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TECHNICO-ECONOMIC ANALYSIS OF OVER THE SUN PUMPING FOR DATE PALM TREES IRRIGATION IN SEMI ARRID AREA: CASE OF SAHEL REGION IN BURKINA FASO

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ABSTRACT
The Sahelian zone in sub-Saharan Africa is an arid zone under constant climate change threat, which causes great social and environmental vulnerability. Agriculture in Sahelian countries must face up to this development in order to guarantee food security for their increasingly growing populations. The cultivation of the date palm (Phoenix dactylifera L.), which is a plant species with great phenological plasticity, makes it possible to provide adequate responses to Sahel difficult pedoclimatic conditions. As surface water is very ephemeral in the Sahel, the groundwater exploitation is essential to satisfy water needs for date palm irrigation. However, the groundwater dewatering at optimum cost, comes up against energy lack, which is essential for pumping water. This work presents over the sun pumping system optimization of groundwater stored in aquifers, at a lower cost, for date palm irrigation in Sahelian zone. The techno-economic optimization is done by Homer software. The simulation is carried out at four sites located in Burkina Faso Sahel region, in West Africa. The simulation results gave the water costs at the four sites: 0.092 $/m^{3}at Oudalan site, 0.109 $/m^3 at Seno site, 0.108 $/m^{3}at Soum site and 0.118 $/m^{3}at Yagha site. Over the sun pumping system optimization has made it possible to have very competitive cost per cubic meter of pumped water, which will allow irrigated date palm cultivation development in the Sahel area.

KEYWORDS: Date palm, irrigation, pumping, photovoltaic, optimization.

1. INTRODUCTION
The Sahel is one of the most vulnerable regions in the world to climate change, in a context of its economy dominating by agriculture that is 97% dependent on rainfall [1]. Food insecurity, low income and instability are major obstacles to economic and social development in the Sahel. The high poverty rate, particularly in rural areas, accentuates emigration and rural exodus, compromising the region stability and security. However, the Sahel has comparative advantages to capitalize on: strong sunshine, large rivers, an abundant groundwater resource, etc. The map of groundwater resources shows that the Sahel in sub-Saharan Africa is characterized by the abundance of groundwater and displays resilience face to climatic variations [2], [3]. It is necessary to control water for agriculture, in order to increase Sahelians resilience to climatic shocks and to accelerate agricultural intensification. Plant species use with high phenological plasticity, such as date palm (Phoenix dactylifera L), is one of responses to difficult pedoclimatic conditions to which few plants are adapted [4]. The date palm grows well in desert and sub-desert soils, where most cultivated plants are difficult to grow. The most internationally cultivated date palm varieties are "Medjool", "Barhee" and "DegletNour" [4]. Date palm cultivation or phœniciculture appears extremely important for the subsistence of populations in desert environments [5]. In fact, dates constitute a food supplement or even an essential food for the populations of world arid zones. Many studies have demonstrated the excellent nutritional quality of dates thanks to their antioxidant and calorific properties [6],

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[7]. Phœniciculture requires a lot of water [8]. In arid conditions and a prolonged dry season, as in the Sahel, irrigation is essential to compensate evapotranspiration deficit due to insufficient or irregular rainfall [9]. This study deals with the pumping of groundwater for young date palms irrigation, using photovoltaic solar energy [10]. The date palm cultivation in the Sahelian zone has several advantages. In addition to their usefulness for food, date palms can be used to form an arch with their branches, in order to cultivate plants such as orange trees, lemon trees, vegetables and cereals at their foot, which would sweat more if they were in full sun [11]. Among the pumping methods used for dewatering the water necessary for date palm irrigation, there is manual pumping to irrigate about 20 palm trees per well, wind pumping to irrigate about 50 palm trees per day, pumping with a generator to irrigate about 50 to 70 palm trees per well and solar pumping which allows the irrigation of 70 to 120 palm trees by pumping system. An energy system choice for pumping obeys and respects certain rules [12]. Photovoltaic solar power for pumping has previously demonstrated its economic and technical competitiveness compared to other pumping systems for the same service provided [13]. Among the solar pumping techniques, over the sun pumping has the best energy efficiency [14]. Over the sun pumping flow depends on sunshine at site, photovoltaic modules performance, pump and borehole characteristics.

This present study objective is phœniciculture development by optimizing over the sun pumping system, at lower cost, for young date palms irrigation in rural areas, at four sites, in the Sahel region of Burkina Faso, in West Africa.

