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RESEARCH ARTICLE **OPEN ACCESS**

COST-EFFECTIVENESS AND EFFICIENCY OF PV PUMPING SYSTEMS UTILIZING ARTIFICIAL INTELLIGENCE ALGORITHMS

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ABSTRACT

We conduct this research for thirty-six months from 2021 to 2023 in Souk-Ahras (Tiffech), Algeria, to evaluate the effectiveness and costs of a direct-coupled photovoltaic pumping system for agricultural irrigation, considering the region's potential for solar energy. This study presents an analytical method of dimensioning based on water quantity, sunlight data, pump group efficiency, and well and reservoir characteristics to provide insights for better economic installation management. We evaluated the viability of a solar photovoltaic- SPV, water pumping system using the software PVsyst. However, we employed artificial intelligence- AI, methods to optimize irrigation and conserve water resources, thereby enhancing energy efficiency. Four AI methods, Support Vector Machine- SVM, Random Forest- RF, Naive Bayes- NB, and k-Nearest Neighbors- kNN, are utilized. Energy-efficient systems promote a reduction in overall costs, enabling users to maintain financial balance while meeting their pumping needs. According to AI findings, the k-NN model exhibits high accuracy at 0.960 precision. The cost-effectiveness comparison of the SPV system to a diesel generator demonstrated a significant decrease in the cost of pumped water, thereby making the SPV system more viable and profitable. This approach has demonstrated its effectiveness and robustness.

I. INTRODUCTION

The Algeria, the largest country in Africa, faces increasing pressure on its water resources due to rapid socio-economic development and agricultural expansion, leading to groundwater overexploitation. With 95% of rural water supply relying on groundwater, rural farming plays a critical role in Algeria's economy, supported by government investments aiming for self-sufficiency in food supply. Photovoltaic- PV, water pumping emerges as a sustainable solution to replace diesel-powered systems, addressing both environmental concerns and declining water tables [1-3]. PV technology is economically viable, offering decentralized energy solutions, especially in rural areas where grid extension is unfeasible [4], [5]. Despite diesel subsidies reducing the appeal of PV systems, real cost analysis shows PV water pumps are competitive over their lifecycle [6], [7]. Research by [8], [9], highlights seasonal variations in PV pump performance, showing optimal efficiency at panel temperatures between 12-32°C. Similarly, [10] emphasize the economic and environmental advantages of solar irrigation systems, noting significant improvements in farm income and reduced dependency on electricity. In Souk-Ahras, Algeria, this work employs artificial intelligence and PVsyst software to assess the cost-effectiveness and performance of a direct-coupled PV water pumping system. The research is structured into four parts: panel design and sizing, motor and pump evaluation, comparative analysis based on cost and efficiency, and concluding recommendations. Findings aim to guide decision-makers in selecting the most efficient motor, optimal pump type, and suitable PV module configuration to maximize energy efficiency and cost savings. By integrating electronic control systems, the study explores how motor speed adjustments and pump type selections can enhance long-term operational sustainability. The study employs four artificial intelligence methods: SVM, RF, NB, and kNN. Ultimately, this research demonstrates the robustness and efficiency of AI-optimized PV water pumping systems for sustainable agricultural irrigation in Algeria.

II. MATERIALS AND METHODS

II.1 PRESENTATION OF PVSYST SIMULATION SOFTWARE

PVsyst is software for sizing solar panels that allows you to obtain various information such as energy production, irradiation, installation cost, area required, or annual energy production. An advanced mode makes obtaining much more information for a complete study possible pursuant to [11], [12]. The software mainly includes two modes of operation, the first and a reasonably simple pre-sizing application to learn and accessible to neophytes. The second allows a much more in-depth study and considers many more parameters. Moreover, it is based on concrete material for its calculations, unlike the first mode, which performs calculations for a general case [13], [14]. For each of the two modes, the principle is the same: the geographical location of the installation is given, then the data concerning the installation is entered. Then comes a results section where we choose the data that interests us. This software is, therefore, accessible to experienced and neophytes alike. This documentation will not deal with the “pumping installation” parts and the financial aspects in mind to [15], [16]. Sizing and simulation of a PV pumping system with the PVSyst software. We will see how to size and simulate a PV pumping system, to start it is necessary to check three settings [17], [18]. First you need to know the site and its characteristics (location, weather, irradiation, etc…). Secondly, it is necessary to know the characteristics of user needs (reservoir, well and pipes...). Thirdly, it is necessary to know the choice of components (PV panels, pump, and connection…).

