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Assessing the Performance of Solar Photovoltaic Pumping System for Rural Area Transformation in West Africa: Case of Sekoukou Village, Niger

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Abstract: Energy is a critical foundation for socio-economic development of any country. This study assesses the performance of the Solar Photovoltaic Pumping System toward an integrated rural area transformation in the village of Sekoukou in Niger (West Africa). Electrical parameters, meteorological data and the PVsyst software are used respectively for data measurement/collection and the systems performance analyses based on three different scenarios related to population growth The results of the study reveal that the output power of the PV arrays depends significantly with the sun irradiance with an average peak power of 540 W for 783 W/m^2 average sun irradiance. The average performance of the motor-pump discharge observed is 35%. The study shows that the performance of the system depends significantly on the meteorological condition as well as the water demand and also the size of the storage tank. Moreover, the simulation results using PVsyst model show that the solar pumping system could afford respectively 84.7 %, 74.8%, and 62.5% of the water demand for the community according to population growth scenarios in 2025, 2030 and 2035 respectively. Additionally, the installed PV arrays is oversize compare to the pump energy requirements, therefore the system could not provide the sufficient water demand in the horizon 2035 due to the lower discharge of the motor-pump.

Keywords: Performance, Solar Photovoltaic Pumping, PVsyst, Scenarios, Rural Area, West Africa, Niger

1. Introduction

Energy is generally recognized as an important component and/or a critical foundation for economic growth and social progress. Indeed, an increasing energy demand is highly correlated with socio-economic development [1]. The majority of the population in most developing countries are from rural area. According to the United Nation department of Economics and socials Affairs, global rural population is now close to 3.4 billion and is expected to rise slightly [2]. Yet, the rural populations of many developing countries have been excluded from most of the benefits of economic development, the transition to better energy services and the access to safe drinking water [1]. Thus, to meet the sixtieth United Nations' Sustainable Development Goals (SDGs 6), Energy and Water resources are essentials and required. Water supply in many developing countries is subject to diverse problems especially in Sub Saharan Africa (SSA). Arid and semi-arid countries in SSA such as Niger are particularly facing severe water scarcity due to rapid population growth correlated to increasing demand of water resources and supply. Although, Niger has a huge potential of solar radiation whereas the major part of the population especially in rural area [3], are facing the problem of access to a safe drinking water. And some of the challenges contributing towards inefficient and poor water supply have to do with population growth, inappropriate system design, and poor management of water supply facilities, low profile of operation and maintenance as well as insufficient and inefficient use of funds [4].

Renewable energy such as solar photovoltaic system (PV) is considered as one of the solutions of water access in most rural and remote area in SSA. The advantage of using solar PV water pumping system (PV-WPS) includes its cost effectiveness, no emission of greenhouse gases, improvement of the technology, easy installation, low maintenance, reliability as well as matching high water demand and the power generated. Despite these advantages, the solar PV water pumping systems present low performance, low energy efficiency and intermittent of solar radiation though the solar PV is one of the most suitable alternatives for energy transition [5]. Furthermore, reliable solar PV pumps are now emerging on the market and are rapidly becoming more attractive in order to increase the efficiency of the systems. These technologies, powered by renewable energy sources such as solar PV system, are especially useful in remote locations where a steady fuel supply is problematic and skilled maintenance personnel are scarce [6]. Solar PV technology applied to water pumping system (WPS) is based on conversion of solar energy into electrical energy by solar panels to power a water pump which drains the aquifer water into a storage tank to be distributed for water supply for populations and/or directly for agriculture practices (e.g., irrigation).

Many studies have been conducted to investigate the performance of PV pumping system (e.g. [7-9] etc.). For instance, Hamidat, A. [10] have used a surface centrifugal pump and three PV arrays installed in Algeria and found that the total dynamic head of the pump has varied the results and has concluded that the average daily flow rate for a 14.5 m of Total Dynamic Head (TDH) is 60m^3/day with a water delivered cost is found to be US \$0.04/m^3. The surface PV pumps are recommended by this study to supply water in the remote Sahara regions for the socio-economic development of the region. Also, Jafar, M. [11] have developed a simple method using a reliable easily measurable data for modeling a solar photovoltaic water pumping output. The model predicts at a given head and irradiance the water flow rate of the system. The predicted flow rates are within 8% of the measured values. The fluctuations in the solar irradiance and unsteady module temperatures are the reasons of the small deviation observed during the measurements. Meah, Kala [12] have highlighted the need for using PV pumping in drought prone states. The study has analyzed the performance of 75 systems in operation and has shown excellent performance and cost effectiveness besides benefit of reduction of carbon emissions. It urges the need to provide solar pumping system for livestock in some remote locations in the western part of USA. In [13], the authors have carried out detailed measurements of an experimental PV water pumping system with a 610Wp PV generator which provides daily water to more than 200 consumers in remote locations of Greece. The system operates reliably with relatively low electrical losses 10%, and is an environment friendly application. Saidou M. [14] have studied the performance of a PV water pumping system in a village of Niger to cover the domestic water need of 500 inhabitants and found that the cost of the water pumped using solar PV source is more cost-effective than other source.