2. STUDIED SITES

The Sahel is the strip of territory marking the transition, both floristic and climatic, between the Saharan desert in the North and the tropical savannas in the South [15]. It stretches from Atlantic Ocean to Red Sea between 12° and 20° North latitude over approximately 5.4 million km^2 areas [16].

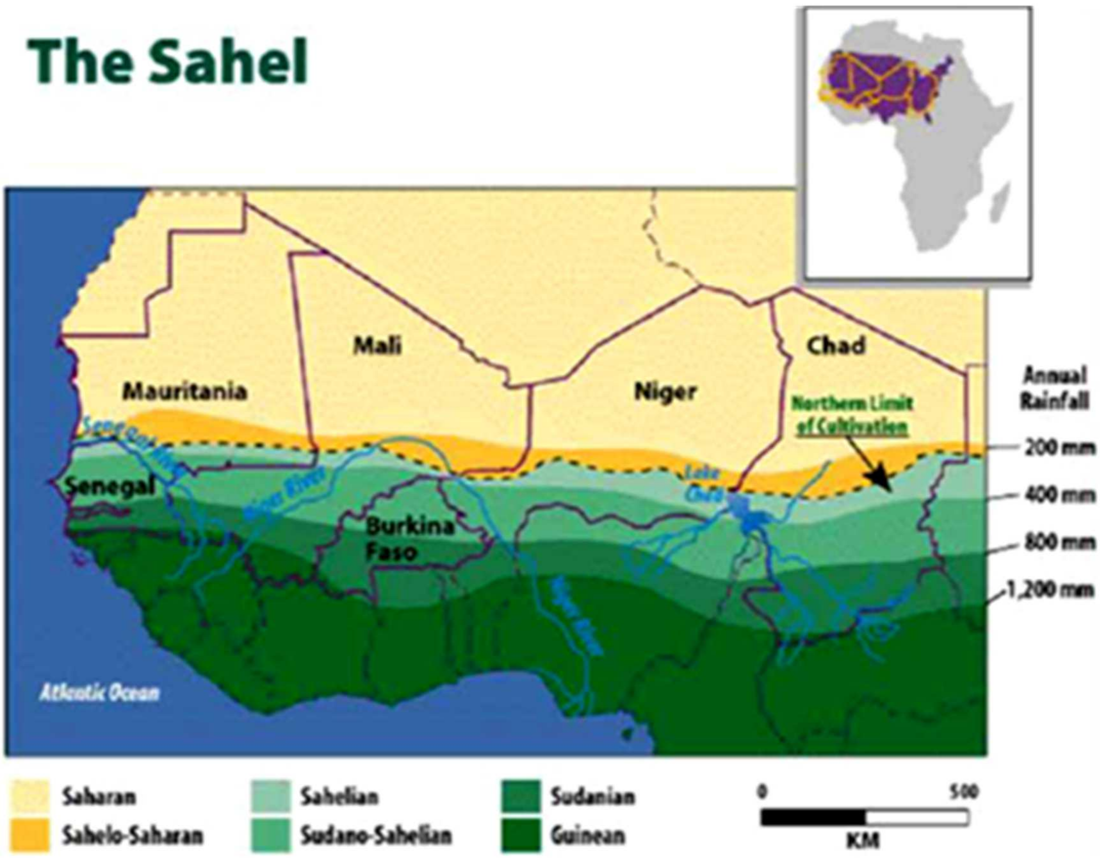

Figure 1: Sahelian zone location in Africa

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In Burkina Faso, Sahel region extends between 13th and 15th parallel of north latitude and covers approximately 35,000 km² area [17]. The Sahel region includes Oudalan, Seno, Soum and Yagha provinces. These provinces administrative centers are respectively Gorom-Gorom, Dori, Djibo, and Sebba (Fig. 2).