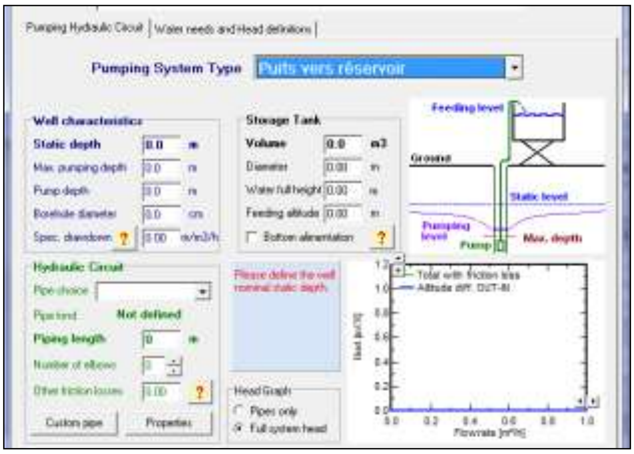
II.2 CHOICE OF SITE AND THEIR CHARACTERISTICS

First of all you have to know the location. The type of installation you are considering (on the roof, on the ground, etc.). As well as the orientation of the installation, to be able to define the solar yield available. The path of the sun: In our case, choose the site of Souk Ahras (Tiffech), where the geographical and meteorological data are included in the PVsyst software. Fig. 1, represents Souk Ahras (Tiffech) geographical site parameters, the site's coordinates are 36.08 49 North, 7.46 13 East, and 889 m altitude.

Figure 1: Site parameters Souk Ahras (Tiffech) geographical.
Source: Authors, (2026).

II.3 THE CHOICES NEED OF USER

Accurate water requirement assessment necessitates data on well characteristics, storage reservoirs, and hydraulic circuits, including height, reservoir diameters, and pipe diameters. When dimensioning a PV pumping system, the primary constraints are optimizing the size of the photovoltaic generator and the pumps, considering the flow rate and the compatibility of the electric PV pump, as well as the configuration of the system chosen [19]. We start with the sizing of the pump. You must fill in the data in figure 2 below:



Pumping System Type: Puits vers réservoir

Well characteristics
Static depth 0.0 m
Max. pumping depth 0.0 m
Pump depth 0.0 m
Borehole diameter 0.0 cm
Spec. drawdown 0.00 m/m3/h

Storage Tank
Volume 0.0 m3
Diameter 0.00 m
Water full height 0.00 m
Feeding altitude 0.00 m
☐ Bottom alimentation

Hydraulic Circuit
Pipe choice
Pipe kind Not defined
Piping length 0 m
Number of elbows 0
Other friction losses 0.00

Please define the well nominal static depth.

Head Graph
○ Pipes only
● Full system head

Figure 2: The need for the well, the tank and the vacuum pipes.
Source: Authors, (2026).