Much of the reviewed literature on solar photovoltaic pumping system performance analysis pays particular attention mostly to the efficiency of the both solar PV plant and motor-pump whereas the future water need increase due to the population growth is ignored. Also, most of the efficiency evaluation of the solar water pumping systems are based on the database from the internet due to the lack of on-site measured data. According to the best of the author knowledge of the solar photovoltaic water pumping system (SPV-WPS) there is a limit discussion about the solar photovoltaic water pumping system efficiency evaluation in Niger despite of the large usage of this technology. One of the most promising alternatives for water supply in rural area is the SPV-WPS due to the high potential of solar radiation in Niger. Therefore, the aim of this paper is to assess the efficiency of solar photovoltaic water pumping system (SPV-WPS) for rural area transformation in West Africa: case of Sekoukou village, Niger. The paper is structured as follows: the first section describes the study area, the data used and the methodology, the second section presents the results and discussion and the third section shows the conclusion.

2. Data and Methodology

2.1. Description of the Study Area

This study's solar pumping system is located in the department of Kollo at the Sekoukou village (Figure 1), situated in the eastern part of Tillaberi region (Niger). Sekoukou village is located about 40 km south-east of Niamey (the capital of Niger). According to the fourth general census of inhabitant and household of Niger, carried out in 2012 the population is estimated about 467 inhabitants, spread in 64 households, hence 89% of household occupation were Agriculture (Institut National de la Statistique, 2012). It is situated at the latitude and longitude of 13°16'25.49" N, 2°22'0.66" E respectively and has an elevation of about 185 meters above the see level. The average annual rainfall is about 635.5 mm with a temperature of 29°C.

The economy of this village is predominantly based on rainfed farming of millet, cowpea sorghum, rice, beans, off-season small-scale irrigation of potatoes and livestock breeding and rural weekly markets as well. In Sekoukou village, five hundred (500) farm animal heads are estimated. The main local language spoken is Zarma.

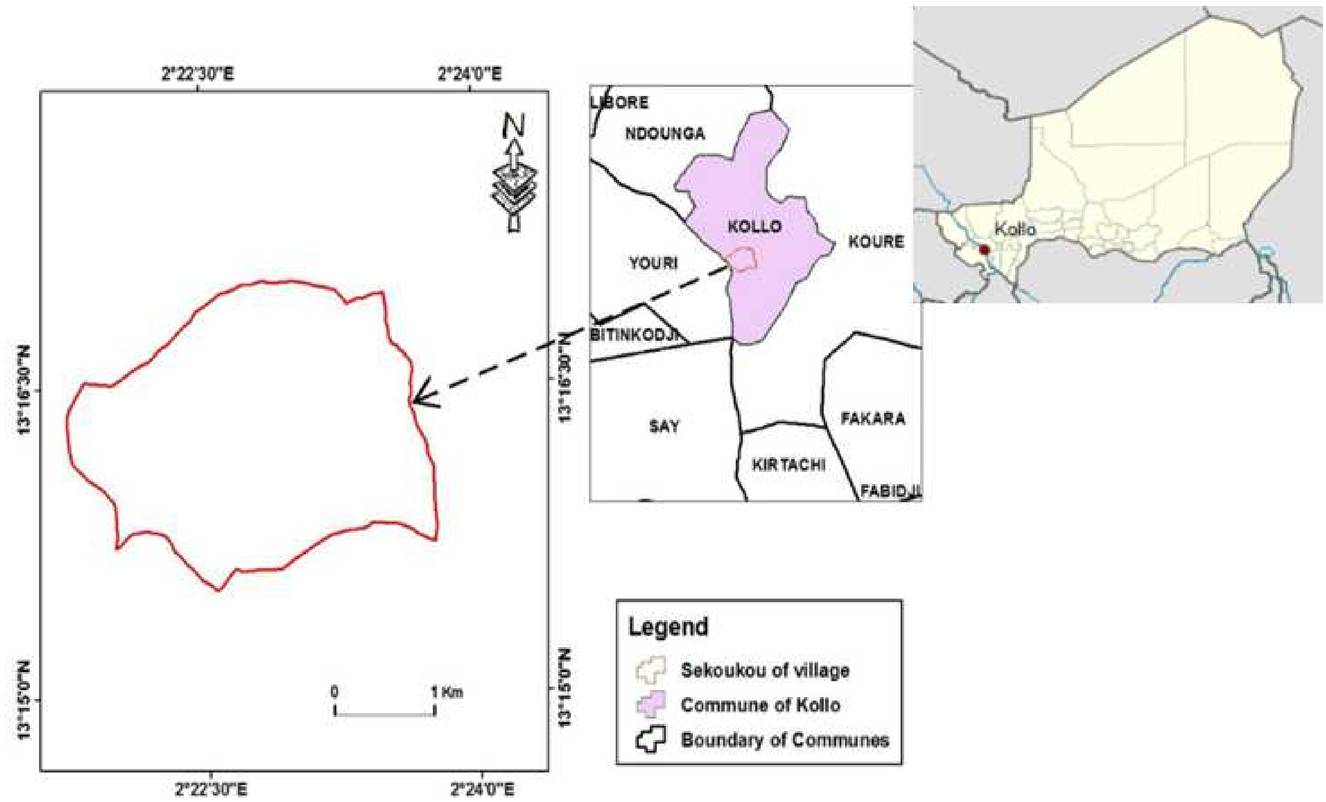

Figure 1. *Map of Sekoukou village location (adapted from [15]).*

2.2. Data Collection

The evaluation of solar photovoltaic pumping system has required both primary and second data collection. A field visit for technical characteristic of the system and a socioeconomic data were collected. The socio-economic data collection has been carried out to find out the main occupation of the household's chief, the average water demand, the state of the potable water supply according to the distance, the inter-seasonal water sources and demand variation. For this purpose, a structured questionnaire-based survey was conducted using Open Data Kit (ODK) and kobo Toolbox. In addition, population growth of Sekoukou village is forecasted using the geometric increase model. In fact, population data of Kollo was collected from the National Institute of Statistic (INS), from 2012.