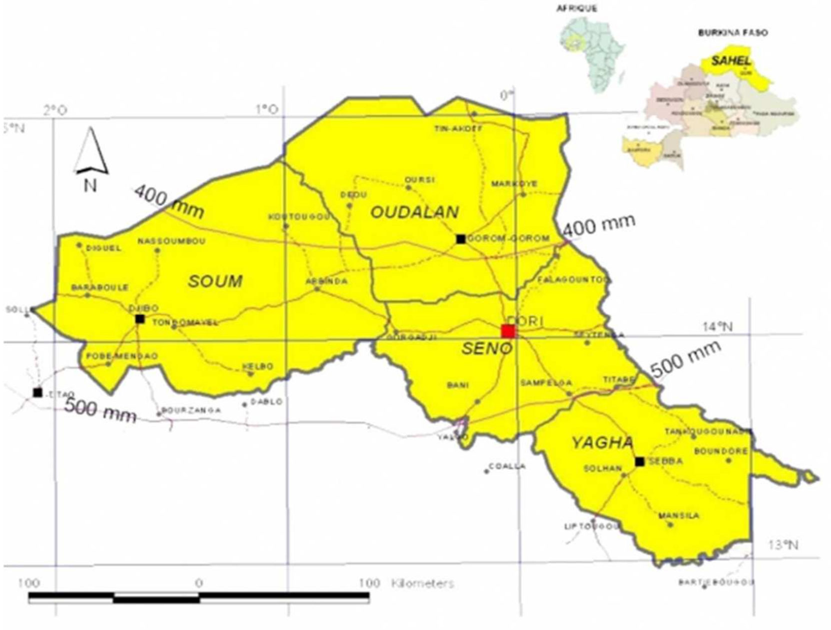

***Figure 2**: Geographical location of studied sites*

The groundwater resources in this region are those of Liptako-Gourma-Upper Volta aquifer system. With approximately 159,500 km^2 area, Liptako-Gourma-Upper Volta aquifer covers a large part of northeastern Mali, northeastern and eastern of Burkina Faso, and southern of Niger [18]. According to Burkina Faso general population census in 2019, Sahel region has 1,094,907 inhabitants [19].

Table 1. Geographical coordinates and the number of inhabitants at studied sites

Region	Province	Headquarters	Coordinates		Area (km^2)	Inhabitants number	Density (Inh/km^2)
			Latitude	Longitude			
Sahel	Oudalan	Gorom-Gorom	14°27’N	0°14’O	9 797	298344	30
	Seno	Dori	14°02’N	0°02’O	6 863	400557	58
	Soum	Djibo	14°06’N	1°38’O	12 222	526898	43
	Yagha	Sebba	13°26’N	0°32’E	6 468	241236	37

The region is characterized by Sahelian type climate. This climate is hot and dry from March to June, cold and dry from November to February and rainy from July to October. The four months, March, April, May and June, represent the dry and hot period, during which water demand is the highest. This Sahelian climate is characterized by alternation of dry and rainy season that lasts 3 to 4 months. The annual rainfall is less than 600 mm. The rainy season is characterized by variability in precipitation distribution, high evapotranspiration around 3 meter per year and large variations in daily and annual temperatures [20]. Solar energy is the most abundant endogenous resource at Sahelian zone in Burkina Faso. The isolation time is 3000 to 3500 hours per year [21]. Livestock is the main socio-economic activity. It is a income source for more than 80% of population of Burkina Faso and contributes 10% to Gross Domestic Product [22]. In Burkina Faso Sahelian region, the bulk of animal husbandry concerns cattle, goats, sheep, donkeys, pigs, horses and poultry.

3. METHODOLOGY

The proposed method is based on determining the updated global cost per cubic meter of water pumped according to needs expressed, the characteristics of the water source and the installation site. The design of over the sun

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pumping for date palm irrigation includes the daily water needs assessment, pump and photovoltaic field sizing, technical and economic analysis. Figure 3 shows the over the sun pumping system configuration.

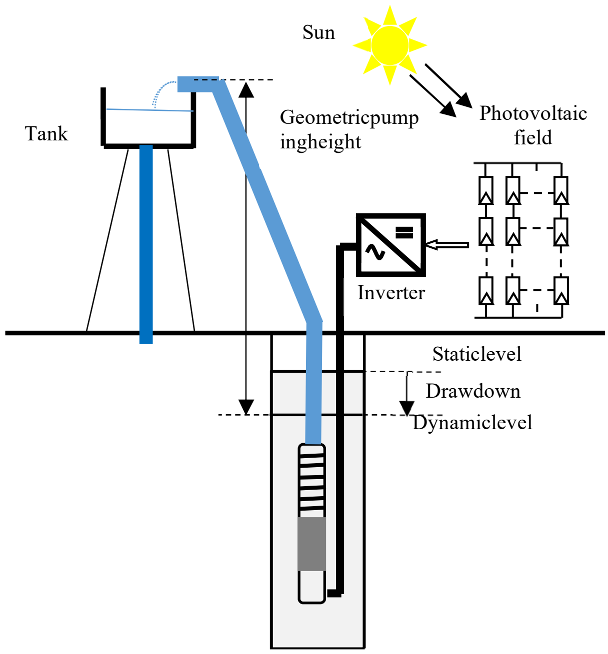

Figure 3.Over the sun pumping system configuration

Water needs for date palm irrigation assessment

Water consumption for date palm irrigation varies considerably depending on palm variety, climatic conditions, seasons and soil types [23]. Deglet Nourdate is the date palm variety chosen in this study.