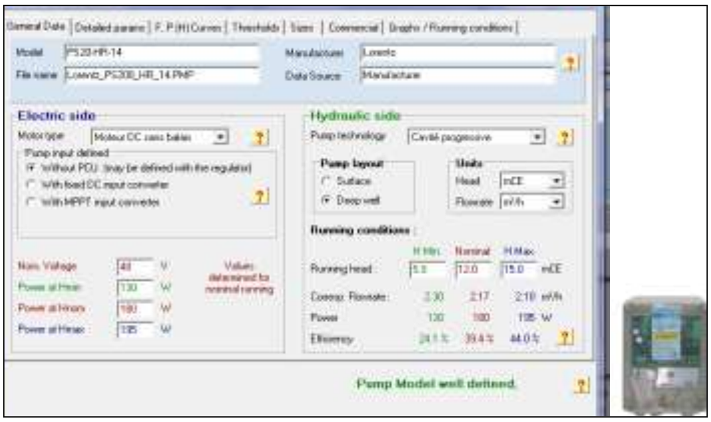
To determine the pump adapted to the needs, it is necessary to know several parameters, including the following:

The desired flow rate (in m^3/h);
The Total Manometric Height- TMH;
The supply voltage of the pump.

The flow rate is determined according to the needs. It is advisable to draw up a sizing sheet containing the number of cubic meters needed daily for domestic water, gardening, market gardening and drinking water for livestock. Flow Rate and (TMH), these 2 data mean the amount of operating water and the height at which the pump will have to discharge. Adding the pressure drops and the discharge pressure in the pipe will be necessary.

$$TMH = (Ha + Hr) + J + Pr\ (mCE) \tag{1}$$

The drip-fed farm is situated close to Tiffech in Souk Ahras, Algeria. It is therefore necessary for a submerged pump capable of delivering at 19 meters with a flow rate of 0.85 m³/h or 5.1 m³/day (6 hours/day). PVsyst has given us a range of pumps (brand and model). So, according to the availability in Algeria and the robustness of the brand, we chose the Allman LORENTZ product in the PS200_HR-14 range, which has the following characteristics (see Figure 3).



Model: PS200-HR-14
File name: Lorentz_PS200_HR_14.PMP
Manufacturer: Lorentz
Data Source: Manufacturer

Electric side
Motor type: Moteur DC sans balais
Pump input defined
● Without PCU (may be defined with the regulator)
○ With fixed DC input converter
○ With MPPT input converter
Nom. Voltage: 48 V
Power at Hmin: 130 W
Power at Hnom: 180 W
Power at Hmax: 195 W
Values determined for nominal running

Hydraulic side
Pump technology: Cavité progressive
Pump layout: ○ Surface ● Deep well
Units: Head mCE; Flowrate m³/h

Running conditions :

	H Min	Nominal	H Max	
Running head	5.0	12.0	15.0	mCE
Corresp. Flowrate:	2.30	2.17	2.10	m³/h
Power	130	180	195	W
Efficiency	24.1 %	39.4 %	44.0 %	

Pump Model well defined.

Figure 3: Pump feature PS200_HR-14.
Source: Authors, (2026).

Then, we must determine the power and number of photovoltaic panels needed to operate the pump. As a reminder, the peak watt-Wp, is the maximum power of a device. Its unit is the watt in the International System. For example, in a photovoltaic installation, this is the maximum electrical power that can be supplied under standard conditions:

An irradiance (energy illumination) of 1,000W/m^2;
A panel temperature of 25 °C;

A spectral distribution of the so-called AM 1.5 radiation, corresponding to the solar radiation reaching the ground after having passed through an atmosphere with a mass of 1 kg at an angle of 45°. If the temperature is higher than 25°C, it is necessary to count on a loss of yield of 0.4% per degree. Now that we have determined the appropriate pump, it remains to calculate the necessary power and, therefore, the number of photovoltaic panels to operate it in optimal conditions. To choose a pump that provides the desired water volume, with a specific flow rate and for a set time period, PVsyst has provided us with a selection of pumps. So as we said before, depending on the availability in Algeria also the robustness of the brand, we chose the Allman Sun Power product, in the SPR-X20-327-COM model. PVsyst allows users to simulate weather patterns by adjusting parameters and storing variables in monthly results. Figure 4 represents the influence of solar radiation variability on water production during a year.