As the future water demand of the Sekoukou village is forecasting till 2035. In this study the domestic water demand per capita in rural area is estimated at 20liters/day/inhabitant according to the World Health Organization (WHO) norm in 2012 [16]. So, the average daily domestic water consumption is determine using the following formula (1).

$$C_{dailydomesticwater} = C_S \times P_n \quad (1)$$

Where:

$C_{\text{Daily domestic water}}$: The average daily water consumption (l/day).

C_S: Per capita water consumption (l/day/inhat) (in this case 20 l/day).

P_n: Population at the target year.

The geographical increased model is used for the population forecast with a growth rate of 3.9 %. The formula of the model is given in the equation (2).

$$P_n = P_0 \left(1 + G_R\right)^n \quad (2)$$

Where:

P_n: The projected population after nth year from initial year.

P_0: The population in the initial year of the period concerned.

Moreover, on-site electrical parameters of the site were collected using measurement instrument. Meteorological data such as direct sun irradiance, diffuse, wind speed and temperature of the site were collected for 2019 year from the installed meteorological data station of the village.

2.3. Methodology for Efficiency Evaluation of the (SPV-PS)

The solar pumping system installed at sekoukou village is intended to supply water for domestic usage. The system is consisting of 8 PV module (4Seriesx2Parallel) with 250 Wp per module. The PV generator convert the incident solar radiation into direct current to operate the electric SQFlex motor-pump using CU 200 pump controller. The motor-pump is located at 25 m head deep into a well. The power of the motor-pump is 1.4 kW with a wide voltage range in DC and AC. Water pumped by the SQFlex motor-pump is stored into a tank at about 7m from the surface upward with an average volume of 15 m^3. Water from the storage tank is then distributed through gravitation using the water distribution network for the different hamlet of the sekoukou village. In order to make available water from the solar pumping system close to the end-users, five (5) taps have been installed and each was equipped with flowmeter the table 1 give the characteristic of the system component.

However, in order to evaluate the daily performance of the PV generator and the motor-pump a set of measurements have been performed. Pyranometer and temperature measurement sensor, of the meteorological station were used to collect respectively horizontal solar irradiance (W/m^2) and the ambient temperature of the Area on 15 minutes (mn) basis from 7:00 AM to 6 PM from 12^{th} to 22^{nd} august 2020. Then, a multimeter equipped with clamp (fluke 736) meter was used to measure the output voltage and current of the PV generator. While the power supply to the helical rotor pump is collected from the display unit of the CU 200 controller.

Moreover, data from the meteorological stations are uploaded in the PVsyst software so that the performance of the system was analyzed as, there are a lack of real time daily water consumed with the correspondent solar radiation within a long-term data recorded. The meteorological data of the sekoukou village such as the solar radiation, the wind speed and the temperature of one-year 2019 was upload in the PVsyst software, the total dynamic head was also calculated to study the system performance.

Hence, the following equations are used to calculate the efficiency of the system component.

The total input power Pi is determined using the incident solar radiation on the surface of the solar PV arrays installed (3):

$$P_i(W) = G \times A \tag{3}$$

Where:
G: solar radiation (W/m^2),
A: effective module cell area (m^2).

The DC output power (W) from the PV array is given by (4):

$$P_0(W) = V \times I \tag{4}$$

Where:
V: the DC operating voltage (V),
I: the DC operating current (A).

Array efficiency Ea is defined as the output of the electric power versus the incident solar radiation (5)

$$E_a = \frac{P_0}{P_i} \times 100\% \tag{5}$$

The hydraulic power output Ph is the power required to lift a volume of water through a given head (6):

$$P_h(W) = \rho \times g \times Q \times TDH \tag{6}$$

Where:
ρ: water density (Kg/m^3);
g: specific gravity (m/s^2),
Q: the water discharge (m^3/s),
TDH: the Total Dynamic Head.

Efficiency of the subsystem (7) is the efficiency of the entire system component (controller, wire, motor-pump):

$$E_s = \frac{P_h}{P_0} \times 100\% \tag{7}$$

Afterwards, the system is resized in order to be able to cover the current and future domestic water demand. The total dynamic head (TDH), the electrical power need and the peak power of the system are determined for adequate SPV-PS within the lifetime of the system estimated as 25 years. The aforementioned parameters are evaluated through the following equation.

The total dynamic pumping head (8) is represented by [17] as:

$$TDH = hs + hf + hm = (Z_2 - -Z_1) + \frac{V^2}{2g}\left(f\,\frac{1}{d} + \sum K\right) \tag{8}$$

Where:
h_s: the sum of the total static head loss,
h_f the friction head losses,
h_m: the minor head losses,
V: the velocity of flow (m/s),
F: the friction factor,
L: the length of pipe (m),
d: the diameter of pipe (m), and
K: the loss coefficient for different components.

The electric power (9) to the input of the motor-pump unit, P_{EL} [kW] ([18]):

$$P_{EL} = \frac{P_h}{\eta_{MP}} = \frac{Q x TDH.\rho.g}{\eta_{MP}} \tag{9}$$

Where:
η_{MP}: Efficiency of the pump unit (%);
P_h: the hydraulic power of the system (W).