Figure 4. Photo of young Deglet Nourdate palms trees

The Penman model based on evapotranspiration knowledge is adopted to estimate the water requirements for the date palm irrigation [24]. The E_{T0} reference evapotranspiration is given according to [25], [26] by:

$$E_{T0} = \frac{0{,}408\,\Delta\left(R_n - G\right) + \gamma \dfrac{900}{T+273} u_2 \left(e^0 - e\right)}{\Delta + \gamma\left(1 + 0{,}34\,u_2\right)} \quad (1)$$

where:
• E_{T0} is the reference evapotranspiration,
• T is the air temperature,
• u_2 is the wind speed at 2 m above the ground,
• Δ is the ratio between the vapor pressure difference and the corresponding temperature,
• γ is a psychrometric constant,
• R_n is the net radiation at the soil surface,
• G is the heat flux of the soil,
• $e$is the vapor pressure,
• e^o is the saturated vapor pressure at the reference temperature T_0.

The palm water needs evaluation is given according to [27] by:

$$Q_{water} = E_{T0} K_c S_a \quad (2)$$

where:
• Q_{water} is the palm water requirement,
• E_{T0} is the reference evapotranspiration,
• K_c is the crop coefficient,
• S_a is the palm evapotranspiration active area.

With

$$S_a = \pi R_a^2 \quad (3)$$

where:
• R_a is the active ray.

The crop coefficient is determined according to [28] by:

$$K_c = K_s K_{cb} + K_e \quad (4)$$

where:
• K_{cb}, is basic crop coefficient which represents the E_T/ E_{T0} ratio when the soil surface is dry,
• K_e is evaporation coefficient which allows the quantification of evaporation from the wet surface of the soil,
• K_s is coefficient reduction in water stress, between 0 and 1.

The net need Q_n in irrigation water, in liters per palm tree and per day is given according to [28] by:

$$Q_n = \frac{Q_{eau}}{1 - D_L} \quad (5)$$

where:
• D_L is leaching rate,
• Q_{eau} is palm's water requirement.

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The gross irrigation water requirement Q_b, is given according to [28] by:

$$Q_b = \frac{Q_n}{E_a} \qquad (6)$$

where:
• Q_n is net irrigation water requirement;
• E_a is efficiency of applying water to the plot.

Irrigation technique
The localized irrigation technique known as "drip" is chosen to preserve the water resource, thus allowing pumping system optimal sizing [29]. An empirical relationship exists between the quantities of water necessary for irrigated cultivation in gravity mode and those to be provided in the event of localized irrigation [30], [31]:

$$Q_l = Q_b \times (k_0 + 0{,}90p) \qquad (7)$$

where:
• Q_l is water volume for localized irrigation,
• Q_b is gross volume of water for gravity irrigation,
• p is soil fraction covered by plant foliage,
• k_0 is oasis effect coefficient.

Solar energy modeling
The Direct solar radiation S on a horizontal plane is given according to [32] by:

$$S = 1370 \times \exp\left[-\frac{T_L}{0{,}9 + 9{,}4\sin(h)}\right] \times \sin(h) \qquad (8)$$

where:
• T_L is link haze factor,
• h is height of the sun.

The Diffuse solar radiation D is calculated according to [32] by:

$$D = 54{,}8\sqrt{\sinh}\left(T_L - 0{,}5 - \sqrt{\sinh}\right) \qquad (9)$$

where:
• T_L is link haze factor,
• h is height of the sun.

The global solar radiation on a horizontal surface is given by:

$$G = S + D \qquad (10)$$

Photovoltaic field modeling
Photovoltaic field performance depends on solar radiation, temperature and load to be supplied. The maximum power P_{mp} at photovoltaic field output is given according to [33] by:

$$P_{mp} = \eta_{PV} A_{PV} G \qquad (11)$$

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where:
• S_{PV} is photovoltaic field area,
• G is solar irradiance,
• η_{PV} is photovoltaic modules efficiency.