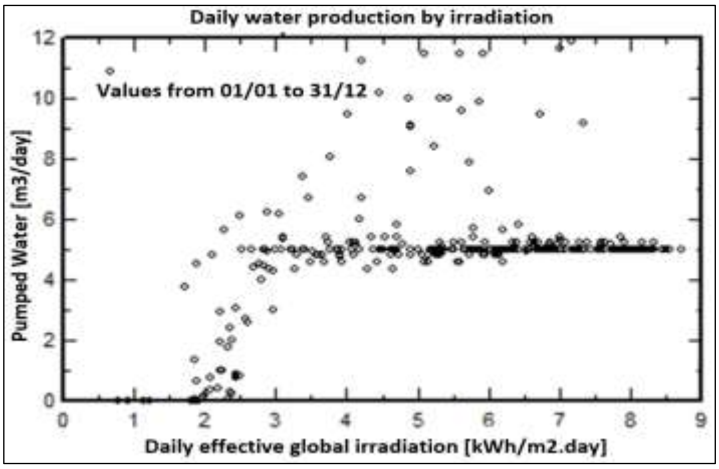


Figure 4: Daily water production according to irradiation.
Source: Authors, (2026).

We notice on the daily water production graphic display according to the irradiation that the relationship is almost linear. Knowledge of the apparent movement of the sun for a given point on the earth's surface is necessary for any solar application. The position of the sun is defined by two angles: its height HS (angle between the sun and the horizontal plane of the place) and its Azimuth AZ (angle with the direction of the south, counted negatively towards the east). Given the high price of PV modules, it is necessary to choose optimal orientations and inclinations for energy production. Optimization tool have a complete and precise calculation using comprehensive hourly weather data over a year (see Figure 5). Our software contains a tool aimed at showing the most suitable orientation for a photovoltaic pumping system where the transposition factor- FT, is the ratio of the incident irradiation on the plane, up to the horizontal irradiation. That's to say. What you gain (or lose) when tilting the collector plane.

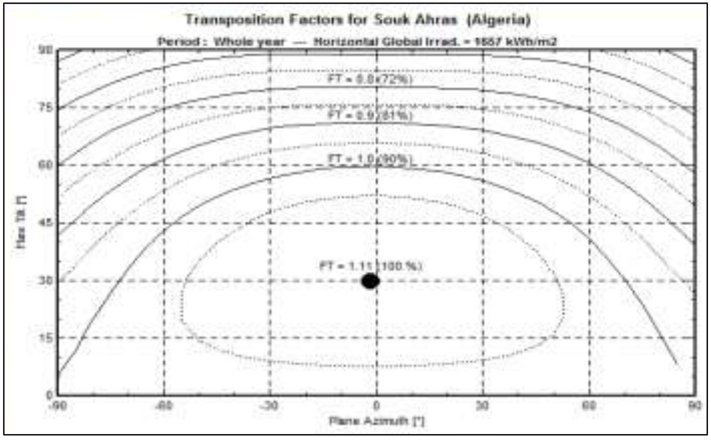


Figure 5: Souk Ahras transposition factor.
Source: Authors, (2026).

Quick optimization tool in the "Orientation" section: When choosing the plane orientation (fixed), an information panel indicates the corresponding transposition factor, the difference (loss) compared to the optimal orientation and the irradiation available on this inclined plane. So PVsyst chose an annual inclination plan of 32° (compared to the horizontal), this is the optimal inclination given by the PVsyst software, apart from the latter the yield decreases (see Figure 6).