To determine, the photovoltaic power needs, a simplified method proposes a simple arithmetic formula that can be used to determine the approximate value of the rated power of the Photovoltaic panel according to Equation (3.5):

$$P_{PV} = \frac{P_{EL} \times G_{REF}}{G_{Global} \times F_Q} \tag{10}$$

Where:

1) PPV is the peak power of the PV array under Standard Test Conditions,
2) (STC: radiance = 1000 W/m2, AM 1.5, cell temperature

= 25°C) [kWp],

3) GGLOB is the global solar radiance on a horizontal surface [kW/m^2],

4) GREF is the incident solar radiance at STC [1 kW/m^2],

5) FQ is the quality factor of the system.

In the theoretical limiting case, supply and demand values are equivalent and the quality factor is therefore equal to one (FQ = 1). In the case of measured value, for example, FQ = 0.75 means that 75% of the electric power, which is converted from the incident solar power, is used whereas 25% of the electric energy is lost between the solar cell and the system output or it is not used. This helps to make a decision reasonably on the system type [18].

Table 1. *System component characteristic.*

PV array AP-PM-250 characteristics	
Maximum power (Pmax)	250Wp
Current at Pmax	8.47 A
Voltage at Pmax	29.5 V
Short Circuit (Isc)	9.49 V
Open circuit voltage (Voc)	35.5 V
Characteristic of the Motor-pump SQFlex 2.5-2:	
Rated Power	1.4 KW
Rated current	8.4 A
Rated DC voltage range	30-300 V
Rated AC voltage range	90-240V
Total dynamic head max	120 m
Flow rate max	2.2 m^3/h
CU 200 Controller	
Back-up fuse	10A
Range of ambient temperature	30 to 50°C
Self-power consumption	5W
Voltage rated range	30-300 V

3. Results and Discussion

3.1. Water Consumption Scenarios

The domestic water demand of the sekoukou village is forecasted regarding the population growth. Thus, will allow to investigate the sustainability of water supply to the end-user within the life time of the solar photovoltaic pumping system.

The figure 2 shows the populations increase in the sekoukou village from 2025, 2030 and 2035.

Generally, the populations increase sharply from the reference year up to the last scenarios in 2035. This shows about 20.6 % of population increase from 2020 to 2025. In addition, as the year advances the population growth still increased gradually, hence about 70% of increase will be observed to the year 2035.

In order to cover the total water demand of sekoukou village regardless climatic variation, the daily peak water demand per population growth scenarios was determine. The figure 3 gives the variation of the water demand within the lifetime of the study.

The figure 3 depicts also the variation of the total water demand in the sekoukou village per scenario which increases steadily from 2020 to 2035, respectively from 14.7 m^3/day to 24.54 m^3/day. From 2020 to 2035 the water demand increased by 70 % which is equal to 9.84 m^3/day. As, the water demand increase within the lifetime of the system it is worthy to evaluate the performance of the system and to re-design the system in order to cover the water need to the end-users.

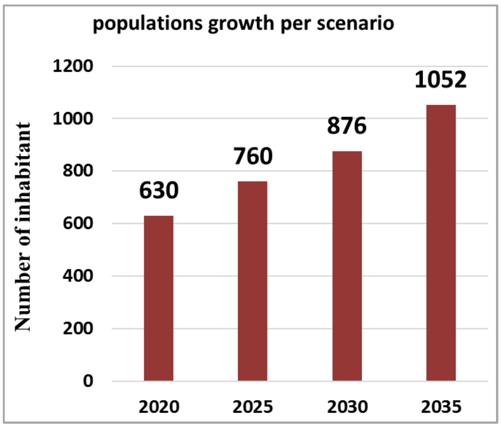

Figure 2. *Sekoukou village population forecast using geographical increased method.*

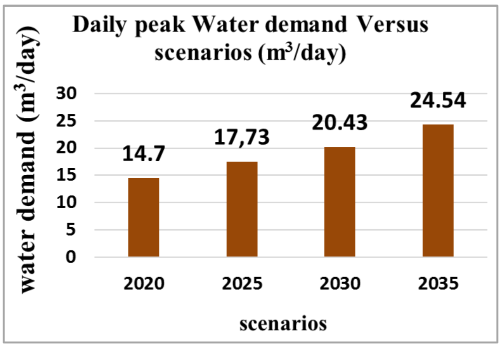

Figure 3. *Daily water demand variation.*

3.2. Meteorological Data Assessment

Meteorological data of the sekoukou weather station are collection such as horizontal solar radiation and temperature while the diffuse solar radiation is collected from ANERSOL (Agence Nationale de l'Energie Solaire) meteorological station. The parameters are depicted in the figure 4.

The two parameters of the solar radiation evolve in the same profile. In more details, the horizontal solar irradiance is higher in the hot season compared to the rainy and cold one because of the cloud cover and sun declination. Thus, the months of March, April and May registered the higher sun irradiance and temperature in 2019 at sekoukou village with an average value of respectively 6590 Wh/m^2/day and 31°C. While the months of December recorded the lowest solar radiation and temperature (4267 Wh/m^2/day and 24.9°C respectively).

Therefore, the meteorological data are used to evaluation the efficiency using the electrical data from the SPV-PS. Moreover, the performance of the solar pumping system is also investigated using PVsyst software versions 7.1. Thus, has been performed within the time life of the system.