With:

$$\eta_{PV} = \eta_{ref}\left[1-\alpha\left(\frac{G}{18}+T_a-20\right)\right] \quad (12)$$

where:
• α is temperature coefficient for the power correction,
• η_{ref} is photovoltaic module reference efficiency,
• T_a is ambient temperature.

An inverter input power is that produced by photovoltaic field. Inverter output power can be expressed from the input power and the efficiency according to:

$$P_{output} = \eta_{inv} P_{input} \quad (13)$$

With:

$$\eta_{inv} = \frac{p}{p+p_0+kp^2} \quad (14)$$

And:

$$p = \frac{P_{output}}{P_n} \quad (15)$$

where:
• P_{input} is inverter input power,
• P_{output} is inverter output power,
• P_n is inverter nominal power,
• η_{inv} is inverter efficiency,
• p_0 and k are coefficients calculated from data provided by manufacturer,
• p is reduced power.

Total manometric height calculation
The pump total manometric height is the difference in water column pressure between the suction and discharge ports.

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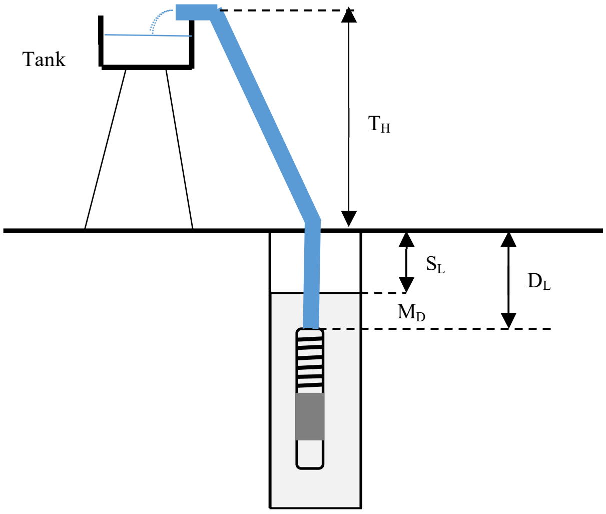

Figure 5. Schematic diagram

The total manometric height is giving by:

$$H_{tm} = T_H + D_L + Loadloss \qquad (16)$$

or

$$H_{tm} = T_H + S_L + M_D + Loadloss \qquad (17)$$

where:
- H_{tm} is total manometric height,
- S_L is borehole static level,
- D_L is borehole dynamic level,
- T_H is tank height,
- M_D is drawdown
- Loadloss is pressure drops in the piping.

Submersible pump modeling
A submersible pump is defined by its flow rate and its total manometric height. The pump curve makes it possible to choose the appropriate pump. A submersible pump power P_l is given by:

$$P_l = \frac{\rho Q H_{tm}}{367\,\eta_{pum}\,\eta_{eng}} \qquad (18)$$

where:
- Q is pump flow rate,
- H_{tm} is total manometric height,
- ρ is water density,
- η_{pum} is pump efficiency,
- η_{eng} is engine efficiency,
- 367 is conversion factor.

The electric power supplied to a pump is given according to [34] by:

$$P_2 = P_1 \eta_{eng} \quad (19)$$

Photovoltaic field sizing
The required energy to lift a quantity of water is given by:

$$E_d = \frac{\rho \times Q_{water} \times g \times H_{tm}}{3600 \times \eta_G} = \frac{2{,}725 \times Q_{water} \times H_{tm}}{\eta_G} \quad (20)$$

where:
- E_d is daily energy required to lift water,
- ρ is water density,
- g is gravity acceleration,
- Q_{water} is maximum water requirement,
- H_{tm} is total manometric height,
- η_G is the overall efficiency,
- 2.725 is conversion factor.

With:

$$\eta_G = \eta_{PV} \cdot \eta_{inv} \cdot \eta_{eng} \cdot \eta_{pum} \quad (21)$$

where:
- η_{PV} is photovoltaic array efficiency,
- η_{inv} is inverter efficiency,
- η_{eng} is engine efficiency,
- η_{pum} is the pump efficiency.

The photovoltaic field peak power is given according to [35] by:

$$P_C = \frac{E_d}{G_{\min}} \quad (22)$$

where:
- P_C *is* photovoltaic field peak power,
- E_d is daily energy required to lift water,
- G_{min} is worst month average irradiation.