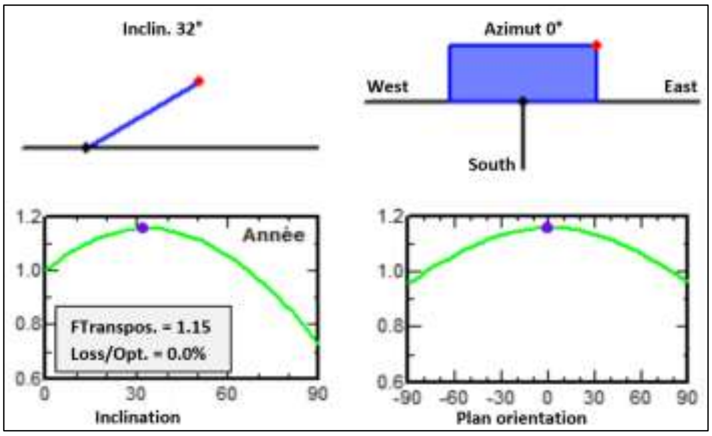


Figure 6: Optimal orientation of PV panels.
Source: Authors, (2026).

Table 1 summarizes three years of weather conditions for the site of Souk Ahras (Tiffech).

Table 1: Meteorological data from the Souk Ahras site (Tiffech).

	Global Irradiation (kWh/m^2.day)			**Diffus. (kWh/m^2.day)**			**Temperature (°C)**		
Months	2021	2022	2023	2021	2022	2023	2021	2022	2023
Jan.	2.28	2.38	2.43	0.91	1.04	1.14	8.0	6.9	10.0
Feb.	3.15	3.05	3.11	1.17	1.47	1.57	9.2	7.4	10.4
Mar.	4.25	4.32	4.38	1.55	1.86	2.07	12.0	11.0	13.6
Apr.	5.21	5.53	5.60	1.97	2.25	2.53	15.4	14.1	16.2
May	6.25	6.19	6.22	2.18	2.63	2.95	20.8	18.3	19.7
Jun.	6.98	7.03	7.04	2.18	2.47	2.93	25.7	23.2	23.5
Jul.	7.14	7.08	7.10	1.99	2.33	2.83	28.7	27.2	26.7
Aug.	6.08	6.41	6.43	1.91	2.16	2.64	28.5	26.1	26.7
Sep.	5.00	5.05	5.07	1.60	1.93	2.12	23.9	21.3	23.2
Oct.	3.57	3.97	4.01	1.29	1.49	1.67	19.6	17.8	20.3
Nov.	2.45	2.81	2.87	0.99	1.08	1.14	13.7	11.4	14.8
Dec.	2.02	2.25	2.29	0.83	0.94	1.04	9.6	8.0	11.4

Source: Authors, (2026).

IV. RESULTS AND DISCUSSIONS

In this work, the PVSyst program was used to simulate the design and analysis of an on-grid solar PV system. The most pleasant results were found and reviewed in the results analysis section after numerous simulations runs and calibrations. The model should be simulated following the previously outlined design procedure, and the results can be analyzed to determine plant efficiency. A comprehensive simulation has been conducted and multiple outputs have been produced in order to gain a better knowledge of the installed plant. The report includes calculating energy losses from the system's operation, tracking proportional losses from solar energy receipt to pump operation. Figure 7 displays losses and includes a fee schedule. The process begins with the energy losses incurred by the system, including those from the atmosphere and shadows. The efficiency of the cells here is 20.05% after the different system losses of the construction (queues, temperature, etc.), up to the final energy that is exported from the system to the pump.

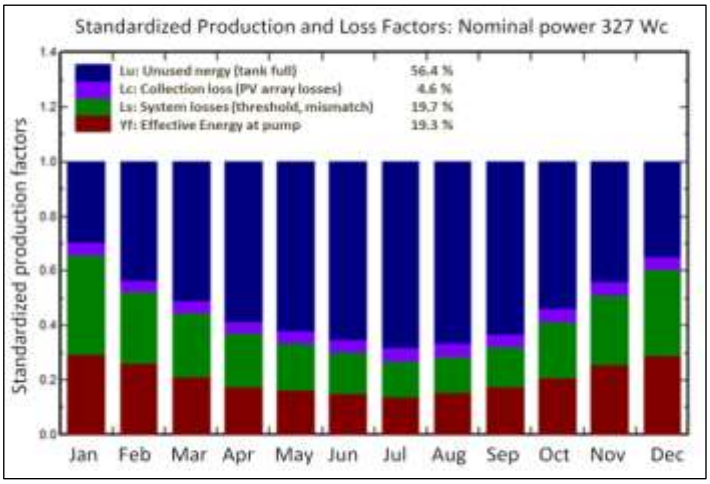


Figure 7: Standardized production and part factors.
Source: Authors, (2026).