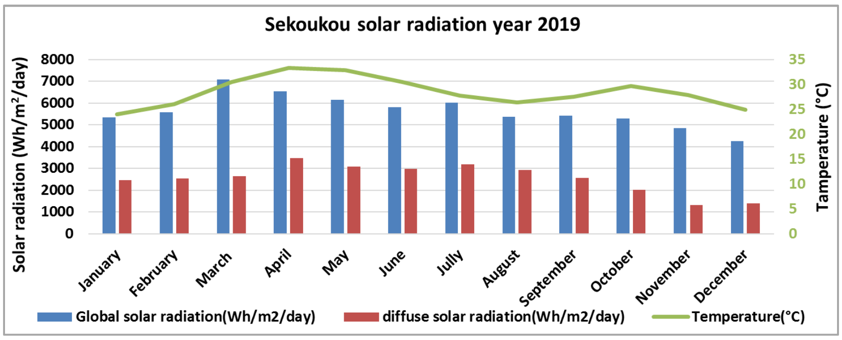

Figure 4. *Average Horizontal solar radiation and temperature in Sekoukou village.*

3.3. Solar Motor-Pump Discharge with the Radiation

The pump discharge of the sekoukou solar pumping system with solar irradiance variation is shown in the figure 5. The figure describes the pump discharge of the system from 7:00 am to 6:30pm.

It is clear from the figure 5 that the pump discharge varies in the same way as the solar irradiance as well as the water demand variation due to water level sensors that disconnect the pump supply when the water storage tank is full.

In the figure 5, the red graph illustrates the pump water discharge in function of the solar irradiance (blue graph). Thus, the system starts running from 7:00 am with around 0.21m^3/h for 100 W/m^2 sun irradiance and continue improving moderately until reaching the peak water discharge of 2.61m^3 /h at 1:00 pm with a maximum solar irradiance of 793W/m^2. On the other hand, from that time the pump discharge has begun going down to reach the lowest value of 0.19 m^3/h at 6:00 pm with 102 W/m^2 of solar irradiance. Furthermore, the figure shows also that the solar irradiance variability affects significantly the pump discharge of the system. Thus, the average water discharge from the pump is 1.28 m^3/h which corresponds to 15.37 m^3/day for 12hours of minimum solar irradiance. According to the study carried out by Benghanem, M., [19] the water discharge for the same type of Grundfos motor-pump and the daily water discharge can go up to 22 m^3/day (1.83m^3/h) at 80 m head. The daily pump water discharge is low because of the lower water demand during that period when there are various water sources mainly the Niger River and the cool weather condition. Hence, the results obtained by [20] on performance investigation of solar pumping system is in good agreement with the current study, the daily water discharge vary between 1.68 m^3/h to 2.03 m^3/h regarding the PV panels configuration.

Moreover, the figure 6 represent the motor-pump efficiency of the sekoukou solar pumping system that have calculated using the hydraulic power over the solar power generated. It shows a decrease of the pump efficiency from 9AM till 4PM.

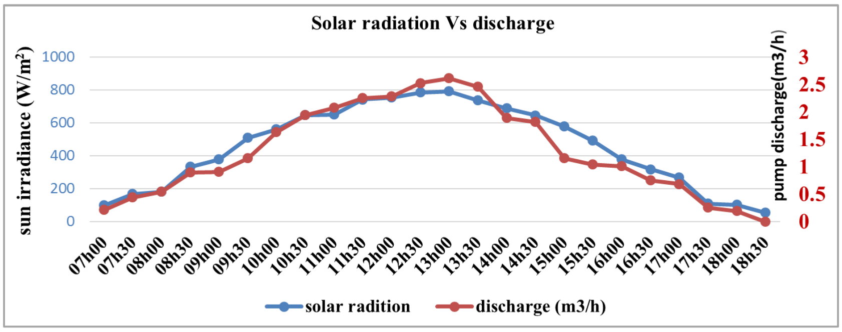

Figure 5. *Pump discharge variation with the solar irradiance.*

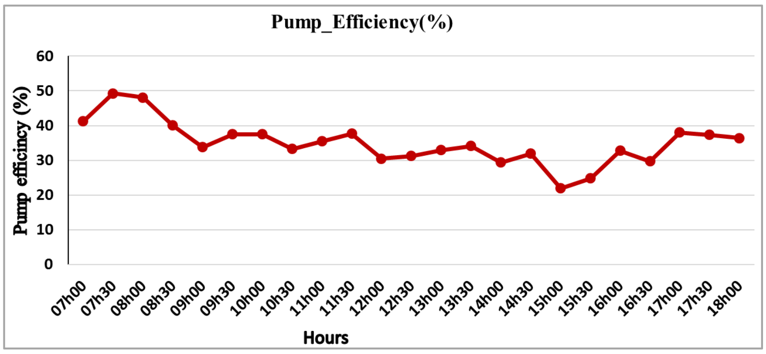

Figure 6. *Efficiency of the motor-pump.*

3.4. Output of the Photovoltaic Arrays

The figure 7 gives the power output of the solar PV arrays regarding the solar radiation along the days from 12th to 22nd August 2020 within a time step of 30mn. The electrical parameters measured namely the voltage and current have been used to calculate the output power through the equation (4) as described in the figure 7.