Ssubmersible pump sizing and choice
With the chosen photovoltaic field, the actual pump flow is given by:

$$Q_{act} = \frac{P_C \cdot E_d \cdot \eta_G}{2.725 \cdot H_{tm}} \quad (23)$$

where:
- Q_{act} is actual pump flow,
- P_C *is* photovoltaic field peak power,
- E_d is daily energy required to lift water,
- η_G is global efficiency,
- H_{tm} is total manometric height,
- 2.725 is conversion factor.

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The maximum flow rate is given by:

$$Q_{\max} = \frac{Q_{act}}{G} \quad (24)$$

where:
- Q_{max} is maximum flow rate,
- Q_{act} is actual pump flow,
- G is global radiation.

Technical-economic analysis

The pumped water cost calculation takes into account investment cost and discounted costs of maintenance, operation, renewal, as well as elements residual value of pumping system [36]. The actual cost per cubic meter of water is given by:

$$C_{act} = \frac{\sum C_n + C_I - V_R}{D \times d} \quad (25)$$

where:
- ΣC_n is sum of pumping system discounted costs of operation, renewal, maintenance, during project lifetime,
- C_I is initial investment cost,
- V_R is pumping system residual value,
- D is annual water demand,
- d is project lifetime.

Tables 2 to 5 present simulation parameters values of pumping system at each site.

Table 2 Photovoltaic field simulation parameters

Photovoltaic field	Value	Unit
Peak power	35	[kW]
Lifetime	25	[Years]
Acquisition coefficient 1	6724	[$/kW]
Acquisition coefficient 2	35.68	[$/kW]
Maintenance coefficient	2	[%]

Table 3 Inverter simulation parameters

Inverter	Value	Unit
Nominal power	40	[kW]
Lifetime	20	[Years]
Acquisition coefficient 1	1662.6	[$/kW]
Acquisition coefficient 2	0,27	[-]
Efficiency	0,95	[%]

Table 4 Simulation parameters of borehole equipped with pump

Elements	Value	Unit
Borehole lifetime	25	[Years]
Total manometric height	120	[m]
Pump nominal power	30	[kW]
Pump lifetime	10	[Years]
Pump flow	185	[m^3/h]

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Table 5. Discount rate

Elements	Value	Unit
Inflation rate	3	[%]
Discount rate	8	[%]

4. RESULTS AND DISCUSSIONS

The chosen sites for this study are those of Oudalan, Seno, Soum and Yagha located in the Sahel region of Burkina Faso, in West Africa. The aim is to increase the access to water resources supply, at a lower cost, for date palm irrigation, by pumping groundwater from aquifers using solar energy, which is the most abundant endogenous renewable energy at these sites. The study is carried out for 20 years project duration.

Assessment of water needs for palm irrigation

The water demand is calculated for one hectare area of date palms, which is equivalent to 129 date palms, spaced seven meters apart, at each site. The profile of the water demand to irrigate one (1) hectare of date palms at Oudalan, Seno, Soum and Yagha sites is determined and represented (Fig. 5).

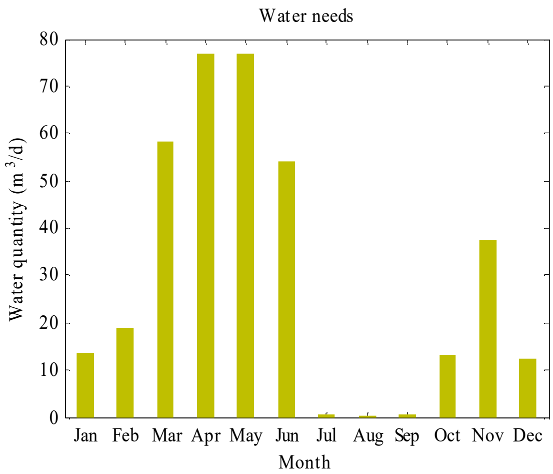

Figure 5. Daily water requirement Profile

The monthly water consumption profile is established according to date palm average crop coefficient equal to 0.75 at studied sites. The maximum water demand at each site is 76.8 cubic meters per day. The maximum water requirement is in April month, with 76.8 cubic meters per day water demand. This is because it is in April that the daily temperatures are highest and evapotranspiration value is highest. The submersible pump hourly flow rate calculation result gave 11.4 cubic meters per hour.

Solar energy potential assessment

Solar energy potential assessment at studied sites will ensure that electrical energy required for pumping can be obtained from solar energy conversion. Global radiation and sunstroke at studied sites are represented.