Solar pumping systems are deep well-type, using submersible pumps at the bottom of boreholes. These pumps are designed to be below water level and connected to the surface via water pipes and electrical supply wires. The water is pumped into a storage tank, depending on sunlight availability. The system requires specific parameters such as static depth, maximum pumping depth, pump depth, borehole diameter, and specific drawdown. The storage tank and hydraulic circuit parameters are also defined. Table 2 summarizes the totals of the main results for thirty-six months from 2021 to 2023.

Table 2: Assessments and main results for three years.

Years	**GlobEff (kWh/m^2)**	**EArrMPP (kWh)**	**E PmpOp (kWh)**	**EtkFull – (kWh)**	**H Pump (mCE)**	**W Pumped (m^3)**	**W Used (m^3)**	**W Miss (m^3)**
2021	2083.0	607.02	133.09	229.50	10.00	1804.8	1805.7	19.332
2022	1873.5	1180.0	391.52	355.98	10.00	1804.9	1811.7	49.85
2023	1871.3	628.84	387.72	211.29	10.00	1832.5	1840.5	20.98

Source: Authors, (2026).

III.1 ECONOMIC COMPARISON WITH THE CLASSIC PUMP DRIVE SOLUTION WITH AN INTERNAL COMBUSTION ENGINE

The analysis will be restricted to a direct economic comparison between the Internal Combustion Engine- ICE and the Classic Pumping Engine- CPE, as heat engines [20]. The CPE and ICE both run on the idealized thermodynamic cycle that is employed by heat engines to transform heat into work output. The engines' methods for turning heat and air pressure into work vary widely, thus in order to compare them economically, we must examine the costs and efficiencies associated with producing the desired amount of work. The data in the economic assessment form are prepared with an investment of 240,000 DZD, covering the PV modules, pump, controller, and additional accessories. With a 17% tax, the net investment rises to 280,800 DZD. The total annual cost amounts to 22,532 DZD, spread over a 20-year depreciation period at a 5% rate. However, the amount of pumped water is 1417 m^3/year for a total annual cost of 22532 DZD/year, which gives us a cost of water per cubic meter of 15.9 DZD. Let's know that one Algerian dinar is equivalent to 0.0074 US dollars (1 DZD = 0.0074 USD). A 133 kW diesel engine is what the 133 kW generator needs to be powered by.Diesel engine fuel consumption is typically 190220g/kW/h, though this might vary depending on the equipment and fuel grade.

The computation used currently is 133 g/kW/h: 133 (kW) × 0.2 (kg) × 6 = 159.6 (kg). Diesel No. 0 (your 133 kW diesel generator) has a density of roughly 0.84 (kg/l), so 159.6/0.84 = 190 (l). In six hours, this diesel generator uses about 190 liters. Diesel generators typically use 0.2 liters of fuel per kilowatt-hour of power. The fuel consumption index of diesel generators is influenced by various factors, as their energy production varies based on their fuel consumption. Algeria has one of the lowest diesel prices in the world due to subsidies. For example, the price of a liter of diesel in Algeria is 29 DZD (~ 0.2146 US Dollars) for an average world price of diesel of 1.26 (US Dollars). Fuel subsidies are therefore considered as a shortfall or a potential loss for the State, which sells petroleum products, particularly fuels, below their international price [21]. The question that arises is until when the price of fuel will remain subsidized in Algeria? To this end, in this study, we will not take into consideration the current price of a liter of diesel in Algeria and we will use the world average price.

