumping system at the NYETASSOBA farm

N°	Items	Quantity	Unit Price (F CFA)	Total amount over 10 years F CFA
1	Fuel	9 234 500 L	864	797 860 800
2	Maintenance and servicing	10	500 000	5 000 000
TOTAL				**802 860 800**

The total expenditure over ten (10) years on operating a generator-powered pumping system at the NYETASSOBA farm amounts to 802,860,800 CFA francs.

3.2.4. Operating costs of the generator-powered pumping system at the Amadou Sidibé farm

The operating costs of the generator-powered pumping system at Amadou Sidibé's farm are set out in Table 12.

Table 12 :Operating costs of the generator-powered pumping system at Amadou Sidibé's farm

N°	Items	Quantity	Unit Price (F CFA)	Total amount over 10 years F CFA
1	Fuel	1 762 950 L	864	152 318 880
2	Maintenance and servicing	10	250 000	2 500 000
TOTAL				**154 818 880**

The total expenditure over ten (10) years on operating a generator-powered pumping system at Amadou Sidibé's farm amounts to 154,818,880 CFA francs (thirty-two million four hundred and forty-two thousand two hundred and forty CFA francs).

3.2.5. Operating costs of the EDM-SA pumping system at the NYETASOBA farm

The operating costs of the EDM-SA pumping system at the NYETASSOBA farm are set out in Table 13.

Table 13: Operating costs of the EDM-SA pumping system at the NYETASSOBA farm

N°	Items	Quantity	Unit Price (F CFA)	Total amount over 10 years F CFA
1	Electricity bill (11 hours' use)	361 3500	130	469 755 000
2	Labour (Installation costs)	10	100 000	1 000 000
TOTAL				**470 755 000**

The total expenditure over ten (10) years on operating an EDM-SA pumping system at the NYETASSOBA farm amounts to 470,755,000 CFA francs.

3.2.6. Operating costs of the EDM-SA pumping system at the Amadou Sidibé farm

The operating costs of the EDM-SA pumping system at Amadou Sidibé's farm are set out in Table 14.

Table 14: Operating costs of the EDM-SA pumping system at Amadou Sidibé's farm

N°	Items	Quantity	Unit Price (F CFA)	Total amount over 10 years F CFA
1	Electricity bill (7 hours' use)	611156	130	79 450 280
2	Labour (Installation costs)	10	100 000	1 000 000
TOTAL				80 450 280

The total expenditure over ten (10) years on operating an EDM-SA pumping system at Amadou Sidibé's farm amounts to 80,450,280 CFA francs.

3.3. Comparison of the results obtained

3.3.1. Comparison of installation costs for solar-powered, generating set and EDM-SA pumping systems at the NYETASSOBA farm

Figure 2 shows the installation costs for the solar, generator set and EDM-SA pumping systems at the NYETASSOBA farm

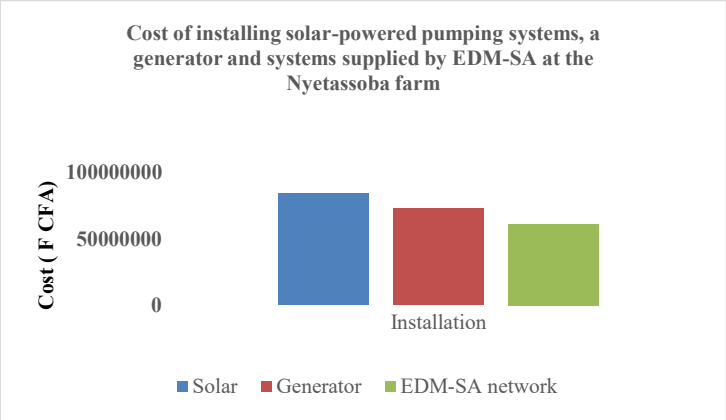

Figure 2: Cost of installing solar-powered pumping systems, a generator and systems supplied by EDM-SA at the Nyetassoba farm

At the NYETASSOBA farm, we have observed that, at the time of installation, the solar-powered pumping system is more expensive than the generator-powered pumping system and the EDM-SA pumping system. Furthermore, the generator-powered pumping system is also more expensive than the EDM-SA pumping system.