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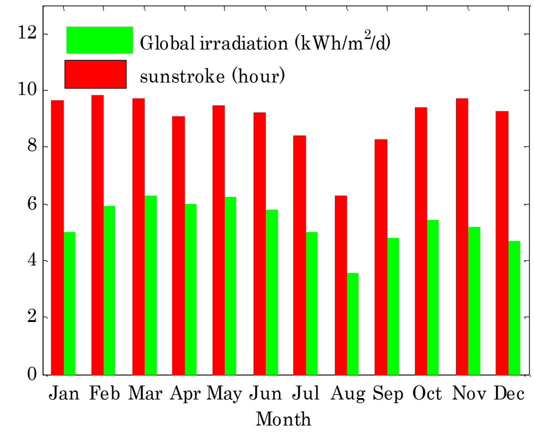

Figure 6. Global irradiation and sunstroke curves at studied sites

The highest solar radiation value is in the period from March to April, with a value reaching 6 kWh per square meters and per day. It is also during this period that the energy demand for pumping is highest. However, the insulation value is average, around 9 hours per day. The average daily sunshine is 5.5 kWh per square meter and per day. The insulation time is 3,000 to 3,500 hours per year, with an estimated average yield of 1,620 kWh per kWp installed. Solar radiation characteristics at these sites are favorable to groundwater pumping, to satisfy the water needs expressed in figure 5. Electricity demand for pumping and photovoltaic field production curves are giving. Daily electricity demand and photovoltaic field production curves are represented.

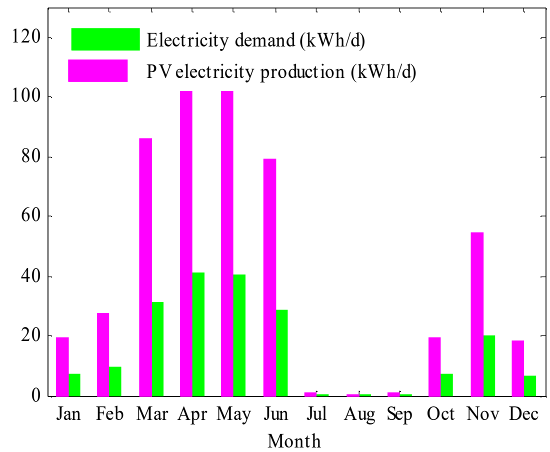

Figure 7. Daily electricity demand and photovoltaic field production curves

The photovoltaic field production is in line with the electricity needs of March, April and May during which water demand is very high (Fig. 7). The lowest production is recorded during the months of July, August and September during which the pumping activity is reduced, because this period corresponds to wintering at sites studied.

Total manometric height assessment

The pressure drops in the pipes are calculated according to pump hourly flow rate, pipes length and diameter. Borehole characteristics, total pressure drops in the piping and the total manometric height are given.

***Table 6. Borehole characteristics and total manometric* height**

Water static level (m)	Water dynamic level (m)	Drawdown (m)	Tank height (m)	Total pressure drop (m)	Total manometric height (m)
84.8	63.5	1.31	7	0.3	70.8

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The total manometric height is calculated taking into account drawdown at the highest flow rate added to pressure drops and tank height. The total manometric height varies with the pressure drops and drawdown. It is essential to take drawdown into account when calculating total manometric height. However, the ambient temperature at studied sites has an effect on the pressure drops. In the Sahel, the ambient temperature often reaches 45 °C, which can induce losses of up to 15%.

Technical-economic analysis

The simulation is made with the commercial software (Homer). Homer software is a time series model that performs an hourly energy balance along a year for each system configuration entered by the user. In Homer linear cost functions are adopted and components size to be considered must be planned in advance, in order to achieve the optimization. The pumping system elements optimum sizes are determined by simulation in Homer software.

Table 7. Optimal sizes of pumping system elements

Caracteristiques	PV field	Inverter	pump	Borehole
Size (kW)	3	4	2.2	-
Flow (m^3/h)	-	-	12	18 m^3/h
Total manometric height (m)	-	-	70.8	120.89
Lifetime (ans)	25	15	10	30

The date palms irrigation is satisfied with a borehole equipped with an electric pump, whose electric energy for pumping is produced by photovoltaic generator.
A submersible pump is defined by its flow rate and its total manometric height, which define the operating point at the best efficiency at nominal speed, around 2850 rpm for frequency of 50 Hz, for centrifugal pump. The best pump is the one that will work at its best performance, around sites solar noon, which is 12 hours GMT. The optimal costs of the pumping system, outside infrastructure (borehole and water storage tank) and the peak watt of electricity produced are given.