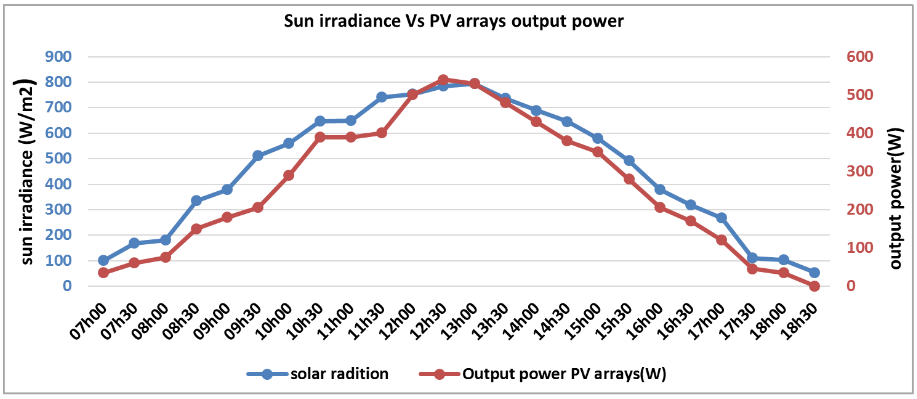

Figure 7. *Daily output power variation regarding the solar radiation.*

The graphs describe the variation of the solar radiation and the output power of the PV arrays during the day from 7am to 6:30 pm. In general, the output power of the PV arrays is increasing as the sun irradiance increases. Moreover, the solar radiation increases gradually from about 100W/m^2 around 7am and still continue to rise until reaching the peak at zenith where the maximum sun irradiance is 783.94 W/m^2. While the PV arrays starts producing early in the morning an average power output 85 W and keeps increasing slightly up to 540W at 12:30 am. In contrast, afterwards the solar irradiance and output PV arrays power begin declining until reaching the lowest value around 6:00 pm. Therefore, the power output of the solar PV arrays depends strongly on the irradiance which is also dependent on the time of the day and weather conditions (e.g., cloudy and sunny day). The decrease of the PV power output could be not only to the weather condition to the temperature variability, the inclination of the arrays but also the sun declination.

3.5. Performance Evaluation for the PV Arrays Using Measured Data

The efficiency of the PV arrays during the day has been determined using the equation (5). The figure 8 describes the variability of the efficiency throughout the day and indicates that the efficiency is an average 4.14 % in the morning around 9:00 am which increase sharply up. to 5.53 % in average before % at 12:00 am. Moreover, the peak efficiency of the PV arrays is reached at 5.74% around 12:30 pm then followed with slow decrease slightly until 4.51 % at 4:00 pm and goes down to the lowest efficiency of 2.85 % at 6:00 pm. It is important to outline that when the storage tank is full the water level sensor disconnect the PV power output which is being lost. Hence, the power from the PV arrays is lost due the size of the storage which is smaller regarding to the water discharge potential of the pump. Therefore, this lower efficiency of the panels is due to the cloud cover and aerosol during the measurement period (August) which is a rainy season.

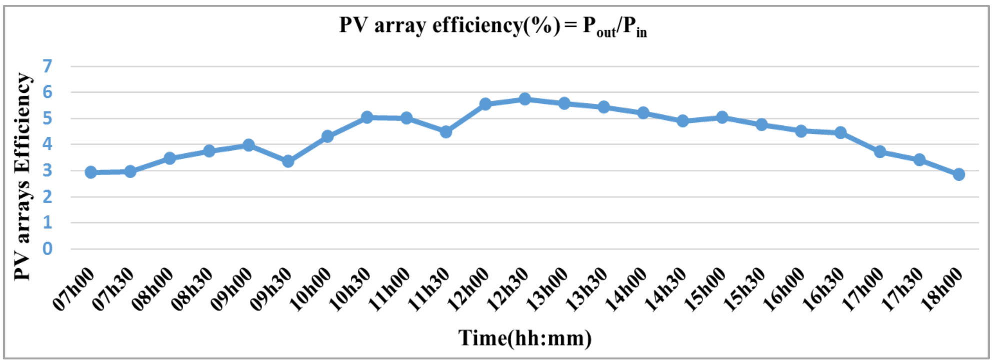

Figure 8. *Efficiency of the PV arrays of the system using measured data.*

The average solar PV arrays efficiency is about 4.3 % in light of the electrical data measured whereas the peak of the efficiency is around 12:30 am about 5.74 %. According to the research undertook by [19] on performance of the solar water pumping system using helical pump for a deep well in Saudi Arabia, the maximum efficiency of the PV array obtained are

7.4%, 8.9% and 9.58% depending on the arrays configuration with respectively an average of 3.56%, 4.12% and 4.77%. So, the result obtained in the present research is lesser than to the results of [19]. This may due to the lack of some parameters such as temperature, dust as well as climate conditions of the study area that have not been taken into account during the data collection. While, the results from the conducted study by [21] in India on performance evaluation of solar pumping revealed a PV panels efficiency vary from 3.48% to 4.32% which is in good agreement with the results obtained in the current study.

3.6. Performance Evaluation of the SPV-PS

The performance of the solar pumping system of sekoukou village was also evaluate using the PVsyst software since there is lack of a long-term measured electrical parameter of the system. In order to study the long-term performance of the system the future water demand of the village has been determined regarding the population growth. Moreover, the water pumped by the system using PVsyst software compare to the water demand forecast within the three scenarios built namely in 2025, 2030 and 2035 is given in the Table 2, 3 and 4 respectively.

3.6.1. Performance of the Solar Pumping System Scenario 2025

In this section, the simulation results of the solar pumping system installed at Sekoukou village using PVsyst 7.1 is presented. The analysis of the system was performed regarding the water demand variation scenarios. Thus, the simulation results determine for any running hour the flow rate delivered by the pump as a function of the head and the available electrical energy. The tank situation has to be managed whether the tank is full in order to limit the flow of the pump by disconnect the energy feed from the PV panels.

The results given by the PVsyst model, after running the simulation, take into account the energy balance mainly the water delivered to the users, the missing water, the excess (unused) PV energy, the efficiency of the pump, and the performance ratio.