3.3.2. A comparison of the installation costs of solar-powered pumping systems, generator sets and the EDM-SA system at Amadou Sidibé's farm

Figure 3 shows the installation costs for the solar pumping systems, generator and EDM-SA at Amadou Sidibé's farm

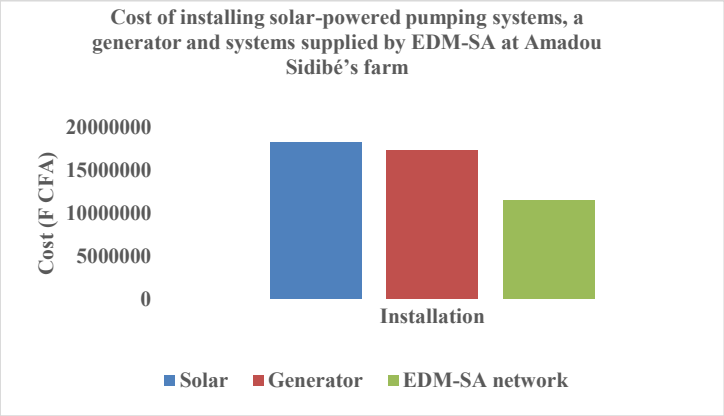

Figure 3: Cost of installing solar-powered pumping systems, a generator and systems supplied by EDM-SA at Amadou Sidibé's farm

The same applies to Amadou Sidibé's farm: we find that, at the time of installation, the solar-powered pumping system is more expensive than the generator-powered pumping system and the EDM-SA pumping system. Consequently, the generator-powered pumping system is also more expensive than the EDM-SA pumping system.

3.3.3. Comparison of operating costs for solar-powered, generator-powered and EDM-SA pumping systems at the NYETASSOBA farm

Figure 4 shows the operating costs of the solar-powered pumping systems, the generator and the EDM-SA system at the NYETASSOBA farm.

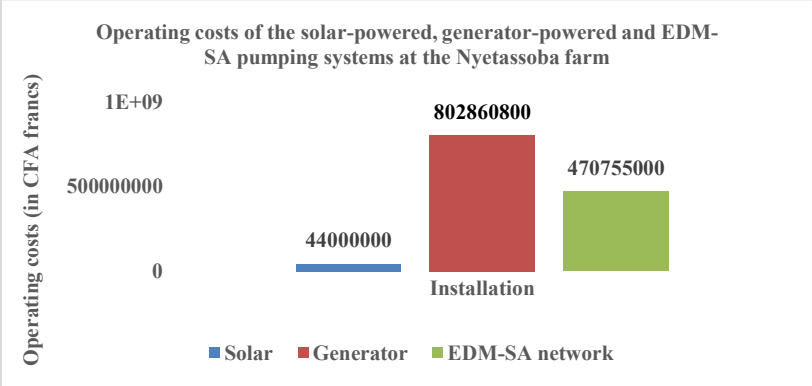

Figure 4: Operating costs of the solar-powered, generator-powered and EDM-SA pumping systems at the NYETASSOBA farm

At the NYETASSOBA farm, we have observed that, over a ten-year (10-year) operating period, the generator-powered pumping system is more expensive than the solar-powered pumping system and the EDM-SA pumping system. The EDM-SA pumping system is also more expensive than the solar-powered pumping system.

3.3.4. A comparison of the operating costs of solar-powered, electronic and EDM-SA pumping systems at Amadou Sidibé's farm

Figure 5 shows the operating costs of the solar-powered pumping systems, the generator and the EDM-SA system at Amadou Sidibé's farm.

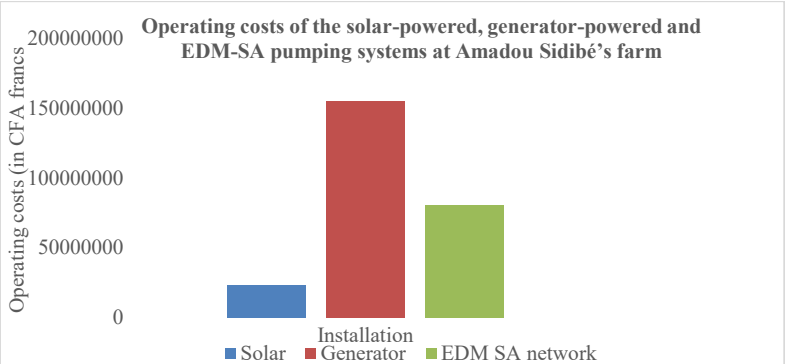

Figure 5: Operating costs of the solar-powered, generator-powered and EDM-SA pumping systems at Amadou Sidibé's farm

The same result applies to Amadou Sidibé's farm: we note that, over a ten-year period, the generator-powered pumping system is more expensive than both the solar-powered pumping system and the EDM-SA pumping system. The EDM-SA pumping system is also more expensive than the solar-powered system.