In the preceding section, the PVsyst software computed the cost per m^3 of water pushed by the PV water pumping system; however, the cost per m3 of water pumped by the diesel water pumping system was not computed. Consequently, the cost annuity technique, which is based on the Life Cycle Cost-LCC, analysis, is used to determine the cost per m3 of water pushed by diesel water pumping system [22].

$$cost\ of\ m3\ of\ water\ pumped = \frac{Annualised\ LCC}{Total\ pumped\ water} \tag{2}$$

Table 3 shows the economic comparison with the classic pump drive solution with internal combustion engine.

Table 3: Economic comparison with the classic pump drive solution with internal combustion engine.

	Classic Pumping Engine	**Internal Combustion Engine**	
Price of diesel per liter (USD)	/	Algeria	Global
		0.2146	1.26
Pumped water (m^3/Year)	1417		
Total annual cost (USD/Year)	166.74	40.75	239.40
Water cost (USD/m^3)	0.1176	0.0288	0.1689

Source: Authors, (2026).

The viability of a solar photovoltaic (SPV) water pumping system has been examined in this work. Water costs about 0.1176 (USD/m^3). If a diesel generator is utilized in place of the SPV water pumping system, the cost of pumping water would be about 0.1689 (USD/m^3) in the absence of any subsidies. When a subsidy is taken into account during simulation, the price of water drops to 0.0288 (USD/m^3). The SPV water pumping system is more practical and cost-effective than the diesel system, according to the life cycle cost study of pumping water. The economic comparison of electric motor drive direct voltage for low voltage networks is justified for irrigation systems like sprinklers. The engine must maintain constant speed, be cheap, and have reduced maintenance costs, making it suitable for medium and large-scale irrigation systems [23]. Variable Frequency Drives- VFDs, are costly for low-powered pumps and have poor electromagnetic compatibility. New technologies utilize direct-drive variable voltage supplies for pumping. These motors draw power from solar systems at variable voltages, converting 24 V DC to AC. This allows photovoltaic-powered AC pumps, helping Algerian farmers reduce electricity costs.

III.2 ARTIFICIAL INTELLIGENCE CLASSIFICATION OF THE PUMP POWER

Artificial intelligence (AI) and machine learning must be used to preserve water resources (optimization of irrigation) and maximize energy efficiency. To this end, optimizing the irrigation of crops can adjust the amount of water supplied to crops according to their actual needs, and enhanced energy monitoring enables precise and efficient management of solar energy in farms. These techniques use sensors and intelligent systems. First, they optimize crop watering by obtaining real-time information on soil humidity, temperature and rainfall. They also improve energy efficiency by adjusting the charging parameters to the actual energy needs. To achieve this goal, in this work, four AI methods have been used: Support Vector Machine (SVM), Random Forest (RF), Naive Bayes (NB), and k-Nearest Neighbors (kNN) algorithm. After processing the data used for the learning and testing of our model, two classes were chosen taking into account the power (low, strong), knowing that there is a correlation between the power and water quantity. However, as shown in Figure 8, four confusion Matrix illustrate the classification of each model.