Table 2. *Summary of the simulation results of the solar pumping system for 2030.*

PV arrays/scenario 2025/250Wp/8 modules in 4 series/ 2 string in parallel	
Daily water demand	17.7 m^3/day
Pump power	1.4kW,
Water pumped annually	5480 m^3
Missing water	15.3%
Energy at pump	788 kWh
Unused energy	22 kWh
System efficiency	20.8 %
Pump efficiency	49.3%
Water pumped (monthly)	Average 15.01m^3/day
Minimum water	12.74 m^3/day, November
Maximum water pumped	17.56 m^3/day, June

As shown in the table 2, the water demand at sekoukou village in 2025 will be 17.7 m^3/day while it was 14.7 m^3/day in 2020 (figure not shown). According to the simulation results, the system installed of PV size and pump power is able to provide 84.7 % of the community water need. From January the water pumped is increasing up to May about 34 % (13.2 to 17.66 m^3/day) which is the maximum flow rate of the pump.

From the month of June, there is a significant water supply reduction of about 28% in September. The lack of matching the water demand-supply could be explained by the fact that there are energy losses through the system from the PV arrays, wire, and subcomponents as well as lower energy during the full tank period. So, the obtained pumped efficiency of the pump and system efficiency are respectively 49.3% and 20.8%.

3.6.2. Performance of the Solar Pumping System Scenario 2030

The simulation of the same SPV-PS is also performed on the PVsyst for the population water demand increase by 2030. The table 3, summarize the simulation results of the system.

The table 3 gives the simulation results of the sekoukou solar pumping system for the year 2030 scenario. The water demand increases in the years as previously. In contrast, the water pumped from the system is relatively low compared to the demand, such situation leads to a missing water of about 25.2 %. Hence, the pumped flow rate reaches the maximum in June with 18.3 m^3/day and the lowest one still 12.74 m^3/day in September. Although, the missing water is higher, the unused energy from the PV arrays is reduced as for the previous scenario with about 59%. The efficiency of the system and the motor-pump remain roughly the same respectively 21.1% and 49.3% compare to the previous scenario.

Table 3. *Summary of the simulation results of the solar pumping system for 2030.*

PV arrays/scenario 2025/250Wp/8 modules in 4 series/ 2 string in parallel	
Daily water demand	20.43 m^3/day
Pump power	1.4kW
Water pumped annually	5574 m^3
Missing water	25.2%
Energy at pump	800 kWh/year
Unused energy	9 kWh/year
System efficiency	21.1 %
Pump efficiency	49.3 %
Water pump Average	15.27 m^3/day,
Minimum water pumped	12.74 m^3/day in November
Maximum water pumped	18.31m^3/day in June

3.6.3. Performance of the Solar Pumping System Scenario 2030

In this case, the forecasted population growth scenarios of 2030 domestic water demand is used to simulate the performance of the SPV-PS of the sekoukou village.

The table 4, give the results of the system performance analysis.

Table 4. *Summary of the simulation results of the solar pumping system for 2035.*

PV arrays/scenario 2025/250Wp/8 modules in 4 series/ 2 string in parallel		
Daily water demand	24.54 m^3/day	
Pump power	1.4kW,	
Water pumped annually	5601 m^3	
Missing water	37.5%	
Energy at pump	804kWh	
Unused energy	4kWh	
System efficiency	21.2 %	
Pump efficiency	49.3 %	
Water pumped	Average 15.33 m^3/day Minimum water pumped	12.74 m^3/day in November
Maximum water pumped	18.36m^3/day in June	

The results depicted in the table 4 represent the energy balance of the studied solar system of sekoukou for a daily water demand of 24.54m^3/day that correspond to the last scenario 2035. The gap of the water missed increase significantly at about 37.5%. Otherwise, the current solar pumping system can provide only 62.5 % of the water demand in 2035. However, the energy losses of the system have decreased slightly due to the higher water demand which can avoid energy loss from the PV when the tank is full. The system and the pump efficiency are still roughly the same 21.2% and 49.3% respectively.

Moreover, the analyzed results from the tables above have showed that the current solar pumping system of the sekoukou village is able to provide respectively 84.7 %, 74.8%, and 62.5% of the water demand for the community according to the scenarios. Therefore, the increase in water demand for the different scenarios improve the performance of the system because the unused energy from the PV arrays for the pump is reduced at about 59% and 81% respectively for the scenario 2030 and 2035 compared to the first scenario. Moreover, the tank size of the system which is 15m^3 has been increased during the simulation in order to find out its effect on the system performance. As a result, for the first scenario, the water pumped from the system increased at about 113 m^3 within the year when the size of the tank is estimated to be 60 m^3.

In addition, the efficiency of the pump is determined using the measured electrical parameters and is in average equal to 35%. While the average efficiency of the pump using PVsyst model is 49.3% due to the lack of taking into account some parameters (e.g., the optimum tilt angle, the drawdown of the water in the borehole, etc.) during the measurement. The overall system efficiency obtained using PVsyst software regarding the different scenarios is at about 21%. Therefore, the average efficiency observed according to the study carried out by [19, 22], correspond (3.56 % to 4.77%) and (5.83% to 9.98%) respectively in reference both to the PV panels configuration.