Indeed, when analysing how operating costs change over the number of years of operation, we can clearly see that, over ten (10) years, the generator-powered pumping system is more expensive than the solar-powered pumping system. Similarly, the EDM-SA pumping system is more expensive than the solar-powered pumping system.

3.4. Comparative study

The various costs are summarised in Table 15 below.

Table 15: Comparative analysis of the various costs of the system

Technology	Installation cost (F CFA)		Operating costs (F CFA)	
	NYETASSOBA Farm	Amadou Sidibé's farm	NYETASSOBA Farm	Amadou Sidibé's farm
Direct solar pumping	84 338 742	18 272 000	44 000 000	23 000 000
Pumping using a generator set	73 039 992	17 332 800	802 860 800	154 818 880
EDM-SA network	61 318 742	11 426 000	470 755 000	80 450 280

In terms of initial investment, pumping via the EDM-SA grid is the cheapest option to install for both farms; however, solar-powered pumping, which operates as the sun rises and sets, requires the largest initial investment. But over a 10-year operating period, solar-powered pumping is the least expensive option, whereas conventional pumping proves to be too costly.

Table 16 summarises the payback period for solar pumping for both farms over a 10-year period.

Table 16: Summary of the payback period for solar pumping for both farms

Farm	Technology compared with solar power	Additional cost of installing a solar system (F CFA)	Annual operating savings (F CFA/year)	Payback period
NYETASSOBA	Pumping using a generator set	11 298 750	75 886 080	0,15 an
	EDM-SA network	23 020 000	42 675 500	0,54 an
Amadou Sidibé	Pumping using a generator set	939 200	13 181 888	0,07 an
	EDM-SA network	6 846 000	5 745 028	1,19 an

Financial viability		
Pre-tax IRR - equity	%	694.8%
Pre-tax IRR - assets	%	694.8%
After-tax IRR - equity	%	694.8%
After-tax IRR - assets	%	694.8%
Simple payback	yr	0.1
Equity payback	yr	0.1
Net Present Value (NPV)	XOF	672,436,655
Annual life cycle savings	XOF/yr	87,083,623
Benefit-Cost (B-C) ratio		60.51
GHG reduction cost	XOF/tCO2	No reduction

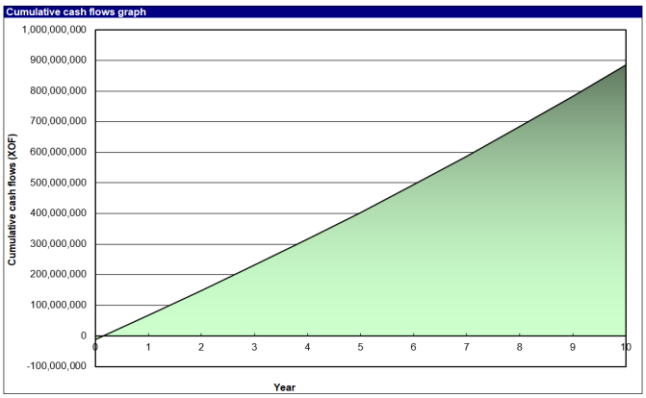

Figure 6: Comparison of a generator set with a solar system at the NYETASSOBA farm

Financial viability		
Pre-tax IRR - equity	%	193.9%
Pre-tax IRR - assets	%	193.9%
After-tax IRR - equity	%	193.9%
After-tax IRR - assets	%	193.9%
Simple payback	yr	0.5
Equity payback	yr	0.5
Net Present Value (NPV)	XOF	361,487,281
Annual life cycle savings	XOF/yr	46,814,257
Benefit-Cost (B-C) ratio		16.70
GHG reduction cost	XOF/tCO2	No reduction