Table 8. Photovoltaic generator optimal costs

Site	Capital initial ($)	Maintenance cost ($)	Opération cost ($)	Renewal cost ($)	Residual value ($)	Peak watt cost ($)	kWh cost ($)
Oudalan	3887.96	1025.92	1857.19	104.40	193.19	1.71	0.594
Seno	21770.13	1857.19	2911.31	104.40	1335.51	11.81	2.251
Soum	21770.13	1857.19	2911.31	104.40	1335.51	11.81	2.251
Yagha	21770.13	1857.19	2911.31	104.40	1335.51	11.81	2.251

The peak watt cost covers all the pumping system elements, except the infrastructure (borehole and water storage tank). According to Table 8 results, peak watt cost is very significant in this photovoltaic pumping system. Indeed, this cost is inversely proportional to water volume pumped daily. The pumping system and cubic meter optimal costs at each site are recorded.

Table 9. Pumping system optimal and water m^3 costs at each site

Site	Initial capital ($)	Operation cost ($)	Maintenance cost ($)	Renewal cost ($)	Residual value ($)	Water cubic meter cost ($)
Oudalan	30266.55	14609.79	22326.38	763.32	1474.76	0.092
Seno	45784.22	12777.88	22279.24	693.93	2502.63	0.109
Soum	44872.17	12768.63	21980.05	693.93	2444.42	0.108
Yagha	48181.32	14609.79	24215.78	763.32	2619.22	0.118

The simulation results give water cost: 0.092 $/m^3$ at Oudalan site, 0.109 $/m^3$ at Seno site, 0.108 $/m^3$ at Soum site and 0.118 $/m^3$ at Yagha site. The finding is that pumped water m^3cost is roughly the same at Seno and Soum sites. On the other hand, water lowest cost per cubic meter is recorded at Oudalan site and the highest cost per cubic meter is obtained at Yagha site, where it is worth 0.118 $. A difference of approximately 0.026 $ is observed between the highest water cubic meter cost (Yagha site) and the lowest water cubic meter cost (Oudalan site).

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This is explained by system initial cost which is higher at Yagha site, compared to this same cost at other three sites. Indeed, according to Table 7 results, the system initial cost is 48181.32 $ at Yagha site against approximately 30266.55 $ at Oudalan site. That is a difference about 17914.77 $. In addition, a difference over 1144 $ exists between pumping system residual values at Yagha site and at Oudalan. These observed various differences in system cost and in residual values led to a higher cost per cubic meter of pumped water at Yagha site. Produced electricity cost from renewable energies increases with solar system power. The electricity cost is necessarily higher at Yagha site and consequently, pumped water cost per cubic meter, more expensive than at other studied sites.

5. CONCLUSION

This study objective is to contribute to irrigated cultivation development by optimizing over the sun pumping system, at lower cost, for young date palms trees irrigation in rural area, at four sites in Sahel region of Burkina Faso. The simulation results give water cubic meter cost of 0.092 $ at Oudalan site, 0.109 $ at Seno site, 0.108 $ at Soum site and 0.118 $ at Yagha site.Optimizing the sizing of groundwater pumping system resulted in very competitive water cubic meter cost, compared to water cubic meter cost charged by the national water distribution company, which is on average 1.81 $ per cubic meter for studied sites water needs.

The water availability in quantity and at a lower cost will boost socio-economic development in a sustainable manner in Sahel region. Photovoltaic solar does not emit greenhouse gases during operation and its use as energy source for the pumping system has no impact on environment. Date palm trees, in addition to their usefulness for food, are used to form an arch with their branches, in order to allow plants to be grown at their foot that would transpire more, if they were in full sun, such as orange trees, lemon trees, vegetables and grains. The date palms using helps to fight against the desert advancing. In fact, the date palm trees, because of its size, are the most suitable for stopping sand dunes. The expected socio-economic impact of this project is employment creation in agricultural exploitation fields, in particular, installation and maintenance technicians in electric pumping systems profession, the renewable energy development, food self-sufficiency and local wealth creation through the dates, cereals and vegetables production. The parameters similarity in the Sahelian zone requires that this study results be applicable to entire Africa Sahelian zone, over approximately 5.4 million km^2 area and which extends from Atlantic Ocean to Red Sea.

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