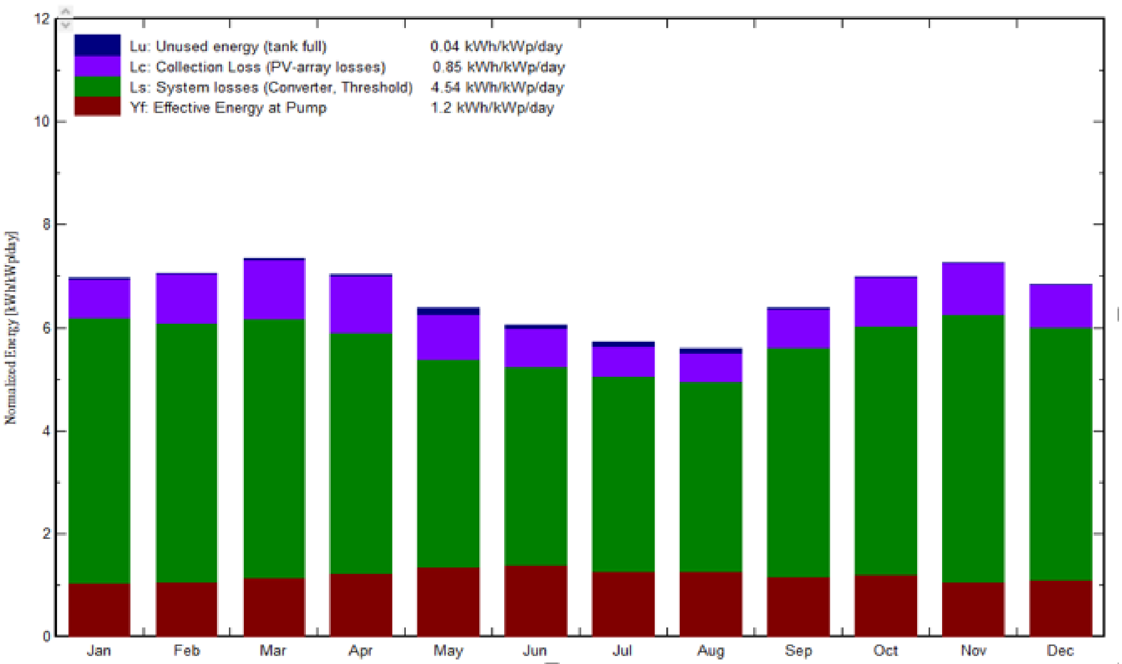

Figure 9. *Energy Balance of the system for the scenario of 2025.*

For instance, the figure 9 is given to illustrate the energy balance of the solar pumping system for the first scenario 2025 for the other scenarios. Indeed, the figure 9 shows the normalized values of the effective energy at the pump, the collection loss, the system loss and the unused energy (tank full) of the system. From the figures 9, the unused energy in the system for all sites are minimum, the highest value is in the month of May. In other hand, the system and collection losses are higher. Because of the PV arrays being over-sized. Regarding the pump size for the given head, most of the energy at the converter input is lost.

When the production is maximized, the system is subjected to higher losses, but if we reduce the amount of water pumped by the system per day, we can minimize the losses but the unused energy in the system will be maximized.

Therefore, the current PV arrays of the sekoukou solar pumping system is significantly oversized compare to the peak power demand using the analytical method of sizing the system particularly the equations (6, 9 and 10). Moreover, the challenge is to meet the required input rated voltage of the pump, which is 90 to 240V for AC and 30 to 300V for DC current. Thus, regardless the peak power demand, more PV panels should be connected in series in order to meet the required voltage range of the controller. This justify the reason why the solar pumping system is often oversized regarding the required PV peak power. The system cannot cover the total water need particularly in the lowest solar irradiance months and the flow rate required is increasing until being higher than the maximum flow rate of the motor-pump used.

4. Conclusion

In this study the performance of the solar photovoltaic system of the sekoukou village has been evaluated. The electrical parameters and the flow rate of the motor-pump are collected to find out the trend of the solar power generation and the water flow rate regarding the sun radiation. Also, the performance of the system is evaluated using PVsyst software taking into account the future domestic water demand regarding the population growth in 2025, 2030 and 2035. The research revealed that the sun irradiance has a significant effect on both the output of the solar PV system and the pump water discharge.

The average output power of the PV system is 270W while the maximum corresponds to 540 W at noon. The pump discharge obtained has an average of $0.21 m^3/h$ in the morning and the peak flow rate is $2.6 m^3/h$ at 12:30 when the sun irradiance is the highest 783 W/m^2. The simulation of the system using the PVsyst software shows that the daily water demand corresponds to 17.7 m^3/day (2025), 20.43 m^3/day (2030) and 24.54 m^3/day (2035). These results show that the system can provide respectively 84.7%, 74.8% and 62.5% of the water demand. In addition.

The size of the storage tank influence also the performance of the system caused by the unused energy from the PV arrays.

Finally, the simulation results using PVsyst software shows that the system cannot afford the required domestic water demand until the end of the system life time. To overcome this challenge the performance of the solar PV pumping system could be improve, by carrying out the following recommendation:

1) Cleaning activity of the PV panels regularly.
2) Cooling the PV panels also by spreading water on in order to decrease the effect of the temperature increase on the system efficiency.
3) Increase the size of the storage tank to 30 m^3 in order to cover the future water demand of the community and reduce the unused solar power generation.
4) As the PV generator is oversized regarding the motor-pump size, and because of the latter cannot afford the required future water demand. The motor-pump should be change before the end the second scenario in 2030 to a SQFlex-7A which has discharge up to 9 m^3/h.

The present study could be pursued by implementing a real time measurement sensor for the solar pumping system to collect a real time data such us (e.g., PV panels temperature, dust measurement, motor-pump discharge, the water flow within the pipe, the water pressure for each tap, borehole water level etc.). Hence, the data can gather in a database for a long-term in order to undertake a performance investigation of the overall system from the real time data.

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