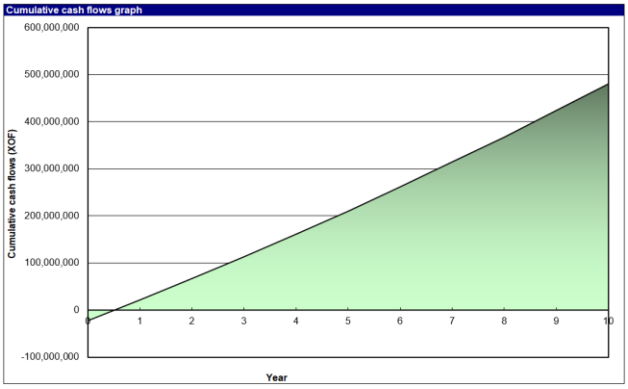

Figure 7: EDM-SA Network compared and Solar Power at the NYETASSOBA Farm

Financial viability		
Pre-tax IRR - equity	%	1448.6%
Pre-tax IRR - assets	%	1448.6%
After-tax IRR - equity	%	1448.6%
After-tax IRR - assets	%	1448.6%
Simple payback	yr	0.1
Equity payback	yr	0.1
Net Present Value (NPV)	XOF	117,829,928
Annual life cycle savings	XOF/yr	15,259,515
Benefit-Cost (B-C) ratio		126.46
GHG reduction cost	XOF/tCO2	No reduction

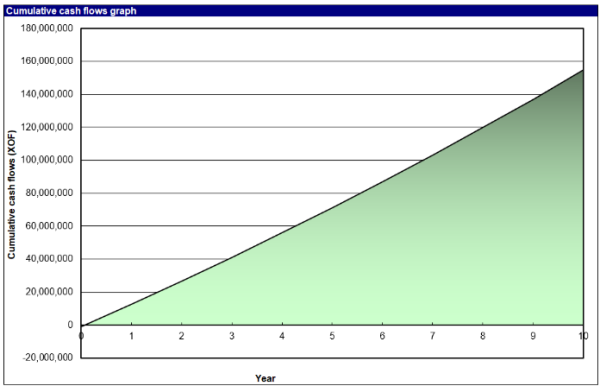

Figure 8: Comparison of a generator set with a solar system at the Amadou Sidibé farm

Financial viability		
Pre-tax IRR - equity	%	89.2%
Pre-tax IRR - assets	%	89.2%
After-tax IRR - equity	%	89.2%
After-tax IRR - assets	%	89.2%
Simple payback	yr	1.2
Equity payback	yr	1.2
Net Present Value (NPV)	XOF	44,916,840
Annual life cycle savings	XOF/yr	5,816,936
Benefit-Cost (B-C) ratio		7.56
GHG reduction cost	XOF/tCO2	No reduction

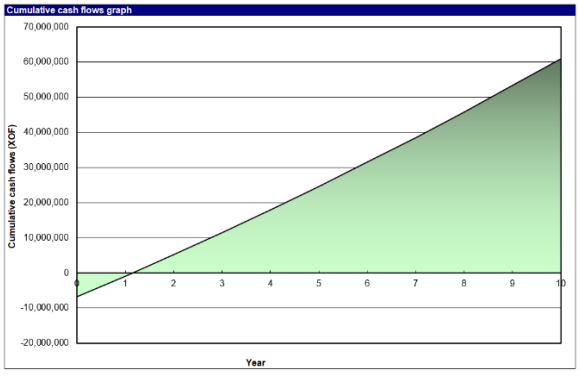

Figure 9: Comparison of the EDM-SA network and solar power at the Amadou Sidibé farm

Indeed, opting for solar power is extremely cost-effective and pays for itself remarkably quickly compared to a generator; the additional cost is recouped within a few weeks thanks to the immediate savings on fuel. Similarly, when compared to the EDM-SA network, the system pays for itself in 6 to 14 months, depending on the size of the farm. Furthermore, over a 10-year project, the remainder of the period (between 8 and 9 years) represents pure profit and virtually zero energy costs.

IV. CONCLUSION

This article highlights the importance of a thorough understanding of the components in order to effectively compare the direct solar pumping system with conventional solutions (generator set and the EDM-SA grid). Thus, the technical and economic assessment carried out over ten (10) years of operation shows that thermal technology using a generator set and the EDM-SA grid incurs the highest operating costs.

Finally, in light of these results, photovoltaic solar pumping represents the most viable alternative for the future, thanks to its cost-effectiveness in use and its low maintenance requirements. These results confirm the findings of [2] [3] and [4].

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