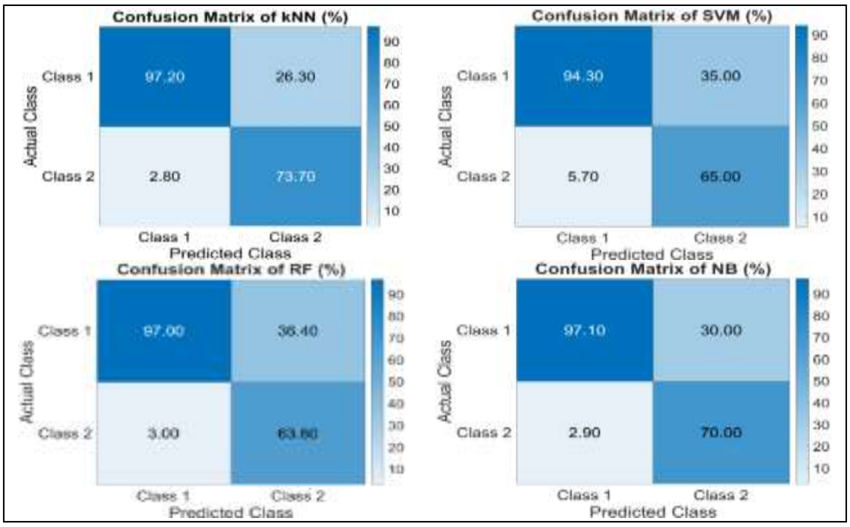


Figure 8: The confusion matrix of various AI methods.

Source: Authors, (2026).

The performance parameters of AI models are calculated from equations (3-7), based on the confusion matrix, as shown in Table 4. Classification Accuracy (CA):

$$CA = \frac{TP + TN}{TP + TN + FP + FN} \tag{3}$$

Precision:

$$Precision\ = \frac{TP}{TP + FP} \tag{4}$$

Recall (Sensitivity):

$$Recall = \frac{TP}{TP + FN} \tag{5}$$

F-measure (F1 Score) harmonic mean of precision and recall:

$$F\text{-Score}\ = \frac{2 \times Precision \times Recall}{Precision + Recall} \tag{6}$$

Matthews Correlation Coefficient (MCC):

$$MCC\ = \frac{(TP \times TN) - (FP \times FN)}{\sqrt{(TP + FP)(TP + FN)(TN + FP)(TP + FN)}} \tag{7}$$

Where:

TP is the number of True Positives, TN is the number of True Negatives, FP is the number of False Positives, and FN is the number of False Negatives [24], [25].

Table 4: The performance parameters of the various models.

MODEL	CA	F1	PREC	RECALL	MCC
SVM	0.907	0.836	0.844	0.879	0.640
RF	0.938	0.836	0.844	0.836	0.667
NB	0.912	0.873	0.897	0.873	0.725
k-NN	0.960	0.891	0.894	0.908	0.757

Source: Authors, (2026).

According to the AI results, k-NN Classifier with k=9, Mahalanobis Metric, and Distance Weighting is the most accurate model with 96 %.

V. CONCLUSIONS

This article describes a straightforward method for sizing a photovoltaic pumping system for agricultural irrigation. We used the PVsyst software to simulate the PV pumping system at an angle of inclination equal to the latitude, allowing us to study the system's daily and monthly performance. Properly sizing a PV pumping system requires careful consideration of various factors such as site selection, site implantation and its characteristics, reservoir selection, well drilling, pump size, and panel size. Thus, it entails the validation process of a model created with PVSyst to classify the required pump power as a response to the solar radiation available in any photovoltaic system. The viability of a solar photovoltaic (SPV) water pumping system has been examined. Water costs about 0.1176 (USD/m³), If a diesel generator is utilized in place of the SPV water pumping system, the cost of pumping water would be about 0.1689 (USD/m³) in the absence of any subsidies. When a subsidy is taken into account during simulation, the price of water drops to 0.0288 (USD/m³). The SPV water pumping system is more practical and cost-effective than the Diesel system, according to the life cycle cost study of pumping water. Based on the AI findings, k-NN emerges as the most accurate model, with 96 % accuracy. Finally, the k-NN model showed high precision, demonstrating the system's effectiveness and robustness.

VI. AUTHOR’S CONTRIBUTION

Conceptualization: Z Chelli, T Khouldia and S Bouraghda.
Methodology: Z Chelli and T Khouldia.
Investigation: Z Chelli and Author Two.
Discussion of results: Z Chelli, T Khouldia and S Bouraghda.
Writing – Original Draft: Z Chelli.
Writing – Review and Editing: Z Chelli and T Khouldia.
Resources: Z Chelli.
Supervision: Z Chelli and T Khouldia.
Approval of the final text: Z Chelli, T Khouldia and S Bouraghda.

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